FINITE ELEMENT ANALYSIS OF STRESS OF VEHICLES FRICTION CLUTCH DIAPHRAGM SPRING

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Abstract: *A friction clutch is mechanical assemblies built between the engine and transmission, that with friction transfers torque from the driving part to the driven (working) part (engine gearbox and other transmission). A diaphragm spring is one of the key component of a clutch assembly. A diaphragm spring is piece to high stress concentration in driving condition, this is often the cause of cracks and crashes spring. The stress of a diaphragm spring is analyzed by finite element method, measurement of stress and performed compare to stress obtained by expressions on Almen-Laszlo.*

Keywords: CLUTCH FORCE, DIAPHRAGM SPRING, EXPRESSIONS OF ALMEN AND LASZLO, FRICTION CLUTCH

1. Introduction

By pressing on diaphragm spring, it creates the pressing force between driving disc, flywheel and pressure plate. With sufficient pressing force, a torque is transmitted from the flywheel to the transmission through the clutch. The centre portion of the diaphragm spring is slit into numerous fingers that act as release levers (unblock). When the clutch is disengagement the fingers are moved forward by the release bearing, it is occurs separation of the driving disc and pressure plate from flywheel and thus prevents rotation of the driving disc.(Fig.1)

Diaphragm spring has not-linear characteristics between load (force) and deflection, compared to the helical compressed springs (hat a straight-line characteristic), this allows one compact assembly. The change to pressing force is in certain limits by wearing of the friction linings, at helical compressed springs force declines. Excluded force is smaller in comparison with helical compressed springs (Fig 2), [2], [5], [4]
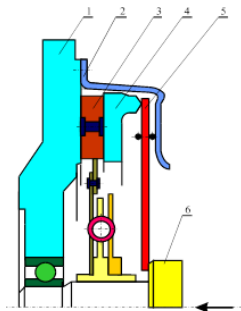
Diaphragm spring is exposed to dynamic loads, increasing the number of changes the dynamic strength of the spring decreases. Dynamic strength of the spring is determined by Weller. Specimens are examined of the exactly same shape, size and quality. They undergo different variables loadings at break of the material. Thus obtained Weller curve from which can be determined dynamic strength.

The stress distribution across the radial width (tangential stresses) of the diaphragm spring is shown in Fig.3, [3].

Fig.3. Stress-deflection

Fig.1. Clutch components :1.Flywheel 2.Clutch cover 3.Driving disc 4, Pressure plate 5. Diaphragm spring 6. Release bearing

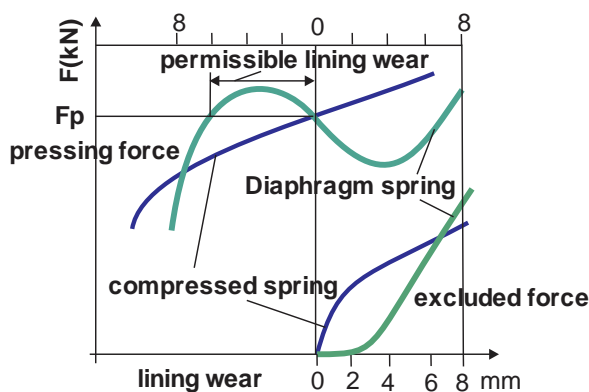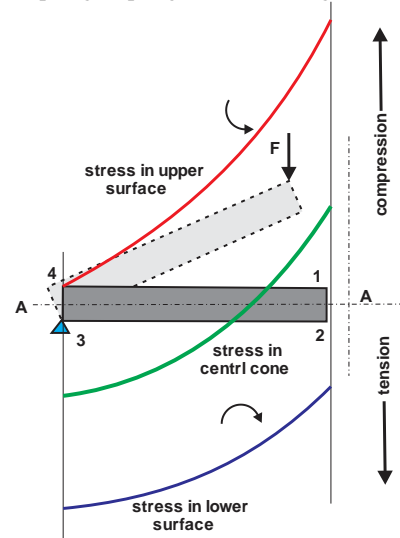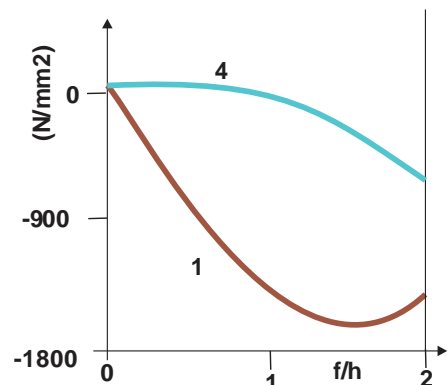**Fig.2.** Pressing force and excluded force

