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CHANGING COIL SPRINGS CHARACTERISTICS BY SHOT HARDENING AND GALVANIZING

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Abstract: *The paper analyzes the springs (usually made from bars of constant section), used in vehicle suspension. Depending on the purpose, the material used, the space in which are mounted and by how that will work, the springs are classified in different variants.*

To meet its goal, must be known relationship between load and deformation of the working spring and finding the action of mechanical work of deformation depending on loading and application point. In operation, in addition to static load, spring is subjected to: uncompensated centrifugal force when passing through curves, wind pressure, the forces of inertia to start and stop the vehicle, vehicle dynamics due to oscillations.
Key words: *coil springs, air springs manufactured, shot hardening, galvanizing.*

1. Introduction

Springs are machine elements that trough special elastic properties of materials that are made off, deforms elastic, under the action of external loads, with in relatively large limits. During the elastic deformation, springs store the mechanical work done by the external loads as deformation energy, with the possibility to restore it during the return to their original state.

The main attributes of the materials of running springs refers mainly: high tear strength, high elastic limit, high resistance to fatigue. In some fields of use, materials for springs impose a series of special features, such as: high temperature resistance, corrosion resistance, no magnetic properties, low thermal expansion, temperatute-independent elastic behavior etc.

For springs subjected to variable loads, surface quality is a determining factor in terms of sustainability. Increasing fatigue resistance can be achieved by: avoiding decarburization of the superficial layer during the heat treatment, fine rectification of surface after the final heat treatment to remove oxide coating, hardening the surface layer (when the correction is not available), jet shot; protecting the spring against corrosion by various coatings [1].

2. Springs characteristic

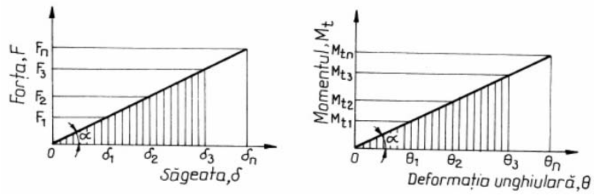
A spring feature is the curve that represents the dependence between the load that is acting on the springs (force or moment) and deformation (arrow or angle) produced by this on the direction of the load; in this respect, the spring characteristic can be expressed by the following relations:

$$F = F(\delta)\,;\ M_t = M_t(\theta)$$

where:

δ = linear deformation of the spring in the direction of the force F (arrow);

θ= angle deflection of the spring in the direction of torque M_t (rotation).



a b

Fig. 1. Linear characteristic of coil springs

Spring graph characteristic (Fig.1) gives the image of stiffness variation c of a spring, defined by the sloap of the curve expressing the load – deformation, when the load is a force (Fig.1 *a*) or a moment (Fig.1 *b*).

$$c = tg\alpha = \frac{F}{\delta};\ c' = tg\delta = \frac{M_t}{\theta}$$

Linear characteristic (Fig.1) is seen in frictionless springs made from materials that comply with the law of Hooke. These springs are represented by the constant stiffness.

Given that basicmechanical work is determined by the expression $dL = Fd\delta$, surface between spring characteristic and abscissa represents the mechanical work of spring deformation, stored by its deformation. Thus in Fig.1*a,* shaded area is equivalent to the mechanical work of deformation of the spring, under F_3 force. Assuming that the linear characteristic, expression of deformation mechanical work – when the external load is a force – is

$$L = \frac{1}{2}F\delta = \frac{1}{2}c\delta^2$$

And when the external load is a torque

$$L = \frac{1}{2}M_t\theta = \frac{1}{2}c'\theta^2$$

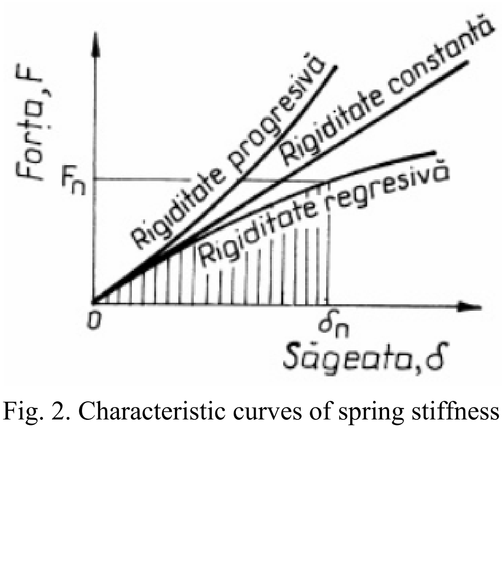


Fig. 2. Characteristic curves of spring stiffness

Springs with constant stiffness are the most widely used in practice. There are, however, variable stiffness springs for which is characteristic the curve in Fig.2. In this case, spring stiffness is given by:

$$c = tg\alpha = \frac{\partial F}{\partial \delta} \neq const.;\ c' = tg\alpha\frac{\partial M}{\partial \theta} \neq const.\ [1].$$

3. Instalation for the manufacture of the coil springs

Installation is designed to be able to execute a wide range of springs bars of various thicknesses. In Fig.3 is presented the winding springs facility, which was designed by the authors, made and used in a factory in Cluj-Napoca.

