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CONTACT PRESSURE AND WEAR IN HELICAL COMPRESSION SPRINGS

V. Gevorgyan, U. Kletzin

Ilmenau University of Technology

ABSTRACT

Among the factors determining the life and liability of mechanical parts in machinery, apparatus and plant is safe functioning of the spring components. The demands placed on helical compression springs by friction will cause wear and can cause failure of the element and therefore of the whole component.

The aim of the present paper is to shed light on the influence of contact pressure on the wear and tear that arises between the end coil and the spring seat or between the end coil and the transition coil by using pressure measurements and FEM calculations; also to shed light on the influence of the surface roughness on the wear by means of tribological tests on a selection of surface roughness types for specially shot peened wires, all in order to improve the function and lifetime of these commonly used parts and the components into which they are installed.

Index Terms – Transfer of force in helical compression springs, contact pressure, friction, wear

1. INTRODUCTION

Springs are among the most important of engineering design elements. Many and diverse forms of them are to be found in the technical products of the mechanical engineering, precision engineering, electrical engineering, automotive manufacturing industries and in many other technical areas [1]-[11]. The intention is to enable frictional overload to be avoided by analysing the friction system (tribosystem) of springs so that design guidelines can be derived.

Losses in a tribosystem can be quantified in terms of the loss of material (the wear) and the loss of energy (the friction). The calculation of these mechanical and energy losses by wear and friction requires exact knowledge of the contact areas and the microgeometry of the contact surfaces [12]-[14].

A research project in progress includes investigations to find the contact areas in dependence on the configuration of the end coils and transition coils and to find the influence on friction and wear of shot peening as a surface treatment [11]. The method and initial results are here presented.

Figure 1 shows the fundamental contact areas within springs and between springs and their surrounding components which are in the tribosystem to be considered. In this paper, the presentation is of experiments with helical compression springs with ground coil ends and flat spring seats. The most important contact areas are those at the friction points 1, 2.1 and 2.2 shown in **Figure 1**.

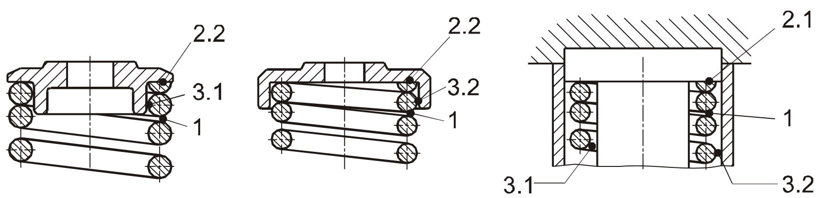


Figure 1: Friction and wear points in helical compression springs between:
1 the coils; 2.1 the coil end and the housing; 2.2 the coil end and the spring seat; 3.1 the coil and the hook, eye or loop (where present) or the spring seat; 3.2 the coil and the sleeve or centering pin

Wear leads to changes in the characteristic curve of the spring: $R = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n}$ (1)

A decrease in wire diameter because of wear will have an effect on the rate or stiffness of the spring. Wear in the area where the end coils are anchored to their surroundings will result in a change to the effective installed length of the spring and thus a parallel shift in the characteristic curve. These two effects overlap and will result in malfunction if the tolerance limits are exeeded. The malfunction may cause the spring component to fail even before its minimum lifetime has been reached, for example because of cracks in the end and transition coils.

Wear between helical compression springs and the components surrounding them, also between the coils of springs, will only occur if there is relative movement between these surfaces. Such relative movements are caused by the force components which are exerted.

In order to clarify the wear activity in the helical compression spring tribosystem it is necessary to analyse the distribution of the pressure. The pitch design and the surface roughness are of great significance. The pitch design is produced during the coiling procedure, the surface roughness is, in the case of helical compression springs, set at the ground spring ends by the grinding parameters and for the spring wire by the shot peening parameters.

2. DISTRIBUTION OF FORCE AT THE BASE SURFACE OF HELICAL COMPRESSION SPRINGS AND BETWEEN END COIL AND CHANGE-OVER COIL

When pressure measurement film is used to measure pressure, the force is shown by the intensity of discolouration of the film. Pressure was measured between spring and spring disc, also between end coil and change-over coil. Sample springs of various shapes (cylindrical helical compression springs with different spring diameters, spring lengths and wire diameters) and with ground ends were tested on a Universal Tension Testing Machine made by Zwick at various loads (100 N to 900 N) for these experiments. The total number of coils was also varied (x.0; x.25 and x.5).