Fig. 3a. Stress-deflection/height of diaphragm spring. Curve 1 for the upper edge of the inner circumference. Curve 4 for the upper edge of the outer circumference.
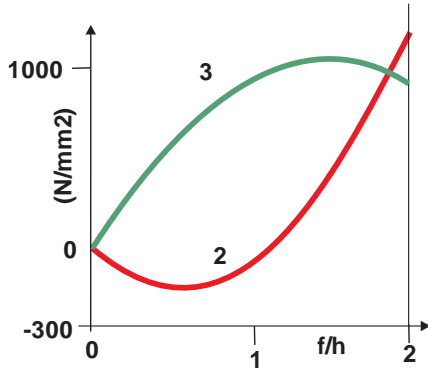
Fig. 3b. *Stress-deflection/height of diaphragm spring. Curve 2 for the lower edge of the inner circumference. Curve 3 for the lower edge of the outer circumference.*

2. Research

The purpose of this research is to calculate the stresses at static and dynamic loads on diaphragm spring. This calculation would have performed by expressions on ALMEN-LASZLO, calculation by finite element method and measurement of force and stress with suitable measuring equipment.

2.1 Calculation of force and stress with 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 (Fig.4) [7], [6], [1]:
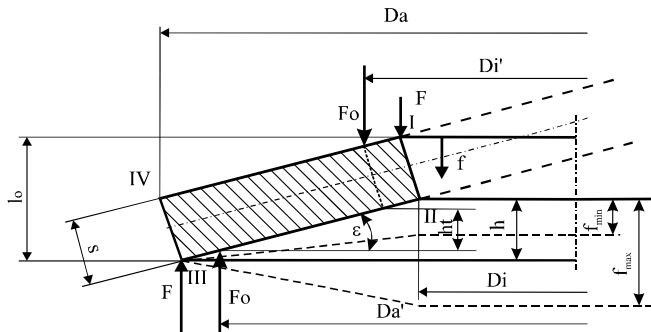

Fig.4. *Forces of the spring*

-Angle bending:

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

where : ε - angle bending, degree, ε_1-angle bending, radian

- Height of diaphragm spring:

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

where : D_a- outside diameter, D_i-inner diameter

-Relationship of diameters diaphragm spring:
$$\delta = D_a/D_i \tag{3}$$

- Coefficients α, $k_1 k_2$, k_3 are defined as follows :

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

$$k_1 = \frac{1}{\pi} \frac{\left(\frac{\delta - 1}{\delta}\right)^2}{\left(\frac{\delta + 1}{\delta - 1}\right) - \frac{2}{ln(\delta)}} \tag{4b}$$

$$k_2 = \frac{1}{\pi} \cdot \frac{6}{ln(\delta)} \cdot \frac{\delta - 1}{ln(\delta)} - 1 \tag{4c}$$

$$k_3 = \frac{1}{\pi} \cdot \frac{6}{ln(\delta)} \cdot \frac{\delta - 1}{2} \tag{4d}$$

$$k_4 = \frac{D_a - D_i}{D_{a1} - D_{i1}} \tag{4e}$$

$$p = \sqrt[2]{9 \cdot h^2 - 6\left(h^2 + s^2\right)} \tag{4f}$$

$$f_{max} = (3h+p)/3 \quad (mm) \tag{4g}$$

$$f_{min} = (3h-p)/3 \quad (mm) \tag{4j}$$

The variable in equation (4) are as follows:
α - Coefficient of elasticity of the spring material, N/mm², E-Module of elasticity, N/mm², μ- Poison number of spring steel, D_{i1}-internal diameter of the diaphragm spring with supporting points, D_{a1}-outside diameter of the diaphragm spring with supporting points, f-deflection, f_{max} and f_{min} - deflection for extreme values of $F_{(f)}$;

- Calculation of stress for the corresponding positions (N/mm²):

$$\sigma_{1,i} = \alpha \cdot \frac{s^2}{k_1 D_a^2} \cdot \frac{ff_i}{s}\left[-k_2\left(\frac{h}{s} - \frac{ff_i}{2 \cdot s}\right) - k_3\right] \tag{5.1}$$

$$\sigma_{2,i} = \alpha \frac{s^2}{k_1 \cdot D_a^2} \frac{ff_i}{s^2}\left[-k_2\left(\frac{h}{s} - \frac{ff_i}{2 \cdot s}\right) + k_3\right] \tag{5.2}$$

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

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

$$(5.3)$$

$$(5.4)$$

where s - spring thickness.

