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## THE NONLINEAR DYNAMIC CALCULATION OF DEFORMED STATE OF VARIOUS TYPES OF SPRINGS

**Abstract:** The results of the computer simulation of the process of constant force loading of the cylindrical and conical compression springs, the tension and torsion springs, and the disc spring are presented in the article. The calculated color contours of equivalent stress, displacement and deformation of material are obtained on the springs models. The most loaded volume of material was determined at deformation of the tension spring. The first coil on the side of the tension spring fixing is deformed as much as possible.

**Key words:** a spring, load, a coil, stress, deformation.

**Language:** English

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### Introduction

The spring is the standard elastic element that restores its the original geometric shape after load removing. Special steel provides the spring elasticity. The springs are used depending on the performed action (compression, tension, torsion, displacement) [1-4].

The coils of the springs are subjected to compression, tension or torsion deformations under the action of loads. Since load acts in one direction on one of the several coils, then deformation that occurs in the volume of the spring will be uneven. Deformation of the spring occurs in cycles (when acting and removing load). In this case, the some coils of the spring will constantly be subjected to maximum deformation, which will lead to critical fatigue of material. The some researches of stress-strain state of

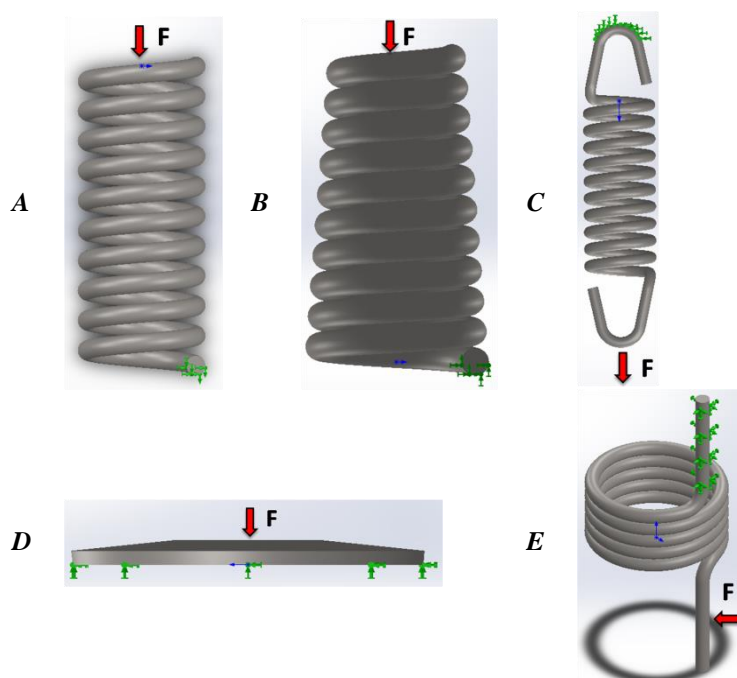
various types of the springs are presented in the works [5-10]. Predicted partial destruction of material can be determined by the results of the computer simulation of the spring deformation process in the dynamic mode.

### Materials and methods

Stress-strain state of material of the cylindrical and conical compression springs, the torsion and tension springs, and the disc spring in the conditions of acting same constant force with duration of 1 s was researched. The calculation was performed in the SolidWorks software package. All springs were made of 51CrV4 steel. The physical and mechanical properties of 51CrV4 spring steel are presented in the table 1. The general views of the spring models and applied loads to them are presented in the Fig. 1.

**Table 1. The properties of 51CrV4 steel.**

Parameter	Measure unit	Value
Mass density	kg/m <sup>3</sup>	7800
Poisson's ratio		0.28
Yield strength	N/m <sup>2</sup>	7×10 <sup>8</sup>
Tensile strength	N/m <sup>2</sup>	9×10 <sup>8</sup>
Elastic modulus	N/m <sup>2</sup>	2.1×10 <sup>11</sup>
Shear modulus	N/m <sup>2</sup>	7.9×10 <sup>10</sup>
Thermal expansion coefficient	K <sup>-1</sup>	1.1×10 <sup>-5</sup>



**Figure 1 – The springs models and applied loads: A – the cylindrical compression spring; B – the conical compression spring; C – the tension spring; D – the disc spring; E – the torsion spring.**

The following parameters of the researched parts were accepted for the calculation:

1. *The compression spring.* The class – 4; the category – 2; relative inertial gap – 0.1; the outer

diameter of the spring – 20 mm; the wire diameter – 3 mm; the number of the working coils – 10; the number of the pre-loaded coils from one side – 0.75; the number of the grinded coils from one side – 0.75;

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working stroke of the spring – 6.25 mm; the spring length – 40 mm; the spring constant – 16.178 N/mm; critical speed of the compression spring – 0.64 m/s; the spring pitch – 3.7 mm.

