

Theoretical background of method of springs recovering

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Abstract. During their life span, high load compression springs lose their resistance and their operating load is reduced. In the course of time, relaxation is observed. The method of compression springs recovering from hardened wire by low-temperature thermo-mechanical treatment and contact predeformation is presented. The results of experimental tests on recovering load bearing characteristics of the lot of springs according to a new technology are reported. Load bearing characteristics of recovered springs are theoretically specified. The difference between theoretical and experimental researches does not exceed 3.2 %. This method of springs parameterization is recommended to be used in the development of technology of springs recovering with the use of low-temperature thermo-mechanical hardening and contact predeformation.

1. Introduction

During their life span, high load compression springs used in modern technics requiring high load speeds and compact installation of the springs in the units lose their resistance, and their operating load is reduced. In the course of time, relaxation is observed. Relaxation of the power of valve springs reduces the power and efficiency of the engine. Decreased resistance of operating valve springs causes the increase of valve train wear [1, 2]. Relaxation of automobiles' suspension springs is the reason for early fatigue of frame rails and the body of a car. Compression of lock valve springs in automobile cargo lift B-28 leads to an emergency situation with the cost of springs used in road and construction engineering reaching up 5000 rubles and higher and automobiles' suspension springs from 2000 to 3630 rubles per set depending on the model of the car. Thus, springs are expensive and they influence the efficiency and reliability of technics. That is why, the task of improvement and theoretical justification of technologies of springs recovering and hardening is urgent.

2. Results and Discussion

Automobile industry is one of the main consumers of springs from hard drawn spring wire [3]. To solve the task the method and devices for recovering compression springs from hardened wire (patented or hard drawn) with the use of low-temperature thermo-mechanical hardening and contact predeformation are worked out [4]. The method is carried out as follows. A heated spring is extended with the interval exceeding that of the completed spring, then it is released, hot and extended, and kept



in such state until it gets cold. Then been hardening and spring contact predeformation with axle load within $10\dots300F_3$ (F_3 – spring force before coils contact) are performed.

The operations of heated spring extension, releasing and cooling in an extended state are referred to the methods of thermo-mechanical treatment leading to the formation of specific structure and substructure of martensite and bainite. As a result, steel acquires high mechanical properties [5]. Due to the operation of pressing plastic spring, hardening occurs, and favorable stress state on the surface and inside the coils antagonistic to spring compression is created [6].

Typical representatives of high load and compact springs from hardened wire are inner valve springs of internal combustion engines of VAZ (figure 1) which were chosen for experimental research. Valve springs must have high fatigue resistance in the multicycle area and high relaxation and creep resistance at high temperature. Minor disturbances in the process of hardening or low quality metal for springs influence their performance qualities [7, 8].