-Pressure force on the diaphragm spring with supporting points is :

$$Ft(f) = \alpha \cdot k_4 \cdot \frac{s^4}{D_a^2 \cdot k_1} \cdot \frac{f}{s}\left[\left(\frac{h}{s} - \frac{f}{s}\right)\left(\frac{h}{s} - \frac{f}{2 \cdot s}\right) + 1\right] \tag{6}$$

The diagram of change on pressing force of spring and spring with supporting points depending of deflection has been shown in Fig.5.
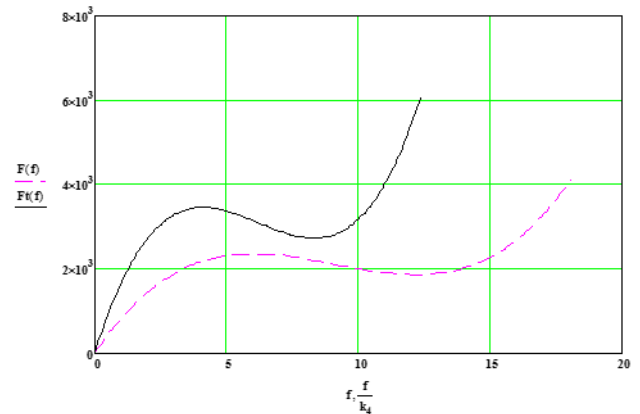
- Calculation of dynamic spring stress

Deflection at disengagement of clutch-control point f_{nis} is a sum of the height of diaphragm spring-h and the deflection from flat position on the spring to position disengagement of the clutch - δ_f

$$f_n = h + \delta_f \quad (mm) \tag{7}$$

where $\delta_f = \dfrac{Da - Di}{Da - d} \cdot l$ and l is path of clutch disengaging

- stress in point 3
- upper stress (OFF-deflection f_p) is :

$$\sigma_s = \alpha \cdot \frac{s^2}{k_1 \cdot Da^2} \cdot \frac{f_p}{s} \cdot \frac{1}{\delta}\left[\left(2 \cdot k_3 - k_2\right) \cdot \left(\frac{h}{s} - \frac{f_p}{2 \cdot s}\right) + k_3 \right] \tag{8}$$

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

$$\sigma_d = \sigma_{3,2} \tag{9}$$

- Dynamic stress is :

$$\sigma_{dt} = \sigma_s - \frac{4}{7}\sigma_t \tag{10}$$

The calculation is performed on diaphragm spring for vehicles, from material (50CrV4-1.8159) and with next parameters:

$D_i = 313$[mm]-internal diameter of diaphragm spring,
$D_a = 395$[mm]-outer diameter of diaphragm spring,
$s = 5.21$[mm]-spring thickness,
$E = 206000$[N/mm²]-Module of elasticity of the steel
$\mu = 0,3$-Poison number of spring steel,
$D_{i1} = 336$[mm]-internal diameter of the diaphragm spring with supporting points
$D_{a1} = 392$[mm]-outer diameter of the diaphragm spring with supporting points,
$\ell = 12$[mm]-path of clutch disenganging,
$d = 120$ [mm] released bearing diameter,
$k_z = 0,95$- efficiency coefficient.

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 $h_o/s \geq 1.4$.

The results are given in the Table 1, 2 and 3.

Table 1: Pressing force and stress on the spring

	Ffi (mm)	FFi (N)	$\sigma_{1,i}$ (N/mm²)	$\sigma_{2,i}$ (N/mm²)	$\sigma_{3,i}$ (N/mm²)	$\sigma_{4,i}$ (N/mm²)
f=f_max	12,16	18590	-1736	497	1415	-354
f=h	9,01	21070	-1534	135	1260	- 62
f=f_min	-6,02	23550	-1172	-67,4	968	93

Table 2 : Pressure force on spring support

$f_{t\,min} = f_{min}//k_4$	4.109	$Ft_{max}=F_{(f\,min)}k_4$	34477
$ft_h = h/k_4$	6.207	$Ft_h = F_{(h)}k_4$	30846
$ft_{max} = f_{max}//k_4$	8.306	$Ft_{min} = F_{(fmax)}k_4$	27215
mm		N	

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/mm²	

2.2 Estimate on stresses of the diaphragm spring with Finite Element Method (FEM)

In the used software package are included: drawing from the spring, dimensions, material, heat treatment (hardness) in the past two days of work the software package. A calculation is made with FEM, with 123845 nodes, the system gives the results of the change in stress from deflection[5].

