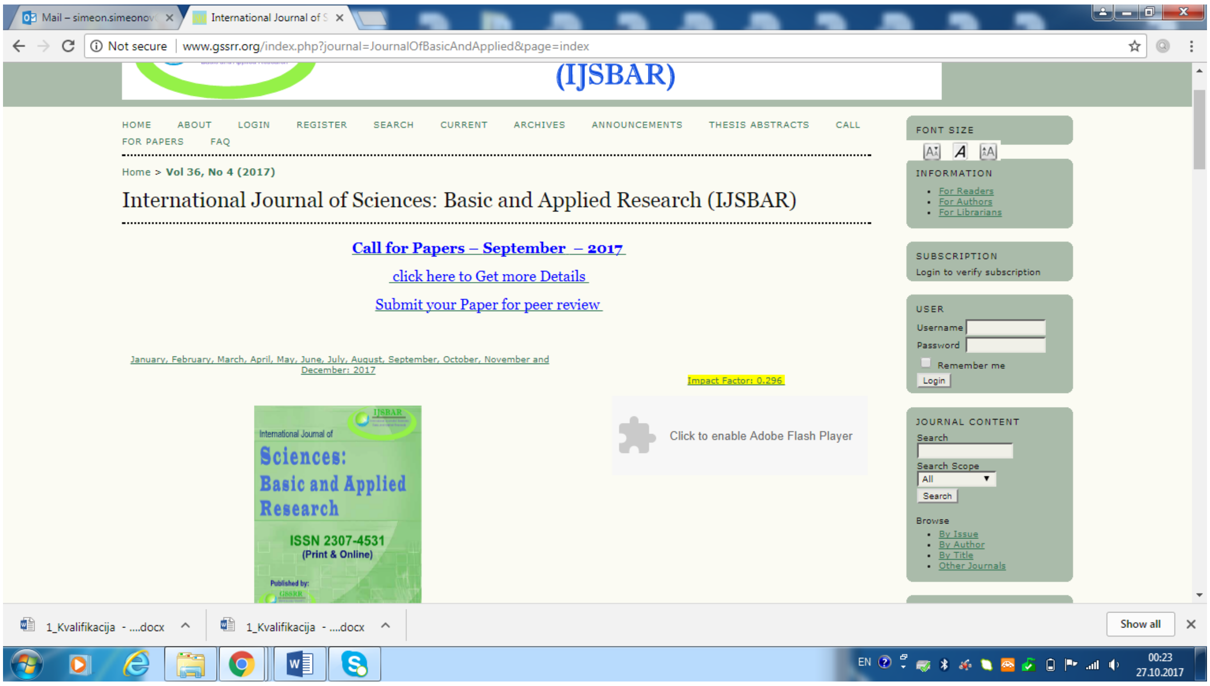

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Impact of the Structural Forms of Diaphragm Spring Beginning on Dynamic Durability of Diaphragm Springs of Vehicle Clutches

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Abstract

Friction clutche is mechanism placed between the engine and the gearbox of the cars and is used to transfer torque from the engine of the vehicles to the transmission. The needed strength of the pressure between the friction surfaces is provided with crunches bandage springs or diaphragm springs.The depletion of the lining of the friction drive comes to a reduction in pressing force of crunch bandage springs and thus to reduce torque. Diaphragm springs are exposed to complex dynamic loads and it is necessary to make a proper selection of the parameters. In this researching it will be considered only one of the structural factors, the diaphragm spring fingers begiming. This paper provides an analysis of a possible response to this kind of challenges. The focus is pertinent to the analytical and experimental analysis. The impact of the analyzed constructive forms of diaphragm spring fingers beginning on stress and the stress of the diaphragm-spring are assessed through a finite element method and experimental tests. It is derived conclusion about the stress progression for different time steps depending on the form of the diaphragm spring fingers beginning.