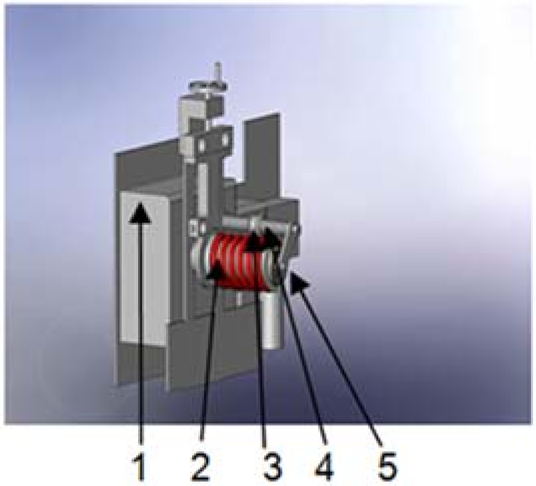


Fig. 3. Instalation for the manufacture of coil springs: 1. drum rotation machanism; 2. coiled spring; 3. driving roller; 4. screw for the driving roller; 5. drum winding

The plant can wrap – hot – springs from bars Ø 10÷40 mm. Springs are running by the technical documentation or by model. In both cases for each type of spring is required to run the winding drum, roller screw for driving and driving roller.

For sizing drum winding, spring step and size must be known, bar diameter and spring length in free state.

To obtain the desired spring step is necessary that all the dimensions of the winding drum, roller screw driver and driver to be well correlated.

$$p = \frac{H_0 - 2,5d}{n}$$

where:

p = spring step;
H_0 = free state spring length;
d = spring bar diameter;
n = total number of turns.

Noting with: D_t – drum diameter; p_a – spring step; d_r – driving whell diameter; p_s – driving screw step, we have:

$$\frac{D_t}{p_a} = \frac{d_r}{p_s}$$

hence:

$$d_r = \frac{D_t p_s}{p_a} \quad \square\text{i} \quad p_s = \frac{p_a d_r}{D_t}$$

Springs are made of the following materials: 60SiCr7, 51CrMoV4, 55Si7 or 55Cr3. Regarding bar surfaces, will supply calibrated round steel bars (annealed, peeled, drawn, polished) RCTS-h11 STAS 1800-2000 [2].

3.1. Engineering roadmap for the implementation of coil springs includes the following steps:

1.**cutting workpiece** – with grinding wheels;
2.**workpiece heating** – heat in an induction furnace to a temperature of approximately 1150 ^{0}C and maintained according to the thickness of the steel bar;
3.**winding** – is wound on a metallic drum made of high temperature resistant steel;
4.**spring calibration** – adding cutting, straightening the end turns;
5.**shaping and milling** the spring heads;
6.**hardening heat treatment** – according to figures 4 and 5;

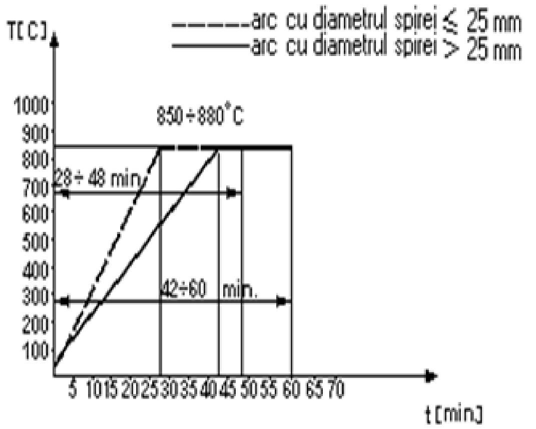


Fig. 4. Diagram of heating coil springs to hardening

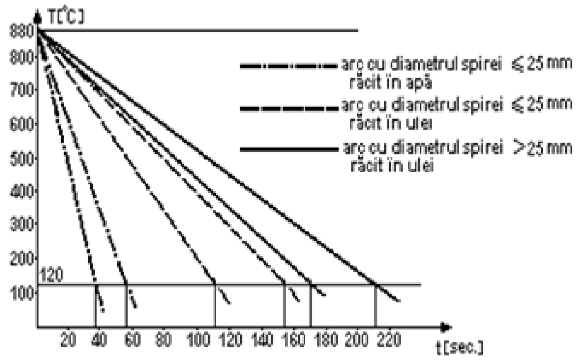


Fig. 5. Hardening diagram of coil springs

7.**shot hardening** (with the blank test – specimen type ALMEN)

This procedure consists in shooting high-speed (40 – 80 m/s) of steel shot, cast iron, glass or ceramic (0,2 – 2 mm diameter) on the work piece. By bombarding parts with shot in conditions that must be perfectly controlled, in the superficial layers of the parts, compressive residual stresses are introduced, opposing operating stresses, substantially improving the life and fatigue strength ot the parts subjected to dynamic loads.