Table 4 gives the results on the change on the stress dependence from deflection with finite elements.

Table 4: Results from calculated stress with FEM

f (mm)	2,72	5,44	8,16	9,1	10,9	12,6	13,6
σ(N/mm²)	375	740	1020	1055	1140	1140	850

Fig. 6. Network of spring calculation. The network of the spring is divided into 21 parts and for each part is measured the stress on the underside of the spring.
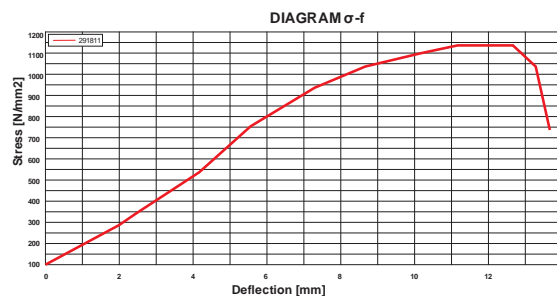

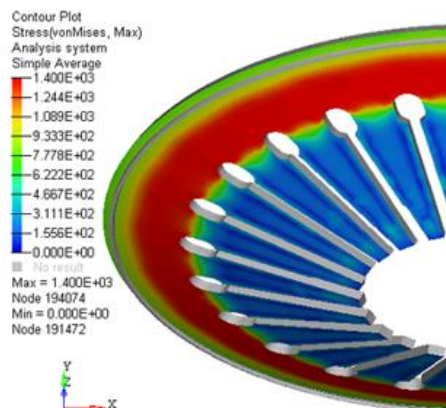**Fig.7.** *Stress change depending on the deflection, calculated by KE for Ø275*

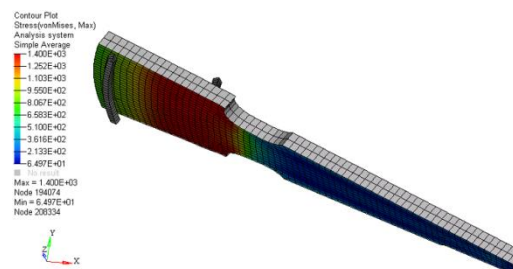**Fig.8a.** *The stress distributing of the lower surface of the spring*

Fig.8b. *The tangential stress of the lower surface of the finger*

2.3 Estimate on stresses of the diaphragm spring with experimental measurement

Measurement of the force is made on the exam table (Fig.9) and with adding to the measured system is measured stress on the diaphragm spring (Fig.10a and 10b)
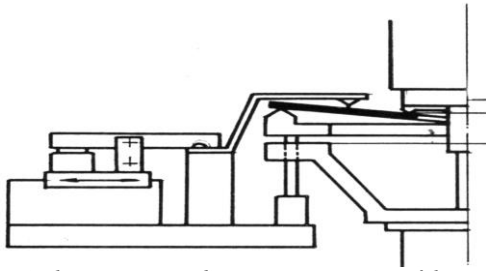

Fig.9. *Diaphragm spring in disengagement position of the spring*

Measuring tapes are mounted on spring 6mm of outer and inner diameter, ie $\varnothing$383mm (measured tangential stress) and $\varnothing$325mm.

Fig.10a. *Diaphragm spring with measuring tapes*

Fig.10b. *Diaphragm spring with measuring tapes and test table*
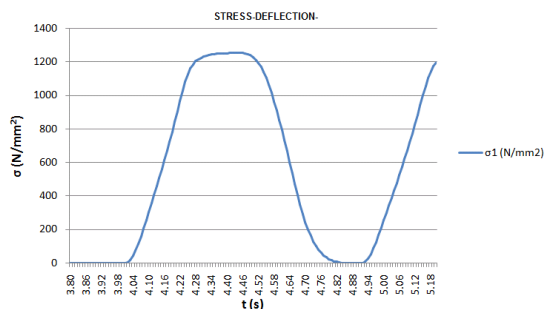

Fig.11. *Diagram stress - time*

Changing on measurement stress in a period of time is the ordinate and the time is the abscissa of the diagram.