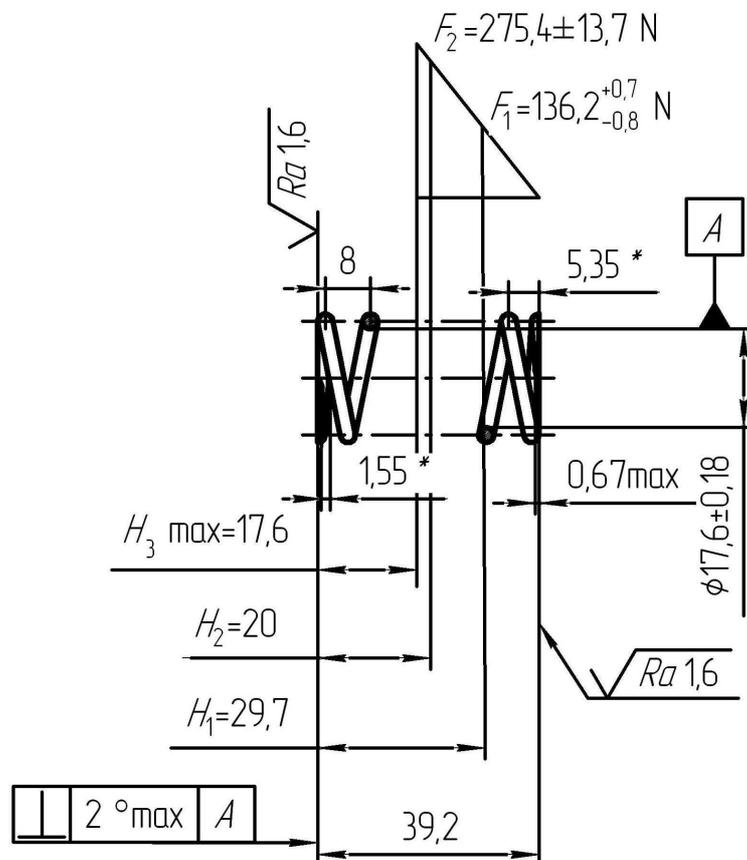


Figure 1. Inner valve spring 2101-1007021: F_1 and F_2 – initial spring load and operating load correspondently, N; H_1 , H_2 , H_3 – spring height on initial spring load, operating load and compression until coils contact accordingly, mm.

Table 1 shows operations and the equipment of the technology of recovering 2101-1007021 valve springs load bearing characteristics of the engine of VAZ automobile worked out according to the new method [4].

Table 1. Operations of the technology of recovering 2101-1007021 valve springs

Sl.No	Description of the operation	Notes, equipment
1	Checking operation: $H_2 = 20$ mm, $F_2=275.4\pm 13.7$ N	Scales TLS-S-2000 by «TIME»
2	Cyclic test 6×10^6 cycles	Stand SBN 0121
3	Washing out (degreasing)	-
4	Checking operation: $H_2 = 20$ mm, $F_2=275.4\pm 13.7$ N	Scales TLS-S-2000 by «TIME»
5	Mandrel heating: heating temperature 420° C, heating time 15 min	Laboratory furnace
6	Spring extension. Height of the operating part of the spring on the mandrel when extended $H_{oper} = 45$ mm. The interval of the spring on the mandrel is 10 mm.	Device for spring extension
7	Releasing on the mandrel: releasing temperature - 400° C; releasing time - 30 min.	Laboratory furnace
8	Predeformation by the load of 12400 N ($40F_3$)	Device for contact spring predeformation
9	Checking operation: $H_2 = 20$ mm, $F_2=275.4\pm 13.7$ N	Scales TLS-S-2000 by «TIME»
10	Cyclic test 10.5×10^6 cycles	Stand DV8-S2 by «Gejrg Reicherter»
11	Checking operation: $H_2 = 20$ mm, $F_2=275.4\pm 13.7$ N	Scales TLS-S-2000 by «TIME»

The work was carried out under the programme “Start” with support of Innovation Promotion Fund and the staff of OAO “Belebey plant “Avtonormal”, Belebey. The results of experimental tests on recovering of load bearing characteristics of the lot of springs (24 units) according to the new technology are represented in table 2 [4].

Table 2. Results of experimental work on recovering of load bearing characteristics F_2 of the lot of valve springs 2101-1007021

	Before test	After test 6×10^6 cycles		After recovering			After repeated test 10.5×10^6 cycles	
	F_2 , N	F_2 , N	$\Delta F_2 / F_2$, %	F_2 , N	$\Delta F_2 / F_2$, %	τ_2^b , MPa	F_2 , N	$\Delta F_2 / F_2$, %
min^c	271.2	265.0	0.6	266.6	0.1	840.0	262.4	0.5
max^d	285.4	281.0	4.7	288.2	-6.0 ^a	909.0	281.0	2.5
X^e	277.0	271.2	2.1	276.0	-1.8 ^a	870.3	271.7	1.6
R^f	14.2	16.0	4.1	21.6	6.1	69.0	18.6	2.0

^a «-» shows that the strength of the spring has increased.

^b τ_2 – torsional tension in springs at the load of F_2 , MPa.

^c min – minimal sampling value.

^d max – maximal sampling value.

^e X – arithmetical average.

^f R – range of dissipation.

In spite of the fact that springs after extension on the mandrel with a 10 mm interval were released at 400° C, after removing from the mandrel the height of their operating part decreased on average from 45 to 42.53 mm [4]. It is connected with residual tension in springs after short-radius bending, arisen in the process of coiling and with residual torsional tension occurred with the spring being

extended. In the releasing process residual tensions do not relax completely but only to $0.3\sigma_y$ (σ_y – yield limit). If the releasing temperature is increased, steel strength and cyclic stress of the spring will be lowered [8].

