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Dynamic Strain of Diaphragm Spring on Vehicles Friction Clutches Depending on the Spring Angle

Simeon Simeonov, Slavčo Cvetkov, Mishko Djidrov, Zlatko Sovreski, Sashko Dimitrov
Faculty of Mechanical engineering, University "Goce Delcev" Stip, Macedonia

Abstract - 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 drive part to the working part (engine gearbox and other transmission). Diaphragm spring as one of the main parts of the clutch creates pressure force of the clutch, where the spring's quality is affected by many structural and technological factors. Here it will consider only one of the structural factors, the diaphragm spring angle..

Index terms: Friction clutches; Diaphragm spring; Motor vehicles; Strains

1. Introduction

It has long been known that metals are less resistant to dynamic (variable) strains than the static ones. With same amount of strain in static loading small deformation appears, but with variable loading, after a number of changes we have a fatigue and breakage of the material.

Fatigue of the material always start at the most loaded place and in one metal grain which has plastic deformation. With plastic deformation this place strengthens and the strain in it does not increase until the other parts of the metal grain deform and strengthen. With variable loading this strengthening comes at smaller strains, and with the static loading at high strains. With the completion of the process of strengthening, metal grain practically loses the ability to further deformation. Then the strains of the most loaded places are increasing and they reach the value of the tensile strength. After this micro cracks appear that on their endings causing concentration of strain, which quickly reach the value of the tensile strength.

This crack affects the neighboring parts of the metal grain. Then the strains are transferred to the neighboring grain and then it occupies the entire section, resulting with tearing of the material.

Dynamic (fatigue) strength of the material is determined by Wöhler, where we examined specimens of exactly the same shape, size and quality. They were subject to different variable loads until the tearing of the material. The result is a Wöhler curve which helps to determine the dynamic strength. Diaphragm spring when performing their function is dynamically loaded.

2. Research Methodology

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 goal of this research is to study the structural factor, the angle of the diaphragm spring, i.e. its impact on the force and the strains.

3. Research Goal

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 goal of this research is to study the structural factor, the angle of the diaphragm spring, i.e. its impact on the force and the strains.

4. RESEARCH

With all respect to the existing theoretical and practical knowledge, experiences and opportunities for more specific research, in this research we accepted one of the following factor that's affecting the dynamic resistance of diaphragm springs:

• Structural factors include dimensional values, the shape of the spring and the quality of the material.

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• Technological factors that occur during the manufacturing process.

From structural factors most dominant on dynamic durability of springs are:

• Diameter of diaphragm spring;
• Thickness of diaphragm spring;
• Angle of diaphragm spring;
•Support points of diaphragm spring.

This research is directed at analyzing the impact of diaphragm spring angle on its dynamic durability.[4] [6] [7] [8]

The angle of the diaphragm spring depends from the size of diaphragm spring. This angle for the overall range of presently developed clutches is with diameter (160-430) (mm) and from (10 ÷ 14) degrees.

Static and dynamic strains are calculated depending on one factor, and the remaining factors remain unchanged. Their confirmation is done through static and dynamic fatigue of the material. Dynamic fatigue is oversized the number of cycles according to the Wöhler curve. Those calculations and tests are carried out to determine the relationship of pressure force and strains on diaphragm spring and constructive influential factors on the durable dynamic strength.
For this purpose, 6 samples of diaphragm springs for car were made. They were mounted on the clutch and after that pressure force, disengaging force and lifting of the pressure plate were measured. Afterward they were put the test bench.

4.1 Calculation of Forces and Strains

Calculation of the strains of the diaphragm spring were conducted on expressions of Almen and Laszlo's theory for calculation of diaphragm springs (Fig.1) [1] [2] [5]:

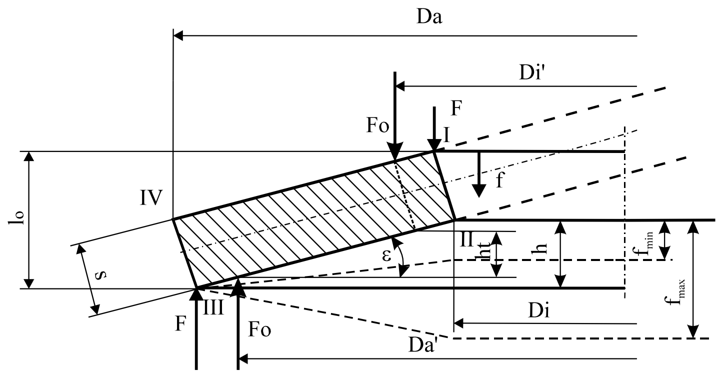

Fig.1 Forces of the spring

-Angle bending:

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

- Height of diaphragm spring:

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

-Relationship of diameters diaphragm spring:

δ =Da/Di (mm)

- Coefficients:α, κ1, κ3

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

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

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

$$k_4 = \frac{Da-Di}{D_{a1}-D_{i1}}$$

fmax and fmin- deviation for extreme values of F (f);

$$p = \sqrt[2]{9\cdot h^2 - 6\left(h^2+s^2\right)}$$

fmax=(3h+p)/3 (mm)
fmin=(3h-p)/3 (mm)

-Calculation of strains:

$$\sigma_{1,i} = \alpha \cdot \frac{s^2}{k_1 Da^2} \cdot \frac{ff_i}{s}\left[-k_2\left(\frac{h}{s} - \frac{ff_i}{2 \cdot s}\right) - k_3\right] \text{[N/mm}^2\text{]}$$

$$\sigma_{2,i} = \alpha \frac{s^2}{k_1 \cdot Da^2} \frac{ff_i}{s^2}\left[-k_2\left(\frac{h}{s} - \frac{ff_i}{2 \cdot s}\right) + k_3\right]$$

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

$$\sigma_{4,i} = \alpha \frac{s^2}{k_1 \cdot Da^2} \cdot \frac{ff_i}{s} \cdot \frac{1}{\delta}\left[(2 \cdot k_3 - k_2) \cdot \left(\frac{h}{s} - \frac{ff_i}{2 \cdot s}\right) - k_3\right]$$

-Pressed force on the clutch

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

The Fig.2 shows the diagram of change on pressure force of clutch and spring depending of deviation.

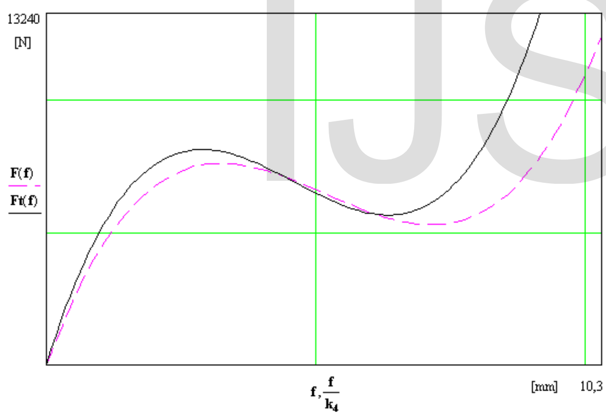

Fig.2 Diagram of the spring force (- - - -) and the clutch force (______)

-Calculation of dynamic spring strains

Devition at disengagment of clutch-control point (Fig.3)

$$\delta_f = \frac{Da - Di}{Da - d} \cdot l \,\text{(mm)}$$

$f_n = h + \delta_f\,(mm)$

Strains in point 3

-Upper strain (OFF-deviation fp):

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

-Lower strain (strain in point 3 at deviation (f = h)) :

$\sigma_d = \sigma_{3,2}$ (N/mm^2)

-Dynamic strain:

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

Di [mm] - Internal diameter of diaphragm spring, Di=165 [mm];
Da [mm] -Outer diameter of diaphragm spring , Da =210 [mm];
s [mm] - spring thickness, s=2.8 [mm]
E [N/mm²] -Module of elasticity (E=206000 [N / mm2] of the steel);
μ [-] - Poison number of spring steel, μ=0.3;
Di1[mm] -internal diameter of clutch point relying , Di1=166.5 [mm];
Da1[mm], outer diameter of clutch point relying , Da1=206.5 [mm];
[mm]- path of clutch disenganging, ℓ =8.5[mm];
d [mm] released bearing diameter, d=46.6 [mm];
kz- efficiency coefficient, kz=0.95;

Static strain is largest in point 1 and dynamic strain is largest in point 2 or 3,
where plastic material deformations occurs. In which point we will have greater strain it will depend on the ratio Da/Di and ho/s≥1.4.
The calculation is performed on diaphragm spring for cars using Math Cad program, and material (50CrV4-1.8159). The results are given in the Table 1.