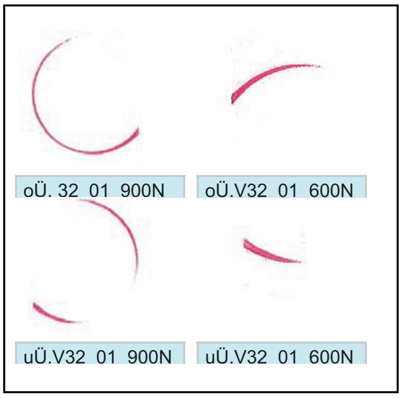
The investigations proved that the distribution of forces between spring and spring disc is not uniform across the entire spring contact surface but is concentrated at two opposite points of the end coil. The reason for this is that the vector of force changes in its components both longitudinally and transversally to the axis of the spring during compression and that this works as much on the change-over coils as on the spring ends (**Figure 2**).

It is also at these points that more wear is found. As the wear surfaces show, the contact areas are at the inside edges of the end coils (**Figure 2c**). This fact is governed by shape and dimension tolerances (DIN 2095). Improvements will be possible in spring manufacture by attending to the configuration of the end and change-over coils, by improving the grinding and by improving the spring disc manufacture.

a) b) c)

Figure 2: Determination of pressure distribution using pressure measurement film: a) Distribution of force at the spring ends at different levels of load (300 N, 600 N and 900 N), b) spring with pressure measurement films, c) areas of wear at the base surface

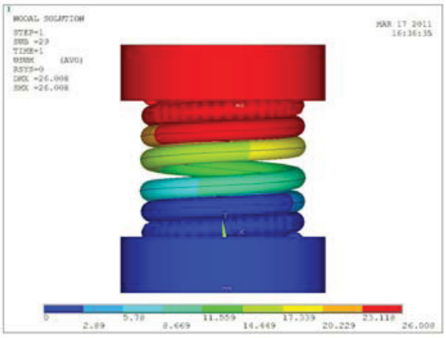
After the force distribution measurements between the change over and end coils a clear difference in force transmission between the beginning and the end of the change over coil becomes apparent. If pressure is low there is contact only between the beginning of the change-over coil and the end of the end coil. The higher the pressure, the bigger the contact area. The pressure is greater at the beginning and end of the relevant change over coil than it is in the turn of the active coil. At higher pressures, the same pressure distribution can be seen as at the spring end (distribution of forces on two sides). When wear has taken place between change over and end coils, the friction surface is enlarged and the pressure is distributed over an even larger area at the same load. Wear then causes the thickness of the wire and the spring rate to change. The Hertzian contact stress becomes surface contact pressure (**Figure 3**).

a) 

b) 

Figure 3: a) Distribution of force and b) wear on change over coils

The experimental investigations are supported by parameter studies using an FEM model (**Figure 4**).

a) 

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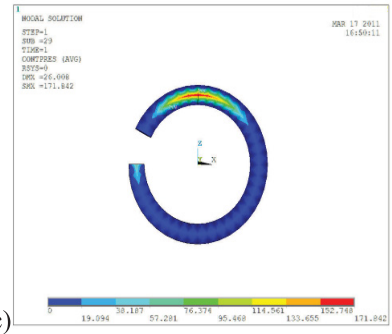
c) 

Figure 4: Distribution of force at change over coils
a) spring deflexion at axial load of 900 N,
b) Pressure distribution at end of spring at axial load 900 N,
c) Pressure distribution at transition coil at axial load 900 N,

Figure 4 shows the pressure distribution of the same spring as was used for the pressure measurements using film shown in **Figure 2**. Exact results in the FEM simulation require exact consideration to be given to the geometry of the spring. This will be possible at an image processing measurement station, for instance.

3. TRIBOLOGICAL INVESTIGATIONS WITH SELECTED SURFACE ROUGHNESS OF SPECIFICALLY SHOT PEENED SPRING WIRES

A mechanical surface treatment given to helical compression springs is shot peening. The surface is hardened by the creation of residual stress. Peened springs thus achieve a considerably longer fatigue life under dynamic loads. The residual stresses achieved by the peening are accompanied by plastic deformation of the surface in various degrees of roughness. Sample pieces of wire made of oil-hardened SiCr valve spring wire were used for an investigation of the effect of different degrees of roughness on the wear between the end and change-over coils. They were shot peened in an experimental shot peening plant with shot made of special wire. The shot peening parameters were varied as shown in **Table 1**.

Table 1: Peening parameters used

Feed	Compressed air (G109B)	Compressed air (G109C)	Compressed air (G109D)	Shot hardness	Shot diameter
1.5mm/s	1.3 bar	2.9 bar	4.5 bar	HV 700	0.6 mm

Three different pressures were used and these resulted in three different levels of roughness (**Figure 5**). The roughness was measured using a profilometer. The roughness levels were $R_a/R_z = 1.26/8.8$ µm at 1.3 bar, $R_a/R_z = 2.54/15.2$ µm at 2.9 bar, $R_a/R_z = 3.36/21.2$ µm at 4.5 bar, and $R_a/R_z = 0.54/3.9$ µm for non-peened wire. The roughness arising was proportional to the pressure at which the shot was peened onto the wires.