Keywords: Diaphragm spring; Stress distribution; Diaphragm spring begiming; Vehicle clutch.

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1. Introduction

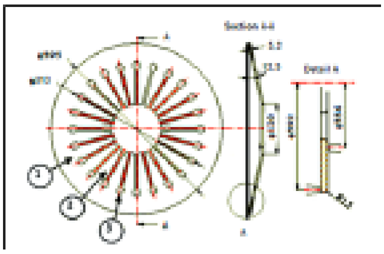

Figure 1: The diaphragm spring : 1.spring plate, 2.spring fingers, 3.spring fingers beginnings

One of the major parts of motor vehicles is the clutch. It is mechanical assemblies built between the engine and transmission that with friction transfers torque from the driving part to the driven part (engine gearbox and other transmission). Diaphragm spring as one of the main parts of the clutch creates pressure force of the clutch it besides creates pressure force of the clutch it enables engagement and disengagement of clutch. Diaphragm spring when performing her function is dynamically loaded.

Diaphragm springs constructive are performed in two shapes: normal and superstructure. The first group includes springs whose shape is in the form of a truncated hollow cone. The second group, the fingers by the same length, profile and equally distributed on the whole circuit (figure 1). The transition from the normal form of the spring to the console levers is made with a circular, elliptical or trapeze form.

Considering the fact that despite recent extensive studies of the work of friction clutches, and thus the diaphragm springs, still during the exploitation of clutch failure of the functioning happen because of weakening or breaking of the diaphragm spring. The main reasons for this may be the incorrect dimensioning of diaphragm spring, inappropriate material and inadequate technological process. The purpose of this research are diaphragm spring fingers beginnings, which are the most stressed elements in the spring because the finger acts as an elastic lever that has free end on one side and are supported on the other.

In the vehicle clutch assembly the force that comes from the release bearing is at the end of the spring finger and the reaction forces and bending moments occur at the place of supporting the lever. That is a simple lever case with a force acting on the free side. The place where highest stresses arise is the joining of the finger with the rest of the spring. Special attention has to be dedicated to these connections of the fingers with the spring plate by using elements with low stress concentration factors such as holes, slots etc. In this paper is analyzed the influence of different shaped holes at the beginning of the spring finger or the connection of the spring finger with the plate.

2. Materials and methods

The material used for model of the spring is obtained from the technical specifications of the examined diaphragm spring and that is structural steel designated as 51CrV4, with modulus of elasticity of E=210000 N/mm², density of R_{ko} = 7.85g/cm³ and Poisson ratio N_s = 0.3 . The yielding point considering the material enhancement for this spring is R_{eh} = 1300 N/mm² .

The methodology of the research include: calculation would have performed by expressions on ALMEN-LASZLO, finite element (FE) analysis of the diaphragm spring fingers beginning and examination of dynamic fatigue of the spring on a test bench.

2.1. Calculation of force and stress using expressions of Almen and Laszlo's theory

Calculation of the stresses of the diaphragm spring were conducted with expressions of Almen and Laszlo's theory for calculation of diaphragm springs [1,2,3].

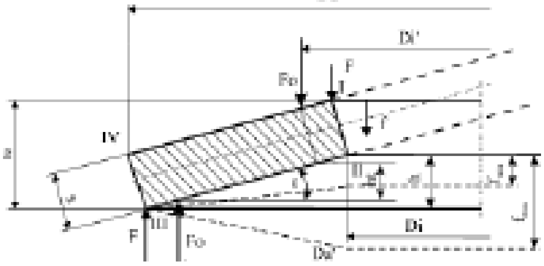

Figure 2: Forces of the spring

-Angle banding:

$$\varepsilon_1 = \varepsilon \frac{\pi}{180} \quad \text{(rad)} \tag{1}$$

- Height of diaphragm spring:

$$h = \frac{D_a - D_i}{2} \tan\varepsilon \quad \text{(mm)} \tag{2}$$

-Relationship of diameters diaphragm spring:

$$\delta = D_a / D_i \quad \text{(mm)} \tag{3}$$

- Coefficients: α, k_1, k_2, k_3

$$\alpha = 4\frac{E}{1-\mu^2} \tag{4}$$

$$k_1 = \frac{1}{\pi} \frac{\left(\frac{\delta - 1}{\delta}\right)^2}{\left(\frac{\delta + 1}{\delta - 1}\right) - \frac{2}{\ln(\delta)}} \tag{5}$$

$$k_2 = \frac{1}{\pi} \cdot \frac{6}{\ln(\delta)} \cdot \frac{\delta - 1}{\ln(\delta)} - 1 \tag{6}$$

$$k_3 = \frac{1}{\pi} \cdot \frac{6}{\ln(\delta)} \cdot \frac{\delta - 1}{2} \tag{7}$$

$$k_4 = \frac{D_a - D_i}{D_{a1} - D_{i1}} \tag{8}$$

-Calculation of stress (N/mm²):

$$\sigma_{1,t} = \alpha \cdot \frac{s^2}{k_1 D_a^2} \cdot \frac{ff_t}{s}\left[-k_2\left(\frac{h}{s} - \frac{ff_t}{2 \cdot s}\right) - k_3\right] \tag{9}$$

$$\sigma_{2,t} = \alpha \frac{s^2}{k_1 \cdot D_a^2} \frac{ff_t}{s^2}\left[-k_2\left(\frac{h}{s} - \frac{ff_t}{2 \cdot s}\right) + k_3\right] \tag{10}$$

$$\sigma_{3,t} = \alpha \frac{s^2}{k_1 \cdot Da^2} \frac{ff_1}{s} \frac{1}{\delta}\left[(2k_3 - k_2)\left(\frac{h}{s} - \frac{ff_t}{2 \cdot s}\right) + k_3\right] \tag{11}$$

$$\sigma_{4,t} = \alpha \frac{s^2}{k_1 \cdot D_a^2} \cdot \frac{ff_t}{s} \cdot \frac{1}{\delta}\left[(2 \cdot k_3 - k_2) \cdot \left(\frac{h}{s} - \frac{ff_t}{2 \cdot s}\right) - k_3\right] \tag{12}$$

Pressure force on the diaphragm spring with supporting points

$$Ft(f) = \alpha \cdot k_4 \cdot \frac{s^4}{D_a^2 \cdot k_1} \cdot \frac{f}{s}\left[\left(\frac{h}{s} - \frac{f}{s}\right)\left(\frac{h}{s} - \frac{f}{2 \cdot s}\right) + 1\right] \tag{13}$$

Calculation of dynamic spring stress

- Deflection at disengagement of clutch-control point

$$f_a = h + \delta_f \quad (mm) \tag{14}$$

$$\delta_f = \frac{D_a - D_i}{D_a - d} \cdot l \ (mm) \tag{15}$$

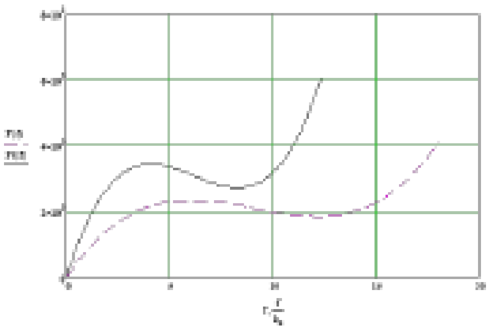

Figure 3: Diagram of the spring force (- - - -) and the clutch force (______)

Figure 3 shows the diagram of change on pressing force of spring and spring with supporting points depending of deflection.