TABLE 1
The results of calculation for ε=13°

	f [mm]	**F [N]**	**σI**	**σII**	**σIII**	**σIV**
			[N/mm²]			
f=max	7.13	5277.2	-1895.8	538.4	1534.2	-378.4
f=ho	5.19	6432.3	-1674.8	97	1367.8	-24.5
f=min	3.25	7587.4	-133.6	-123.8	1014	141.8

Strain	Upper strain σ_g	Lower strain σ_d	Dynamic strain σ_{din}
Value **σ[N/mm²]**	**1545.1**	**1367.8**	**763.5**

TABLE 2
The results of calculation for ε=10÷13(°)

	Angle of spring (°)					
	10.5	11	11.5	12	12.5	13
f_{max} [mm]	4.92	5.45	5.9	6.33	6.74	7,13
f=h [mm]	7.17	4.37	4.58	4.78	5.0	5.19
$F_{f,max}$ (N)	5095.8	5221.1	5300.2	5338	5328.3	5277
$F_{f=h}$ (N)	5163.8	5417.5	5668.5	5922.1	6176.7	6432
$\sigma_{III,fmax}$ [N/mm²]	1078.7	1177.4	1269	1358.1	1446.2	1534
$\sigma_{III,f=h}$ [N/mm²]	991.7	1062.3	1135.1	1210.3	1287.8	1367
σ_{din} [N/mm²]	602.3	632.6	663.4	696	729.3	763
$K=\sigma_{III,famax}/\sigma_{di}$	1.79	1.86	1.91	1.95	1.98	2

Static strength of bending σ_{TM} = 1680 [N/mm^2] for static loads.
Dynamic strength of bending σ_{DM}=830 [N/mm^2] for dynamic loads for s=2,8 [mm] and the number of changes N>2·106 (from diagram) [1]

In Table 2 given characteristic points of forces and strains in the spring, it is a flat position of the spring f = h and f = fmax for force, maximum static strain in point 3, dynamic strain at clutch disenganging for different angles of the spring.

4.2 Experimental Tests

In order to check the dynamic resistance of the springs, they were mounted on the clutch of the car and then put the test bench.

On the test bench examination is performed on clutches without rotation (Fig.4 The maximum diameter of the examining is 250 [mm], the speed of the electric motor 1500 [1/min], engaging frequency 90[1/min]. From the electro motor via a worm gearset to the oscillating plate that has a room for simultaneously testing of up to 6 clutches. [4] [6] [7]
The number of changes of diaphragm springs is $2*10^6$ cycles. The pressure force was measured, disengaging force and raising, before fatigue and after fatigue of the clutches

The results of experimental examination of the strain are given in Table 3.

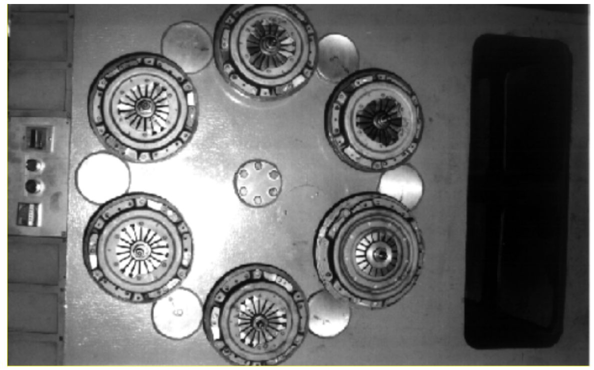

Fig.4 Test bench

Fig.5 shows the functional dependence of the pressure force from the spring angle, and Fig.6 is a functional dependence of the static strain from spring angle. Fig. 7 is a functional dependence of the dynamic strain from spring angle.