2. *The conical spring.* The spring type is the conical spring with the constant pitch; the spiral form is Archimedean; the class – 3; the category – 2; the small outer diameter of the spring – 15 mm; the outer diameter of the spring – 20 mm; the wire diameter – 3 mm; the number of the working coils – 10; the total number of the coils – 11.5; the number of the pre-loaded coils from one side – 0.75; the number of the grinded coils from one side – 0.75; relative inertial gap – 0.25; force at which landing the spring coils begins – 46.8 N; the spring length – 36.09 mm; working stroke of the spring – 3 mm; the uncoiled length of the spring – 524 mm; the spring pitch – 3.309 mm.

3. *The tension spring.* The class – 2; the category – 3; relative inertial gap – 0.1; the outer diameter of the spring – 20 mm; the wire diameter – 3 mm; the number of the working coils – 10; working stroke of the spring – 6.25 mm; the spring length without the hooks in free state – 33 mm; the uncoiled length of the spring without the hooks – 544 mm; the spring constant – 16.178 N/mm.

4. *The disc spring.* The spring class – 2; type of the spring design – 2; the assembly scheme is single; the spring number according to GOST 3057-90 – 468; the outer diameter of the spring – 200 mm; the inner

diameter of the spring – 80 mm; the spring thickness – 8 mm; the spring height – 14 mm; the width of the reference plane – 1.2 mm; the spring constant – 1878 N/mm; working stroke of the spring – 2 mm.

5. *The torsion spring.* The class – 2; the category – 3; gap between the spring coils – 0.1 mm; the outer diameter of the spring – 50 mm; the wire diameter – 5 mm; the spring index – 9; the number of the working coils – 10; the angle of working stroke – 91 degrees; the spring length without the hooks in free state – 56 mm; the uncoiled length of the spring without the hooks – 1440 mm; the spring pitch – 5.1 mm.

The calculation was performed using the NR repeat method and the Newmark integration method.

## Results and discussion

Stress-strain state of the loaded springs was visually displayed by the color contours on the volumes of the models. Stress-strain state of the compression spring is presented in the Fig. 2. Stress-strain state of the conical spring is presented in the Fig. 3. Stress-strain state of the tension spring is presented in the Fig. 4. Stress-strain state of the disc spring is presented in the Fig. 5. Stress-strain state of the torsion spring is presented in the Fig. 6. The color scale on the right is the values range of equivalent stresses and displacements of the springs coils from minimum to maximum.

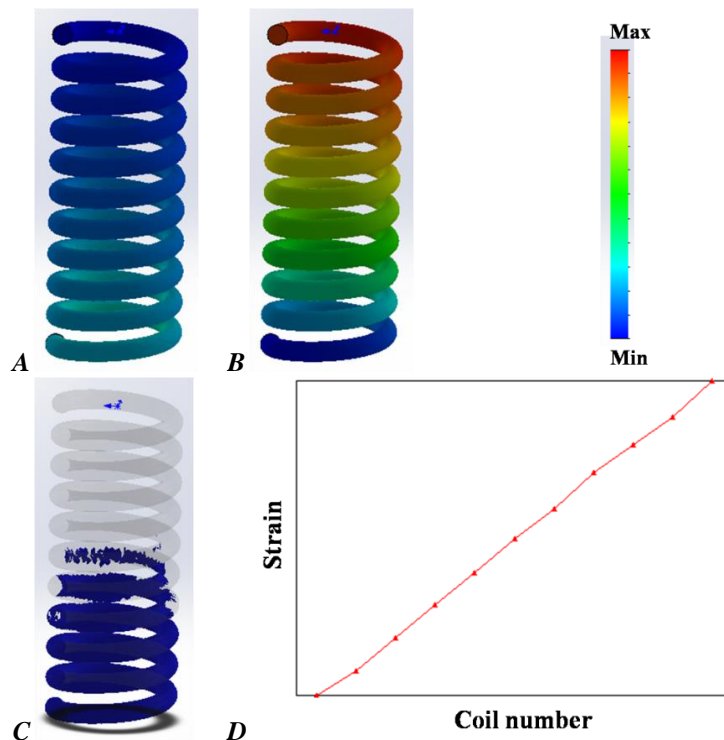


Figure 2 – Stress-strain state of the compression spring: A – equivalent stress; B – displacement; C – the most loaded volume of material; D – the dependence of strain change from the number of the spring coil.