Strength limit of spring wire of the 1st class with the diameter of 2.7 mm according to GOST 9389-75 “Steel carbon spring wire” is 1900 MPa, yield limit is 1520 MPa. Taking into account the influence of residual tensions after coiling and extension releasing [7, 8] tensions under which the residual deformation of the spring σ_y , MPa:

$$\sigma_y = 0.954 \times 1520 = 1450 \text{ MPa.}$$

In further research, this tension should be considered as yield limit.

The influence of residual tensions on spring shortening when it is extended can be calculated:

$$\frac{\Delta H_{\text{oper}}}{H_{\text{oper}}} = \frac{45.00 - 42.53}{45.00} \times 100\% = 5.5\% .$$

The calculations and experiment are presented for springs manufactured from hard drawn spring wire after coiling, cycling test and extension. For springs from patented wire, the results can be different. Since patented wire has residual microtension after drawing, its total level of plastic deformation is much higher, which influences the result of the researches of this kind.

Valve springs must correspond to geometric and load bearing characteristics. Besides, they must pass cyclic loading resistance test in number of 6×10^6 compression cycles from H_0 to H_2 with the frequency not less than 25 s^{-1} [4]. To perform compression cyclic test from H_0 to H_2 , recovered springs, according to the new technology, were installed on the resonant stand DV8-S2 by «Gejrg Reicherter». The tests were stopped after 10.5×10^6 cycles (table 2). This is 1.75, as much as the established norm for springs (6×10^6 cycles). All the springs passed the tests without intolerable compressions and failures [4]. The resource of the recovered springs proved to be not less than the new ones.

Theoretical research of strain-stress state of valve springs when hardened by load of 12400 N ($40F_3$) has been done according to the method expressed in the literature [9]. The parameters of an extended spring before predeformation: mean diameter of the spring $D = 20.239 \text{ mm}$; height in a free state $H_0 = 45.73 \text{ mm}$ (reference size); height of the operating part of the spring $H_{\text{oper}} = 42.53 \text{ mm}$; full coils number $i = 6.5$; operating coils number $i_{\text{oper}} = 4.5$; diameter of the cross section of the coil (of wire) of the spring $d = 2.7 \text{ mm}$; material of the spring – wire 2.7 – 70HGFA-III (70XГΦA-III), Specifications 14-4-1380-86 (Oteva 60); interval of operating spring coils $t = 9.45 \text{ mm}$; modulus of elasticity of the first kind $E = 2.10 \times 10^5 \text{ MPa}$; Poisson ratio $\mu = 0.3$; transverse modulus of elasticity $G = 8.077 \times 10^4 \text{ MPa}$.

Half of the coil section of the spring with the diameter 2.7 mm is divided into 49 elements 1...49. Hardening stress and dependence stress in every element are defined as follows (1): torque data M (table 3, 4).

$$M = \int_s \frac{\Delta \kappa \times G \times \left[x^2 + \left(\frac{d}{2} - y \right)^2 \right]}{Z} dS, \quad (1)$$

where $\Delta \kappa$ – torsional spring coil increment, mm^{-1} ;

x, y – coordinates of coil section point in which stresses and torques are defined, mm [9];

S – coil cross-section area, mm^2 ;

Z – value, characterizing the depth of plastic hardening according to spring coil section.

Table 3. Hardening torque data in spring coil section, N×mm²

x, mm	-1.35	-1.2	-0.9	-0.6	-0.3	-0.1	0.1	0.3	0.6	0.9	1.2	1.35
y, mm												
0												
0.3				94.32	0	0	0	81.27				
0.6			89.23	74.47	43.79	40.93	42.09	73.56	89.12			
0.9		92.05	73.54	45.22	20.90	18.49	20.09	41.35	65.26	92.05		
1.2		83.31	53.95	24.08	7.17	5.03	6.89	22.02	46.46	81.79		
1.35	24.11	39.99	23.34	8.52	1.29	0.27	1.24	7.79	20.10	37.84	24.11	