TABLE 3
The results of testing

Order number	Number of cycles	Strains computational (N/mm²)
1	$2.3*10^6$	σ_{din} =763<830
2	$2.4*10^6$	
3	$2,7*10^6$	
4	$2,7*10^6$	
5	$3*10^6$	
6	$3,2*10^6$	

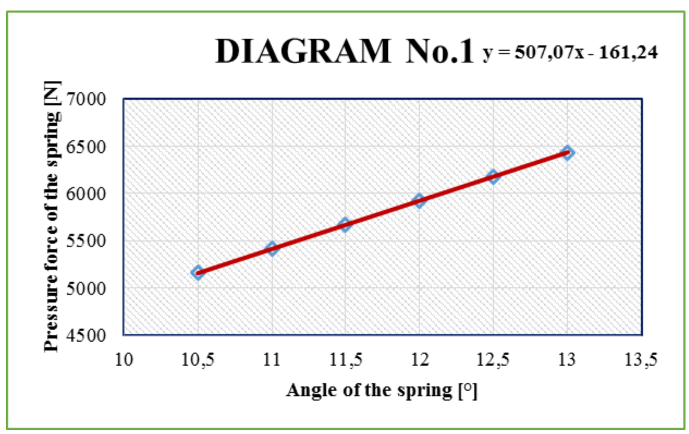

Fig.5 Functional dependence of the pressure force from the spring angle

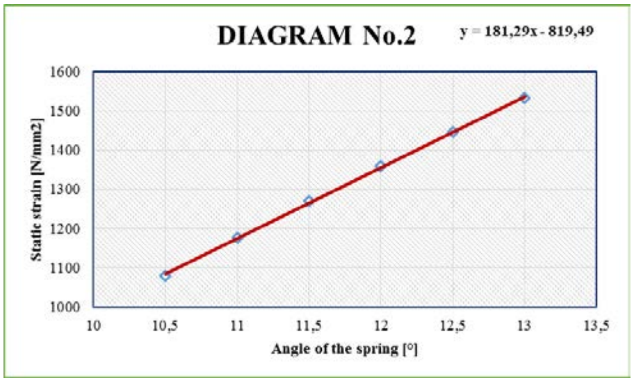

Fig.6 Functional dependence of the static strain from spring angle

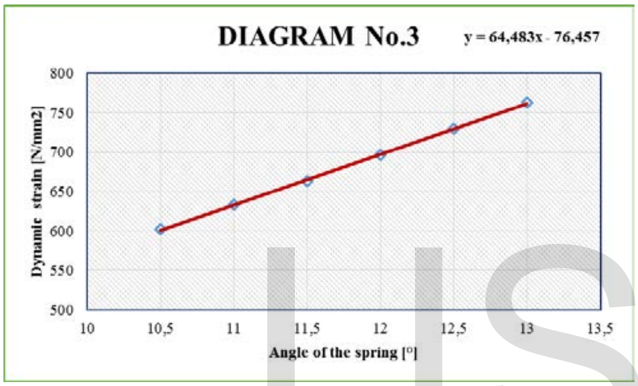

Fig.7 Functional dependence of the dynamic strain from spring angle

5. Analysis of Resultants and Conclusions

From the performed calculation of static and dynamic strain of diaphragm spring for cars it is shown that they were within the acceptable range for the given dimensions of spring. From the results given in Table. 2 we can conclude that the force is greatest at minimum deviation (tilt) and strains are greatest at maximum deviation (tilt). From the examinations of dynamic fatigue we can see that they have satisfied the required number of changes ($N > 2*10^6$) cycles and did not come to significant changes in functional features or breaking of springs.

Starting from the conducted experiments, depending on the impact of the diaphragm spring angle on dynamic persistence of diaphragm spring we can give the following conclusions:

- The angle of the spring is chosen to satisfy the structural requirements of the spring on one side and on the other side strain to be within the acceptable range.
- Increasing the force is proportional to the increase of the angle of diaphragm spring.
- Increasing the strain is proportional to the increase of the angle of the diaphragm spring.
- Function of changing of the strain and force depends on the angle of the spring:
  - o Y =507,07*X - 161,24, spring force (f =h);
  - o Y =181,29*X - 819,49, static strain of the spring;
  - o Y = 64,483*X -76, 457 dynamic strain of the spring;
- Dynamic strain is approximately (1.7 ÷ 2) times smaller than static strain.
- The deviation of pressure and disengaging force were within the acceptable range for $2 \cdot 10^6$ cycles.
- Opportunities for further research of structural factors on the characteristics of the spring were created.

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