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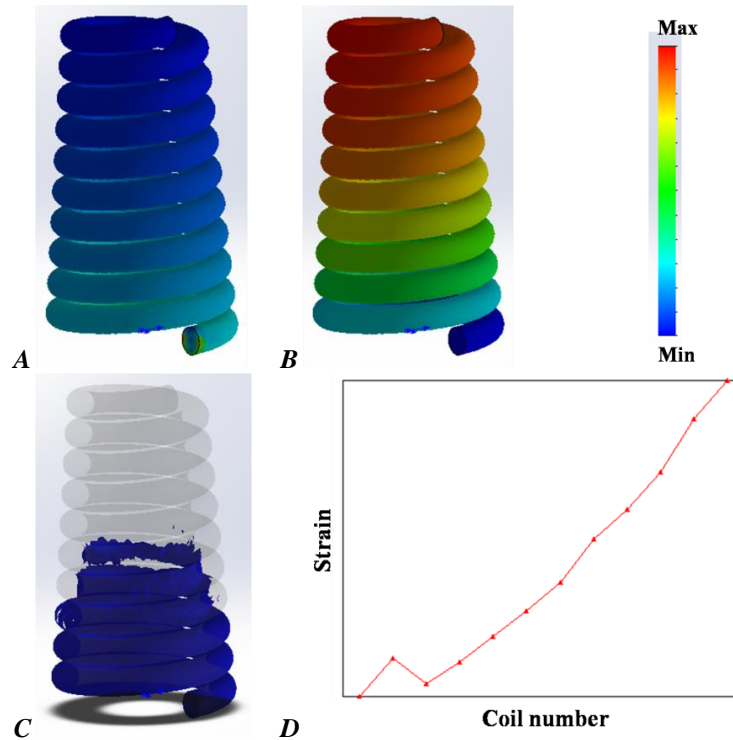


Figure 3 – Stress-strain state of the conical spring: *A* – equivalent stress; *B* – displacement; *C* – the most loaded volume of material; *D* – the dependence of strain change from the number of the spring coil.