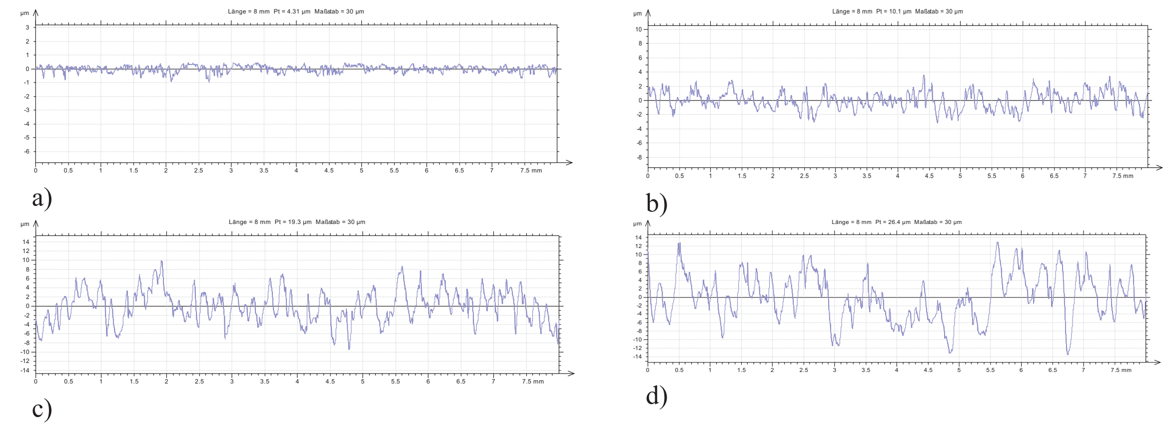


Figure 5: Profiles of surfaces of SiCr oil-hardened valve spring wire:
a) non-peened
b) peened with 1.3 bar compressed air (G109B)
c) peened with 2.9 bar compressed air (G109C)
d) peened with 4.5 bar compressed air (G109D)

For the experiment it was necessary to create frictional contact close to real-world conditions such as is found when the springs are under dynamic load. As the helical springs are compressed, the diameter of the spring increases and there is relative movement between end and transition coils. To simulate this sort of frictional contact, the experiments were carried out using a special wire mount on a vibration wear tribometer made by Wazau which induces translatory relative movement. After initial investigations on this machine, the following conditions were established for the experiments:

normal pressure: 80 N; frequency: 10 Hz; deflection: ± 1 mm (2 mm peak to peak); duration: 1 hour; state: lubricated and non-lubricated

As the experiments showed, the wear with lubricated conditions at lower roughnesses is less than at higher roughnesses (**Figure 6**). This difference is clearly to be seen. The presence of the lubricant means that the relative movement takes place in the area of mixed-type friction, so that the influence of the hardening of the surface plays a subsidiary role and the wear depends largely on the roughness of the samples.

In dry conditions, the association between roughness and wear is similarly to be seen for the peened wires, but in this case the wear is greater on the non-peened wires, although they show the lowest roughness ($R_a/R_z = 0.54/3.9$ µm) in comparison with the peened wires. This phenomenon can only be explained by the surface hardening of the peened wires, due to which there is less material lost from the peened wire than from the non-peened wires even without lubrication. The friction points on the surfaces tested dry, without oil, show wear from galling and abrasion and friction corrosion from fretting (**Figure 7**).

