

# Increasing the resource of high load compression springs

N Y Zemlyanushnova, N A Zemlyanushnov

Federal State Autonomous Education Establishment of High Education «North-Caucasus Federal University», 1 Pushkina Street, Stavropol, 355009, Russia.

E-mail: [zemlyanushnova@rambler.ru](mailto:zemlyanushnova@rambler.ru)

**Abstract.** Valve springs of VAZ automobiles' engines are manufactured by using a new method. The decrease of dispersion of operating load in experimental springs compared to serial ones has been proved. The springs have passed a stress cycling test. With the new method having been used, it has been proved that the resource of high load springs working at high loading speed with coils collision has increased up to 60%.

## 1. Introduction

It is typical of the present day manufacturers of multicycle spring mechanisms both in home and in foreign automobile industries to use high load compact springs more frequently. This reduces mounting space and mass of units [1, 2]. This tendency is especially evident in series and mass manufacturing, for example, in auto industry, engineering, instrument making and defense industry.

Typical samples of high load compact springs are the springs of an internal combustion engine (ICE) valve of a passenger car [2]. These springs are designed at the breaking point of technological capabilities to reduce mounting space, dimensions and mass of an ICE. In the operating process, high load springs lose their initial stiffness and their operating load  $F_2$  decreases (the same occurs after stress cycling tests). Reduction of the operating load of the spring can make more than 10% and can be twice the permissible reduction. The performance requirements of a valve spring imply that it must not fail by fracture or by load, relaxation loses so much of its controlling force that it fails to maintain control between a tappet and a cam [3].

Therefore, the development and introduction of new technologies of the increasing of the resource of high load compression springs remain of current interest.

## 2. Results and Discussion

One of the methods to harden the strings is plastic surface treatment – contact predeformation that is the additional compression of spring coils after their contact. As a result, a stripe of hardened metal (cold working) is formed along the line of coils contact. The process of hardening is accompanied by structural changes in the deformed layer and, correspondingly, by increasing its firmness and strength, the formation of favourable residual compressive stress and entirely new macro- and microgeometry of the surface of spring material [4].

According to the results of springs manufacturing at Belebey Plant “Autonormal”, the optimal temperature for plastic spring hardening is 200-250° C since at this temperature the two-sided compressive stress, created by peen hardening on the surface of springs earlier and preventing the



opening of fatigue cracks, does not have enough time to relax [2]. Therefore, the same temperature for plastic hardening is used in the new method of high load springs manufacturing.

Under the new method, the hardened wire is delivered to a spring-winding machine and is wound with a coil pitch exceeding the coil pitch of a finished spring. Then the spring is tempered at  $410 \pm 10^\circ\text{C}$ . After 100 % fluorescent penetrant inspection face grinding, peen hardening and washing are performed. This method differs from analogous ones by plastic hardening at  $200\text{--}250^\circ\text{C}$ , which is performed by axial compression load being equal to  $(10 \div 300) F_3$  ( $F_3$  — spring force before coils contact). After this, chamfering is performed. Vibrational load can be applied. The final operations are applying protective coating, conservation and packing [5].

Inner valve spring 2101-1007021 is the tensest. According to the method suggested, a pilot lot of inner valve springs for automobiles 2101-1007021 was manufactured together with the employees of Belebey Plant "Autonormal". Plastic hardening of springs was performed at  $250^\circ\text{C}$  with  $(17\text{--}18) F_3$  — 5301 N load. The time for keeping on load is 1-1.5 seconds. Power characteristics of serial and experimental springs are presented in Table 1.

**Table 1.** Power characteristics of serial and experimental springs 2101-1007021

No	serial springs		experimental springs	
	$F_1, \text{N}$	$F_2, \text{N}$	$F_1, \text{N}$	$F_2, \text{N}$
On specifications of the drawing	136.3+13.7/-6.9	275.6±13.7	136.3+13.7/-6.9	275.6±13.7
1	139.3	277.5	134.4	272.1
2	138.3	271.6	132.9	270.7
3	139.3	275.6	135.3	273.1
4	139.3	275.6	131.9	267.2
5	142.2	280.5	132.9	269.2
6	139.7	274.6	137.3	277.5
7	138.3	273.6	<b>131.4</b>	<b>266.7</b>
8	148.1	281.5	132.4	268.7
9	141.2	280.5	132.4	268.7
10	138.3	271.6	134.4	271.6
11	147.1	284.4	139.3	<b>278.5</b>
12	139.7	274.6	132.9	272.6
13	<b>137.3</b>	<b>270.7</b>	132.4	267.7
14	<b>137.3</b>	271.6	135.3	273.1
15	145.6	282.4	132.9	270.7
16	139.3	275.6	138.3	275.6
17	139.3	275.6	137.3	274.6
18	138.8	273.6	137.3	275.6
19	140.2	278.5	132.4	268.7
20	<b>148.1</b>	<b>284.4</b>	137.3	277.5
21	<b>137.3</b>	271.6	134.4	271.6
22	141.2	279.5	132.4	268.7
23	139.3	278.5	131.9	267.7
24	143.2	280.5	<b>140.2</b>	<b>278.5</b>
<b>min</b>	<b>137.3</b>	<b>270.7</b>	<b>131.4</b>	<b>266.7</b>
<b>max</b>	<b>148.1</b>	<b>284.4</b>	<b>140.2</b>	<b>278.5</b>
<b>X</b>	<b>140.7</b>	<b>276.8</b>	<b>134.6</b>	<b>271.9</b>
<b>R</b>	<b>10.8</b>	<b>13.7</b>	<b>8.8</b>	<b>11.8</b>