By bombing with shot occurs a hardening of the superficial layer to a depth between 0,1 – 1 mm. Harden the surface layer has a much finer structure than the basic metal structure. Dislocation and sliding phenomena of crystals that occur during shot hardening creates residual compressive stress state in the harden layer.

Shot hardening is used in particular for increasing resistance to fatigue of metal parts and to prevent their rupture by stress corrosion. This process is also used to improve fatigue resistence in corrosive enviroment.

Currently the applications of shot hardening are numerous in industry. In developed countries this procedure is widley used, particulalry appling to the springs, welded joints, shafts, torsion bars etc.

Shot hardening is successfully aplied to the full range of wire springs with a diameter of 0,1 to 75 mm. Goodman`s diagram, in figure 6, illustrates the allowable stress range compared to the coil springs in wire with a diameter of 5 mm in the shot harden state and not harden.

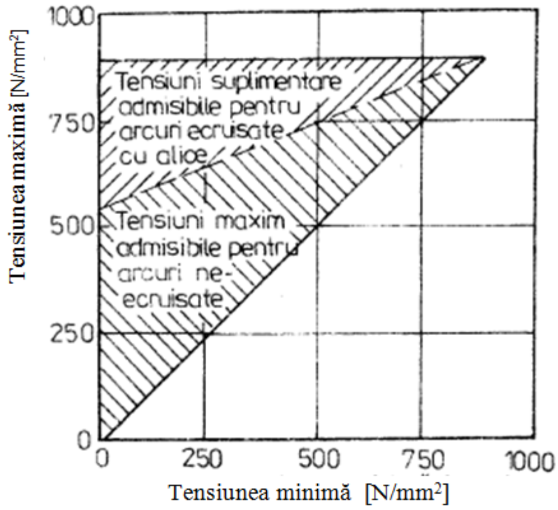


Fig. 6. Allowable stress range for the coil spring wire diameter 5 mm.

Increasing fatigue limit by shot harden wire springs of diferent diameters is given in table 1.

Table 1.

Increasing springs fatigue resistance

ϕ mm	Loading T_{max}	Fatigue limit $2 \cdot 10^6$ cycles		
		Not harden spring [N/mm^2]	Shot harden spring [N/mm^2]	Growth %
20	400-440	$\pm$ 180	$\pm$ 236	29
30	420-440	$\pm$ 170	$\pm$ 216	27
40	440	$\pm$ 163	$\pm$ 204	23

To increase the effectiveness of shot hardening, in practice is often used the method of shot hardening the spring under tension. The need for ways to eliminate microcracks in the process of shot hardening, requires:

- springs to gave medium hardness compared to the maximum acceptable value (50 HRC);
- shot materials show no excesive hardness;
- balls diameter should not be to large, balls to be sorted, whitout edges, pinching or other wastes;
- blasting pressure of the balls to be reduced in case of microcracks.

In figure 7 are presented the effects of shot hardening under stress on the life of the springs [3].

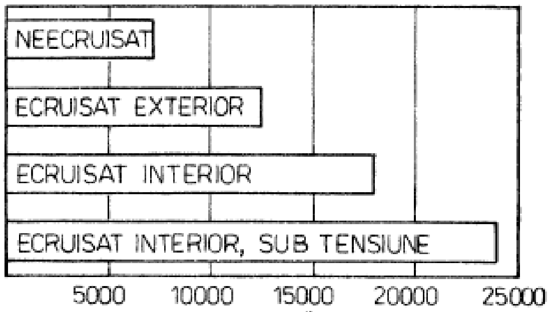


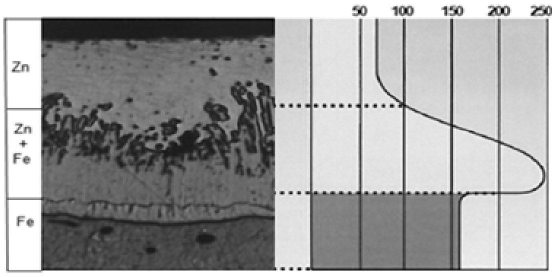
Fig. 7. Influence of the shot hardening on sustainability of an coil spring [3]

8.**protection against corrosion by galvanizing and tempering**

Along with the process of galvanizing, springs are subjected to tempering, with the role of reducing stresses emerged from hardening.