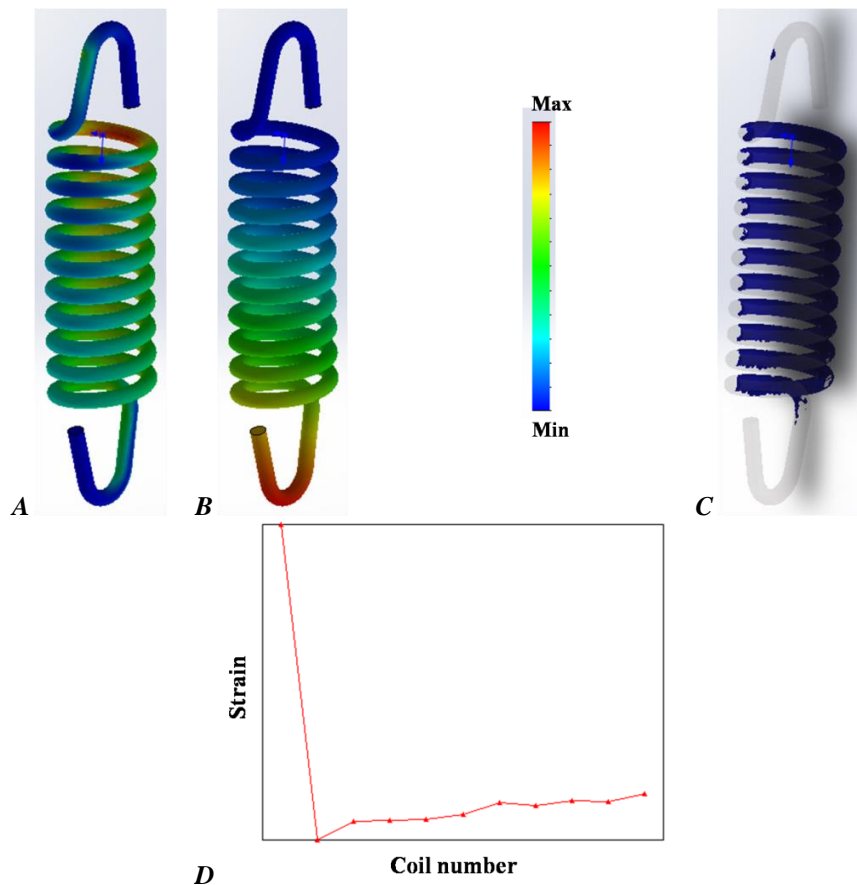


Figure 4 – Stress-strain state of the tension spring: *A* – equivalent stress; *B* – displacement; *C* – the most loaded volume of material; *D* – the dependence of strain change from the number of the spring coil.

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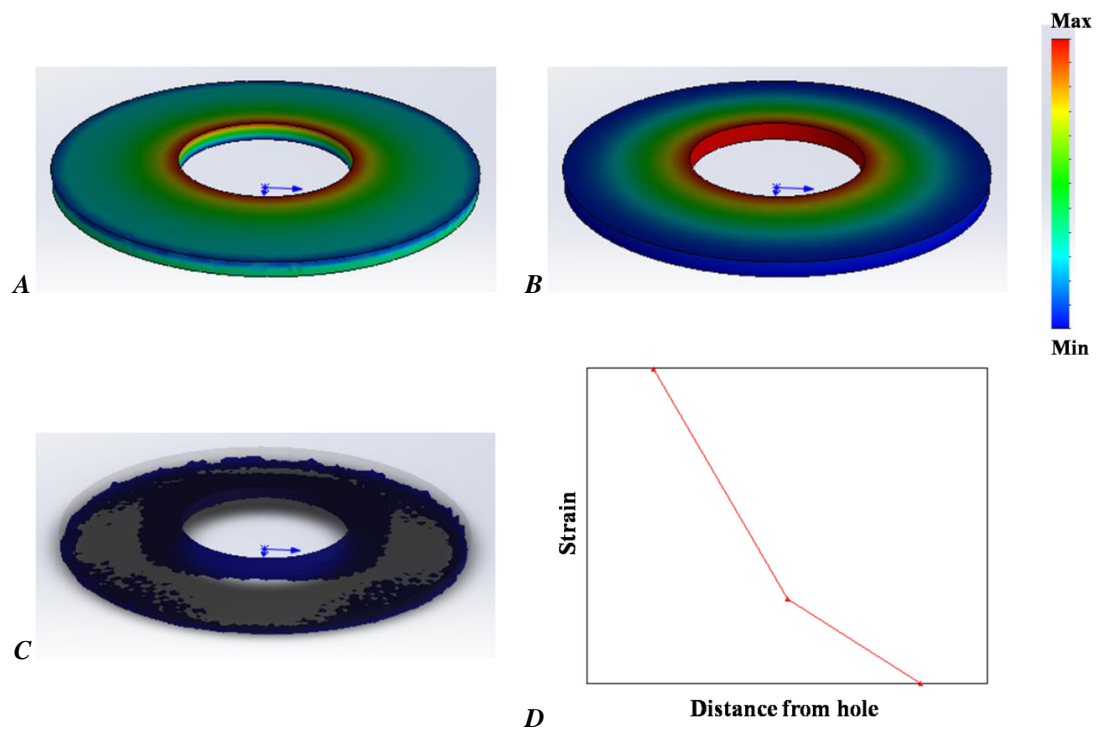


Figure 5 – Stress-strain state of the disc spring: *A* – equivalent stress; *B* – displacement; *C* – the most loaded volume of material; *D* – the dependence of strain change on the distance from the hole to periphery of the spring.