Convention:  $F_1$  - the power of the spring under the preliminary deformation;  $F_2$  - the power of the spring under the operating deformation; min - minimal sample of values; max - maximal sample of values; X - arithmetic average; R - the range of dispersion.

The analysis of Table 1 makes it possible to make the following conclusions. Operating load  $F_2$  of serial springs is within 270.7 – 284.4 N, that is within limits of tolerance  $275.6 \pm 13.7$  N. Dispersion of operating load made 13.7 N.

Operating load  $F_2$  of experimental springs is within 266.7 – 278.5 N, that is within limits of tolerance. Dispersion of operating load made 11.8 N that is less than in serial springs by 14.3%.

According to FIAT-VAZ technical specifications, besides compliance with geometric and power characteristics, the springs must pass a stress cycling test ( $6 \times 10^6$  cycles of compression from  $H_0$  (free height of the spring) to  $H_2$  (the height of the spring under operating load) with the frequency not less than  $25 \text{ c}^{-1}$ , that is, a forced test). Therefore, to pass a stress cycling test from  $H_0$  to  $H_2$ , the springs were placed on the test stand of a resonant type, DV8-S2, by “Gejrg Reicherter”, Germany. The results of serial and experimental springs testing ( $6 \times 10^6$  cycles) are represented in Tables 2, 3.

**Table 2.** The results of a stress cycling test ( $6 \times 10^6$  cycles) for serial springs 2101-1007021

No	before test		after test		$\Delta F_1, \%$	$\Delta F_2, \%$
	$F_1, \text{N}$	$F_2, \text{N}$	$F_1, \text{N}$	$F_2, \text{N}$		
On specifications of the drawing	136.3+13.7/-6.9	275.6±13.7	-	-	-	-
1	139.3	277.5	137.3	273.6	1.41	1.40
2	138.3	271.6	136.8	268.7	1.06	1.10
3	139.3	275.6	137.3	272.6	1.41	1.10
4	139.3	275.6	137.8	273.6	1.05	0.70
5	142.2	280.5	140.2	275.6	1.41	1.70
6	139.7	274.6	137.3	269.7	1.75	1.70
7	138.3	273.6	136.3	269.7	1.41	1.43
8	148.1	281.5	<b>146.6</b>	281.5	0.99	1.00
9	141.2	280.5	138.8	276.5	1.73	1.40
10	138.3	271.6	136.8	268.7	1.06	0.70
11	147.1	284.4	144.2	279.5	<b>2.00</b>	1.70
12	139.7	274.6	137.3	269.7	1.75	1.70
13	<b>137.3</b>	<b>270.7</b>	<b>135.3</b>	<b>267.7</b>	1.43	1.09
14	<b>137.3</b>	271.6	<b>135.3</b>	268.7	1.43	1.08
15	145.6	282.4	144.2	280.5	1.01	0.70
16	139.3	275.6	137.3	272.6	1.41	1.10
17	139.3	275.6	136.8	272.6	1.76	1.10
18	138.8	273.6	137.3	270.7	1.06	1.10
19	140.2	278.5	139.3	277.5	0.70	0.40
20	<b>148.1</b>	<b>284.4</b>	146.1	<b>281.5</b>	1.32	1.03
21	<b>137.3</b>	271.6	<b>135.3</b>	268.7	1.43	1.10
22	141.2	279.5	138.8	274.6	1.73	1.70
23	139.3	278.5	136.3	273.6	2.11	<b>1.76</b>
24	143.2	280.5	142.2	279.5	<b>0.68</b>	<b>0.30</b>
<b>min</b>	<b>137.3</b>	<b>270.7</b>	<b>135.3</b>	<b>267.7</b>	<b>0.68</b>	<b>0.30</b>

<b>max</b>	<b>148.1</b>	<b>284.4</b>	<b>146.6</b>	<b>281.5</b>	<b>2.00</b>	<b>1.76</b>
<b>X</b>	<b>140.7</b>	<b>276.8</b>	<b>138.8</b>	<b>273.6</b>	<b>1.38</b>	<b>1.17</b>
<b>R</b>	<b>10.8</b>	<b>13.7</b>	<b>11.3</b>	<b>13.7</b>	<b>1.32</b>	<b>1.46</b>