Table 4. Hardening torque data on the periphery of spring coil section, N×mm²

x, mm	-1.342	-1.273	-1.122	-0.849	0.6	0.9	1.2	1.2
y, mm	...-1.2	...-1.2	...-0.9	...-0.6	...0.849	...1.122	...1.273	...1.342
0								
0.3					88.23	88.06		
0.6				75.95			75.95	
0.9			25.31					25.31
1.2	46.82							46.82

It is stated that hardening torque data with the load of 12400 N tends to zero in the coils contact point (points with the coordinates -0.3...0.3 mm on the abscissa axis and 0.3...0 mm on y-axis, table 3). This occurs because of sharp rise of Z . Decrease of torque data determines spring compression when it undergoes plastic hardening. Further, according to known dependences [9], geometric parameters of the hardened springs are defined: H_0 , H_{oper} , D . The results are presented in table 5. Being aware of geometric parameters of the hardened springs and their deformation $H_0 - H_1$ и $H_0 - H_2$ under initial spring load and operating load correspondently (figure 1) according to engineer Sazhin's formula (2), recommended for spring calculations [10], forces F_1 и F_2 , arising in springs under the deformations indicated are defined (table 5).

$$H_0 - H_i = \frac{64 \times F_i \times R^3 \times i_{oper}}{G \times d^4 \times \cos^3 \alpha}, \quad (2)$$

where R – spring midradius, mm;

α - angle of coils of the operating part of the spring, deg.

Table 5. Parameters of hardened springs 2101-1007021

H_{oper} , mm	H_0 , mm	d_{el} , mm	D , mm	$H_0 - H_1$, mm	F_1 , N	$H_0 - H_2$, mm	F_2 , N
36.022	39.222	1.962	20.302	9.522	132.54	19.222	267.55

In the process of recovering elastic core value of springs d_{el} (table 5) does not fall outside the recommended value $d_{el} \geq 0,5d$ [11]. The spring is in working order.

3. Conclusion

The new method of high load springs recovering from hardened wire has been presented. The results of experimental tests on recovering of load bearing characteristics F_2 , N, of inner valve springs have been reported. Load bearing characteristics of recovered springs ($F_{2min} = 266.6$ N, $F_{2max} = 288.2$ N) satisfy the requirements for design documentation ($F_2 = 275.4 \pm 13.7$ N). Recovered springs have passed cyclic tests without intolerable compressions and failures. Load bearing characteristics of recovered springs F_1 and F_2 , N have been theoretically specified. The difference between theoretical

and experimental researches does not exceed 3.2 %. This method of springs parameterization [9] is recommended to be used in the development of technology of springs recovering with the use of low-temperature thermo-mechanical hardening and contact predeformation.

References

- [1] Mkrtumian V S 1958 *Investigation of valve springs operation and development of rational method of their recovering. A Ph.D. Dissertation* (Moscow, USSR)
- [2] Elkin S Y 1984 *Development of technology for the recovery of valve springs of engines in mobile agricultural equipment using electromechanical processing. A Ph. D. Dissertation* (Saratov, USSR)
- [3] Krimchanskiy I I 2016 Spring wire in a world and domestic industry *Springs* **1(1)** 19–26
- [4] Zemlyanushnova N Y, Tebenko Y M and Zemlyanushnov N A 2012 *The recovery of cylindrical helical compression springs* (Stavropol: AGRUS)
- [5] Rakhstadt A G 1982 *Spring steels and alloys* (Moscow: Metallurgy)
- [6] Tebenko Y M 2007 *Problems of production of high-velocity springs and methods of their solution* (Stavropol: World of dates)
- [7] Belkov E G 2013 *Production process and strengthening of springs* (Chelyabinsk: Publishing center of the South-Ural state university)
- [8] Lavrinenko Y A, Belkov E G and Fadeev V V 2002 *Strengthening of springs* (Ufa: "Business-partner")
- [9] Zemlyanushnova N Y, Porahin A A and Zemlyanushnov N A 2016 Stress–strain state of the valve spring in an auto engine during plastic hardening *Russian Engineering Research* **36 (7)** 535–540
- [10] Batanov M V and Petrov N V 1968 *Springs* (Leningrad: Mashinostroenie)
- [11] Ponomarev S D 1974 To the justification of elastic core measurements in pre-stressed springs *News of Higher Educational Institutions* **1** 24–27