The springs are placed into an electric furnace and heated to a temperature of 460 ^{0}C, where are maintained depending on the thickness of the spring, then enter the zinc bath where they are mantained until reaction is complete. The internal structure of steel continue to evolve until the steel returns to its normal temperature.

The outer layer of zinc (phase η) is relatively soft and absorbs mechanical shock mostly an eventual impact occurred during handling. Alloyed layers below it (phases ζ, δ, γ) are much harder, even harder than the substrate itself. These alloyed layers are 4-6 times more wear resistant than pure zinc (Fig. 8). Wear resistance of zinc coatings is higher than paint with the same thickness [4].



Hardness gradient

Fig. 8. Microstructure of a galvanized coating and hardness gradient variation

To determine the zinc layer, can be used both destructive and non-destructive methods. The most used are: direct measurement and the jet method.

The jet method is applied to workpiece allowing rapid and complete draining of the solution used for determination (ferric chloride, copper sulphate). Metal thickness δ, in μm, is calculated with the relation:

$$\delta = Kt ,$$

where: K- penetration factor, [$\mu m / s$]; t – the time for dissolution of the layer,[s].

Direct measurement method, befor and after the deposit layer, involves weighing the pieces. With this method can be calculated the average film thickness δ:

$$\delta = \frac{\frac{(G_2 - G_1)10000}{S}}{\gamma} \quad [\ \mu m\ ],$$

where:

G_1 - piece weight before coating;

G_2 - piece coating after coating;

γ - specific weight of the metal coating;

S- work piece surface.

The reason for extensive use of zinc coating is the double protective effect of zinc providing a good anticorrosive resistance, namely:

- Physically, through the protective layer it forms in contact with the air;
- Chemically by its electronegative potential (- 0,76 V) to iron (- 0,44 V), acting as sacrificial anode in micropila iron-zinc.

The zinc protects the steel by cathodic reaction type, slow proces that defines the kinetiks of protection. Through its own corrosion produces a diffusion of ions of Zn^{2+} and OH^{-}, in contact with the ambient they form oxides, carbonates and zinc oxychloride. This insoluble salts reduce the corrosion rates of zinc on the physical medium by cell polarization Fe – Zn [5].

The advantages of zinc coating the springs are:

- is the most effective and cheaper corrosion protection process compared to the lifetime of the product;
- the average lifespan of the protective layer is between 40 and 80 years;
- Romania has a single standard for galvanizing - SR EN ISO 14/61/2002, identical to the Europea Standard EN ISO 1461/1999;
- allows easy verification of surfaces state;
- all surfaces that come in contact with air are evenly covered;
- throughout the life of the product, the protection layer requiers no maintenance coating;
- the obtained layer has a high resistance to vibrations;
- were analyzed costs over the life of a product, galvanizing is considerably cheaper than any other corrosion protection system.

9. the spring checking, marking and storage are the last stages of springs manufacture and are based on size, lenght and material used produce them.

4. Conclusions

Observations and conclusions on the springs of vehicles (generally spring from trick bar). After the purpose, after the material used and space in which are mounted and by how that will work, the springs are classified in different variants.

To meet the goal springs must meet certain conditions:

- establish the contact between task working on the springs and its deformation under the action of load;
- determining the mechanical work of deformation possible depending on the deformation of the

springs and loading of material and depending on the request. In operation, when running, in addition to static load the spring loading additional bow for several reasons: uncompensated centrifugal force acting on the vehicle suspensions parts pass through curves, wind pressure, the forces of inertia to start and stop the vehicle, dynamic overload due to oscillations of the vehicle;

- to prevent damage to spring into operation, maximum neparalelism between the spring seating surfaces and maximum inclination of the axis arch to these areas should not exceed 3% of the height of the arch;
- although coverage by galvanizing is a process more expensive that the paint coating and corrosion protection, in terms of springs and long-term corrosion, zinc layer applied by galvanizing have lowers maintenance costs and increase life.

5. References

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MODIFICAREA CARACTERISTICILOR ARCURILOR ELICOIDALE PRIN ECRUISARE ŞI ZINCARE TERMICĂ

Rezumat: Lucrarea analizează arcurile (în general din bare cu secţiune constantă) folosite la suspensia vehiculelor. În funcţie de scopul lor, de materialul din care sunt fabricate, de spaţiul în care sunt montate, arcurile sunt clasificate în mai multe variante. Pentru a îşi îndeplini obiectivul, trebuie cunoscută relaţia dintre sarcină şi deformaţia arcului solicitat şi determinarea acţiunii lucrului mecanic al deformaţiei în funcţie de încărcare şi de punctul de aplicare. În timpul funcţionării pe lângă solicitarea statică, arcul este supus la: actiunea forţei centrifugale necompensate la trecerea prin curbe, presiunea vântului, forţa de inerţie la pornirea şi oprirea vehiculului, dinamica vehiculului datorata oscilaţiilor.

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