Table 5: Value of stress. $\sigma_{3cal.375}$AL-stress calculated using expressions of Almen Laszlo' theory, $\sigma_{3est.,375}$FEM-stress estimated with Finite Element Method, $\sigma_{3meas,375}$EXP-stress estimated with experimental measurement. All tree values for the stress are expressed in N/mm²

t(s)	4,17	4,27	4,37	4,47	4,52	4,57
f(395) mm	2,72	5,44	8,16	10,9	12,6	13,6
f(375) mm	2,06	4,12	6,16	8,23	9,53	10,3
$\sigma_{3cal., 375}$ AL	319	719	984	1191	1290	1336
$\sigma_{3est., 375}$ FEM	375	740	1020	1140	1140	850
$\sigma_{3meas, 375}$EXP	356	903	1231	1252	1253	1211

Table 6 deflection the calculated in relative to the measured stresses

F_i (mm)	2,72	5,44	8,16	9,1	10,9	12,6	13,6
R_i	1,09	0,79	0,80	0,85	0,95	1,03	1,1
R_k	1,04	0,82	0,83	0,88	0,91	0,91	0,70

From the results shown in the table can be determined deviations from the calculated stresses in relation to the measured stresses:

$$R_i = \frac{\sigma_{3cal,375AL}}{\sigma_{3meas,375EXP}} = \frac{1065}{1243} = 0,85$$

$$R_k = \frac{\sigma_{3est,375,FEM}}{\sigma_{3meas,375,EXP}} = \frac{1085}{1243,5} = 0,88$$

3. Analysis of resultants and conclusions

From the deviations shown in the table can be concluded: there is deflection. Important is at higher loadings, and that's when the clutch is mounted in the vehicle (the spring is in a flat position - deflection 9,1mm) and when the clutch is disengaged, (spring has a maximum `deflection 12,6mm), the deviations on the stress that is measured there is deviations 0,8%. Deviations of the calculated values in the expressions Almen-Laszlo in relation to the measured value of stress is (- 15 ÷ +3)%, it is considered to be relatively good. Deviations of the calculated stresses by the method of finite element in relation to the measured value of stresses are (-12 ÷ -9) %, these results are quite satisfying.

Figure 12 shows a diagram of the change of the stress depending on the deflection of measured, calculated stresses after the expression ALMEN-LASZLO and calculated stresses method finite element.

The curve obtained by Almen-Laszlo equation deviates from the curve obtained by measuring. There is no similarity between these two curves because the stress increases gradually, according to the Almen-Laszlo equation, depending from the deflection. Deflection in a flat position is -15%, and when the deflection is maximum deviation is + 3%.

There is similarity between the curve obtained by FEM and the measurement curve, and it is good, but there are certain derogations. Deviation in flat position is -12% and in position at maximum deflection deviation is +9%. Reason for this derogation can be: the number of finite elements used in FEM, the quality of the spring (the material, its strength, hardness, quality workmanship, shot penning on the surface of the upper and /or lower side, dimensional derogation etc.). More of these parameters on the quality of the spring can not be taken in consideration when the calculation is performed by FEM.
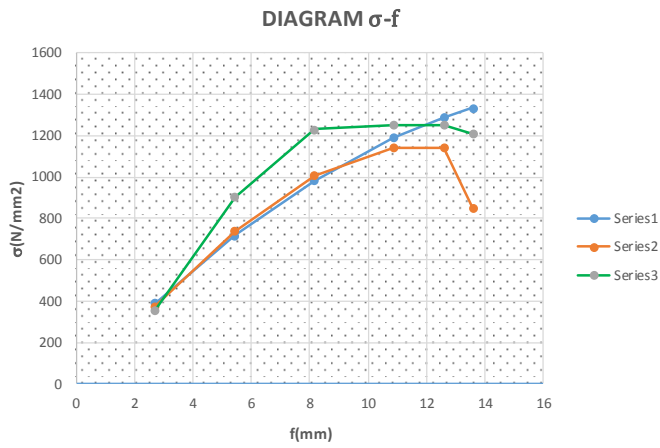
DIAGRAM σ-f

Fig. 12. Stress change depending on the deflection of calculated and measured stress. Series 1-after the calculating AL; Series 2-after the calculating FEM; Series 3-measured EXP

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