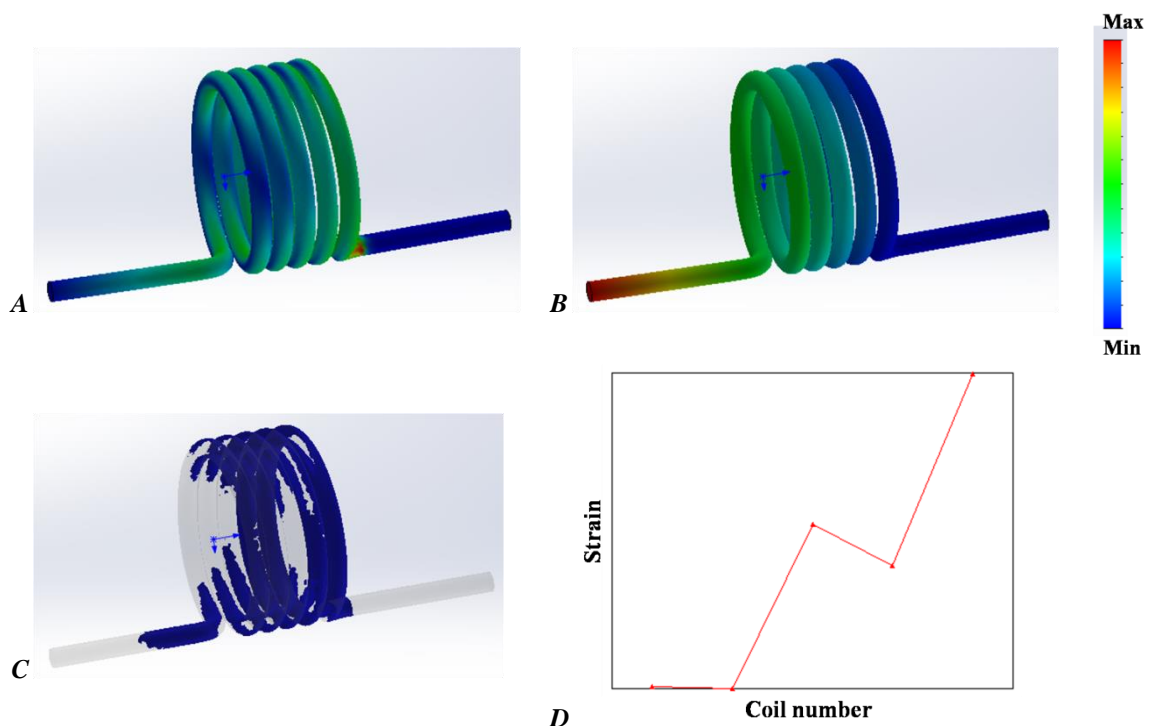


Figure 6 – Stress-strain state of the torsion spring: *A* – equivalent stress; *B* – displacement; *C* – the most loaded volume of material; *D* – the dependence of strain change from the number of the spring coil.

Equivalent stress increases in the direction from application of load to the fixing place for the compression, tension, and torsion springs. In this case, the first coil of the tension spring on the fixing side is

subjected to significant equivalent stress. Taking into account the specific geometry of the disc spring, maximum stress occurs on the surface where load was applied. The coils displacement of the compression

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springs (cylindrical and conical) occurs from the side of load application. The smaller pitch of the spring leads to maximum compression. The hook is stretched from the side of load application (the tension spring). Similar displacement of the coils occurs when loading the torsion spring. Material of the disc spring is subjected to maximum displacement in the hole area.

The most uniform deformation of material was determined when loading the compression spring. Material is deformed according to the linear law.

Deformation of the first coil of the tension spring from the fixing side is several times more than deformation of the remaining coils. Calculated deformation of the third and fifth coils of the torsion spring is more than deformation of the other coils. Deformation of the disc spring material from the hole to periphery was determined from the side of load action.

The most loaded volumes of material of the researched springs are presented in the table 2.

**Table 2. The most loaded volumes of the springs material in the percentage.**

The spring type	Compression	Conical	Tension	Disc	Torsion
The loaded volume, %	34.25	36.24	46.11	43.66	45.96

### Conclusion

Based on the results of the computer experiment to determine of stress-strain state of the springs of various types, we can draw the following conclusions:

1. Possible break of the tension spring may occur at the first coil on the fixing side. Optimal material deformation occurs when loading the compression springs.

2. The disc spring has high rigidity. Distributions of equivalent stress and displacement of the disc spring material coincide.

3. The tension and torsion springs are the most deformed (46.11% and 45.96% of the total volume of these springs); the cylindrical compression spring is the least deformed (34.25% of the total volume of this spring).

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