Stress in point 3

-Upper stress (OFF-deflection f_p):

$$\sigma_s = \alpha \cdot \frac{s^2}{k_1 \cdot D_a^2} \cdot \frac{f_p}{s} \cdot \frac{1}{\delta}\left[(2 \cdot k_1 - k_2) \cdot \left(\frac{h}{s} - \frac{f_p}{2 \cdot s}\right) + k_3\right] \tag{16}$$

-Lower stress (stress in point 3 at deflection f =h) :

$$\sigma_u = \sigma_{3,1} \tag{17}$$

-Dynamic stress:

$$\sigma_{dt} = \sigma_s - \frac{4}{7}\sigma_t \tag{18}$$

The static stress is largest in point 1 and dynamic stress is largest in point 2 or 3, where plastic deformations of material occurs. In which point will has greater stress, it will depend on the ratio D_a/D_i and $h_0/s \geq 1.4$.

The calculation is performed on diaphragm spring for vehicles using commercial software program, and material (50CrV4-1.8159). The results are given in table 1 and table 2.

2.2. Finite element analysis of the diaphragm spring fingers beginning

Numerous simulations were run for bringing closer the spring behavior. Despite the sheet metal form that in general would be modeled with shell elements, for the diaphragm spring volumetric solid hexagon elements were used. Analyzing the results that were concluded by using shell elements, the stress distribution from the upper face was equalized with the stress from the bottom face. When using surface or shell elements both are equalized and non-real stress distribution occurs. Despite the sheet metal form of the spring, for this kind of parts subjected to similar forces, volumetric elements on several layers must be used [4]. Special attention has to be dedicated to these connections of the fingers with the spring plate by using elements with low stress concentration factors such as holes, slots etc. In this paper is analyzed the influence of different shaped holes at the beginning of the spring finger or the connection of the spring finger with the plate, (figure. 4), slot shaped, circular shaped, rectangular shaped beginning [5].

Figure 4: Slot shaped, circular shaped and rectangular shaped beginning

After the model validation of the examined vehicle diaphragm spring by using strain gauge measurement a numerical modeling could follow. It was conducted on a multi-parallel processing computer with 10 hours simulation time. The model was prepared in Finite element method software.

2.3. Examination of dynamic fatigue of the spring on a test bench-Experimental test

In order to check the dynamic durability strength of the diaphragm springs, they were mounted on the clutch of the vehicle and then put the test bench. On the test bench examination is performed on clutches without rotation. The maximum diameter of the examining is 450 (mm), frequency 90 (1/min). The dynamic durabilit strength of diaphragm springs is leading to fracture the tube (machine element) performed by a number changes. The number of changes of diaphragm springs is $2*10^6$ cycles [6],[7].

3. Results

3.1. Results obtained using expressions of Almen and Laszlo's theory

Table 1: Pressing force and stress on the spring

	F_{fi} (mm)	FF_i (N)	$\sigma_{1,i}$(N/mm^2)	$\sigma_{2,i}$(N/mm^2)	$\sigma_{3,i}$(N/mm^2)	$\sigma_{4,i}$(N/mm^2)
$f = f_{max}$	12.16	18590	-1736	497	1415	-354
$f = h$	9.1	21070	-1534	135	1260	-62
$f = f_{min}$	6.02	23550	-1172	-67.4	968	93

Table 2: Pressure force on spring support

$ft_{min}=f_{min}/k_t$ (mm)	4.109	$Ft_{max}=F_{(fmin)}k_t$ (N)	34477
$f_h=h/k_h$ (mm)	6.207	$F_h=F_{(h)}k_h$ (N)	30846
$ft_{max}=f_{max}/k_t$ (mm)	8.306	$Ft_{min}=F_{(fmax)}\,k_t$ (N)	27215

Table 3: Dynamic stress

Point	2	3
Upper stress	571.8	1428
Lower stress	137.8	1260.6
Dynamic stress	449.8	707.7
Durability dynamic strength	770 N/mm^2	

3.2. Results obtained using Finite element analysis of the diaphragm spring fingers beginning

In the following figures 5 and 6 is shown the change in the stress distribution around the circumference of the holes, in the flat position of the spring and the maximum load (the spring lower position) as well as stress distribution curves for all the elements of the analyzed cross section of the spring with holes.