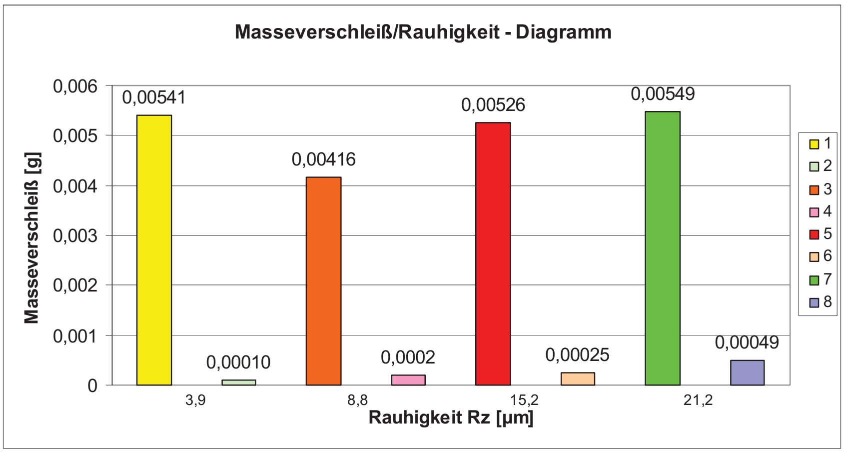
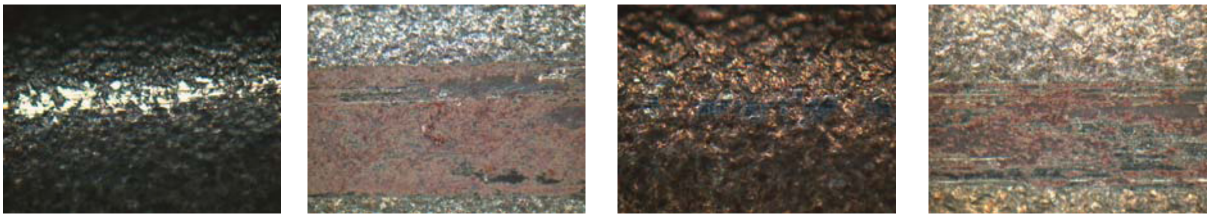


Figure 6: Dependency of material loss on surface roughness:
1 – 450706 without lubrication, 2 – 450706 with lubrication,
3 – G10B without lubrication, 4 – G10B with lubrication,
5 – G10C without lubrication, 6 – G10C with lubrication,
7 – G10D without lubrication, 8 – G10D with lubrication



a) b) c) d)

Figure 7: Signs of wear:
a) shot peened with 1.3 bar compressed air (lubricated)
b) shot peened with 1.3 bar compressed air (non-lubricated)
c) shot peened with 2.9 bar compressed air (lubricated)
d) shot peened with 2.9 bar compressed air (non-lubricated)

The coefficient of friction for all the lubricated wires hardly varies whatever their roughness (**Figure 8**). Even in the non-lubricated state, the coefficient of friction of the non-peened wire is only slightly higher than those of the peened wires.

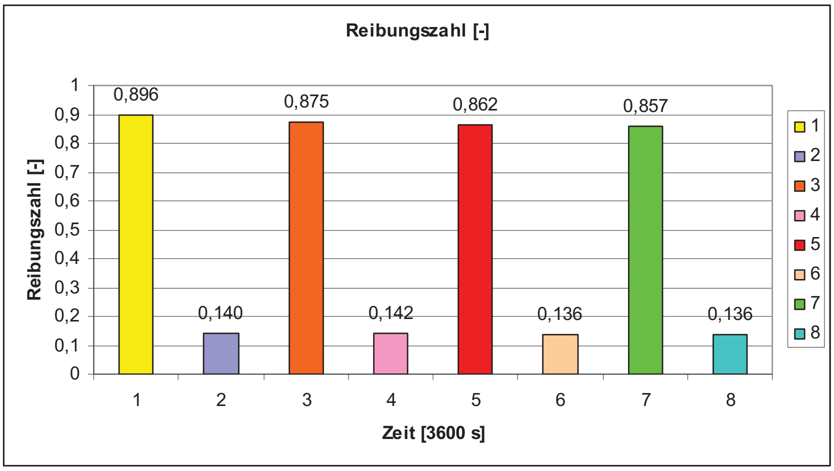


Figure 8: Coefficient of friction of non-peened and peened wires with and without oil:
1 – 450706 without lubrication, 2 – 450706 with lubrication,
3 – G10B without lubrication, 4 – G10B with lubrication,
5 – G10C without lubrication, 6 – G10C with lubrication,
7 – G10D without lubrication, 8 – G10D with lubrication

4. SUMMARY

The results obtained from the experiments carried out were as follows:

Both pressure measurement and FEM simulations indicated that the contact surfaces with a tribological effect within the spring (between the change over and end coils) and between the spring and the spring seat are dependent on the geometrical shape of the end and change-over coils, in particular on the development of the pitch.

Future investigations should focus on full variation of the parameters using the FEM model using the spring shapes already investigated as a starting point in order to derive design rules for helical compression springs optimised for wear in respect of the contact geometry.

For peened springs, attention should be paid henceforward not only to the residual stress achieved but also to the surface roughness, because the higher this is, the more wear there will be. This is true of both lubricated and non-lubricated tribosystems.

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Authors:

Dipl.-Ing. V. Gevorgyan (vahan.gevorgyan@tu-ilmenau.de)
Univ.-Prof. Dr.-Ing. U. Kletzin (ulf.kletzin@tu-ilmenau.de)
Ilmenau University of Technology
P.O. Box 10 05 65
98684 Ilmenau
Germany