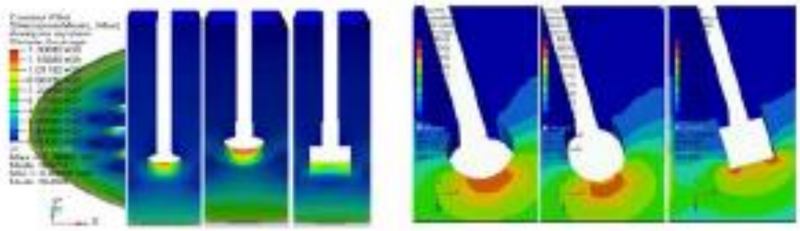

Figure 5: Circular, slotted, and rectangular holes spring behavior for time 0.4s from the top and the bottom view

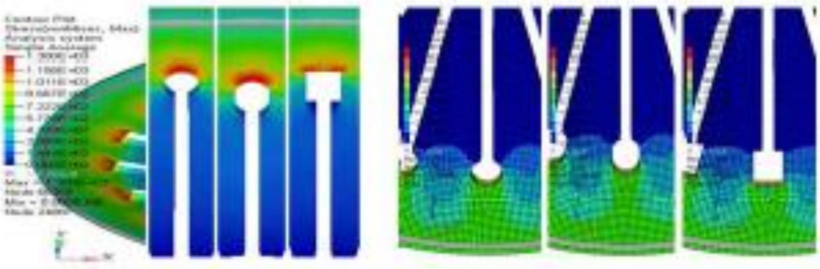

Figure 6: Circular, slotted, and rectangular holes spring behavior for time 0.9s from the top and the bottom view

Figures 5 and 6 show that the maximum stress is occurred in the region of the holes and started expanding. For slotted and circular holes the stress dissipation starts and continues from the top of the circle. For rectangular holes it continues from the upper corners of the rectangular, At the beginning of the elastic deformation the slot hole tip is the one reaching the maximum stress dissipated in largest area around the hole. As the deformation progresses the circular hole has the most stressed elements around the tip of the hole. For all the time duration the rectangular hole has the least stressed elements around the hole and they are located at the rectangular corners.

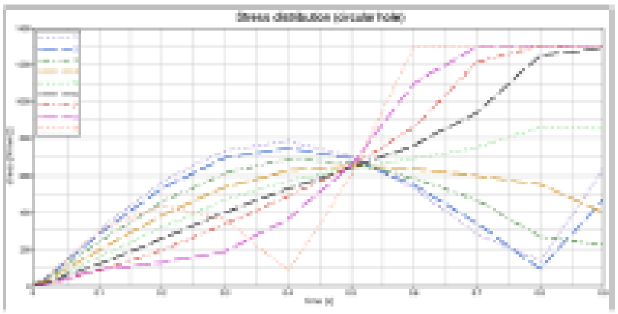

Figure 7: Stress distribution curves, the spring with circular holes

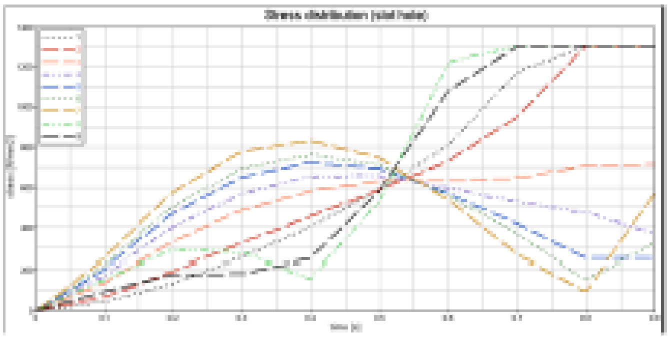

Figure 8: Stress distribution curves, the spring with slotted holes

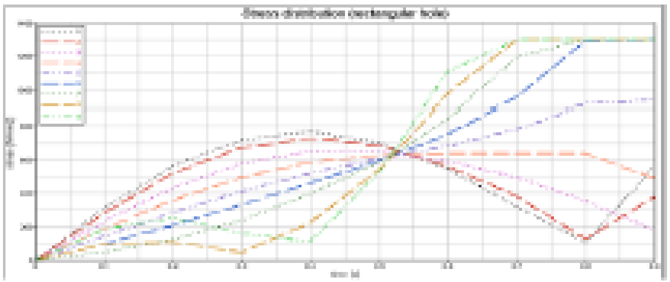

Figure 9: Stress distribution curves, the spring with rectangular holes

Figures (7-9) show that the stress is von Misses and it includes the principal stresses in all of the directions. The spring characteristic curve for most of the elements follows the same trend. The stress curve there is the following flow. When the spring is in a flat position the stress curves are crossing the maximum stress point. It is good to notice that at one point all the elements at the cross section spreading from the spring fingers beginnings to the spring end have nearly same stress. Till this point all of the elements have more compact characteristic except for the rectangular hole spring. After the flat position the spring fingers are bending downwards and the plate end is moving upwards. From a flat position with increasing height to maximum the deflection (to the point of disengagement on the clutch) stress characteristic elements have the opposite flow from the minimum deflection toward a flat position. Maximum stress is achieved faster with a circular hole for lower deviation (0,6 sek) than at rectangular and slot hole (0,7s) in element 9.

3.3 Results obtained by examination of dynamic fatigue of the spring on a test bench-Experimental test

The pressure force was measured, disengaging force and raising of the plate, before fatigue and after fatigue of the clutches. The results of experimental examination are given in table 4.

Table 4: Force of the spring before testing -F_{sopr} , force of the clutch before testing-$F_{isk.b}$ and force of the clutch after testing -$F_{isk.af}$

	Number of	F_{sopr}	$F_{isk.b.}$	$F_{isk.af}$	σ_{din} - Stress computational
1	$2.0*10^6$	21,07	29,30	27,1	=707<770
2	$2.0*10^6$	21,04	29,26	28,38	=707<770
3	$2.0*10^6$	21,05	29,27	26,92	=707<770
4	$2.0*10^6$	21,05	29,27	28,39	=707<770
5	$2.0*10^6$	21,06	29,29	28,45	=707<770
6	$2.0*10^6$	21,07	29,30	28,27	=707<770
7	$2.0*10^6$	21,06	29,29	28,27	=707<770
8	$2.0*10^6$	21,06	29,29	27,15	=707<770
9	$2.0*10^6$	21,05	29,27	28,41	=707<770

*(1-3) Circular, (4-6) Slotted, (7-9) Rectangular holes

4. Conclusion

- The simulation runs from the FE models can give us a full picture of the spring behavior during release bearing loading

- When the spring is moving downwards the stress of the spring, in general, is first increasing until reaching the maximum material stress at the hole tip and then is spreading in the area around the hole.

- The slotted shaped and the circular holes have close behavior. The maximum stress happens at nearly the same time (slotted -0,54s, circular-0,52s) and widens from the circumference of the hole to the spring plate. For rectangular hole the maximum stress occurs (0,53s) later compared to circular hole and before slotted hole. The maximum stress takes place at narrower area around the corners compared to the slotted and circular.

- The calculation was performed by expression the Almen Laszlo for slotted hole, dynamic stress at point 2 and 3 is less than the allowed dynamic stress (durability dynamic strength).

- The dynamic fatigue is performed on a test bench, there was no violation of diaphragm spring characteristic and fracture, pressure force, excluded force and raising on the pressure plate, they are in allowed deviations (permitted derogation is to 10% of the measured initial values).

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