**Table 3.** The results of a stress cycling test ( $6 \times 10^6$  cycles) for experimental springs 2101-1007021

No	before test		after test		$\Delta F_1, \%$	$\Delta F_2, \%$
	$F_1, \text{N}$	$F_2, \text{N}$	$F_1, \text{N}$	$F_2, \text{N}$		
On specificat ions of the drawing	136.3+13.7/-6.9	275.6±13.7	-	-	-	-
1	134.4	272.1	132.9	270.7	1.09	<b>0.54</b>
2	132.9	270.7	131.9	269.7	0.74	0.36
3	135.3	273.1	134.4	271.6	0.72	0.54
4	131.9	267.2	131.4	266.7	0.37	0.18
5	132.9	269.2	131.4	268.2	<b>1.11</b>	0.36
6	137.3	277.5	135.8	277.0	1.07	0.18
7	<b>131.4</b>	<b>266.7</b>	<b>130.4</b>	<b>266.3</b>	0.75	0.18
8	132.4	268.7	131.4	267.7	0.74	0.37
9	132.4	268.7	131.9	268.7	0.37	<b>0.00</b>
10	134.4	271.6	133.4	271.2	0.73	0.18
11	139.3	<b>278.5</b>	137.8	277.0	1.06	0.53
12	132.9	272.6	131.9	271.6	0.74	0.36
13	132.4	267.7	131.9	267.7	0.37	<b>0.00</b>
14	135.3	273.1	134.8	273.1	0.36	<b>0.00</b>
15	132.9	270.7	132.4	270.2	0.34	0.18
16	138.3	275.6	137.3	275.1	0.71	0.18
17	137.3	274.6	136.3	273.1	0.35	0.18
18	137.3	275.6	135.8	274.6	1.07	0.36
19	132.4	268.7	131.4	268.7	0.74	<b>0.00</b>
20	137.3	277.5	136.8	277.5	0.36	<b>0.00</b>
21	134.4	271.6	133.4	270.7	0.73	0.36
22	132.4	268.7	132.4	268.7	<b>0.00</b>	<b>0.00</b>
23	131.9	267.7	131.4	267.7	0.37	<b>0.00</b>
24	<b>140.2</b>	<b>278.5</b>	<b>138.8</b>	<b>277.0</b>	1.04	0.53
<b>min</b>	<b>131.4</b>	<b>266.7</b>	<b>130.4</b>	<b>266.3</b>	<b>0.00</b>	<b>0.00</b>
<b>max</b>	<b>140.2</b>	<b>278.5</b>	<b>138.8</b>	<b>277.0</b>	<b>1.11</b>	<b>0.54</b>
<b>X</b>	<b>134.6</b>	<b>271.9</b>	<b>133.6</b>	<b>271.3</b>	<b>0.66</b>	<b>0.23</b>
<b>R</b>	<b>8.8</b>	<b>11.8</b>	<b>8.4</b>	<b>10.7</b>	<b>1.11</b>	<b>0.54</b>

All the springs passed the test without failure. The value of operating load  $F_2$  of both serial and experimental springs is within limits of tolerance. It is necessary to note that after testing the decrease of operating load in serial springs made, on the average, 1.17%; in experimental springs – 0.23%. During the stress cycling test, the increase of stability of power characteristics of the springs manufactured with the use of the new method is marked. Experimental springs manufactured with the use of the new method were further tested to  $10 \times 10^6$  cycles (Table 4).

**Table 4.** The results of a stress cycling test ( $10 \times 10^6$  cycles) for experimental springs 2101-1007021

No	before test		after test		$\Delta F_1, \%$	$\Delta F_2, \%$
	$F_1, \text{N}$	$F_2, \text{N}$	$F_1, \text{N}$	$F_2, \text{N}$		
On specifications of the drawing	136.3+13.7/-6.9	275.6±13.7	-	-	-	-
1	134.4	272.1	132.5	268.4	1.38	1.37
2	132.9	270.7	131.3	267.6	1.15	1.14
3	135.3	273.1	133.4	270.1	1.43	1.13
4	131.9	267.2	130.5	265.4	1.04	0.70
5	132.9	269.2	131.0	264.7	1.37	1.68
6	137.3	277.5	134.7	272.6	1.83	1.75
7	<b>131.4</b>	<b>266.7</b>	129.6	263.2	1.35	1.31
8	132.4	268.7	130.9	265.8	1.12	1.09
9	132.4	268.7	130.2	265.1	1.65	1.35
10	134.4	271.6	133.1	269.7	0.97	0.73
11	139.3	<b>278.5</b>	136.6	273.9	1.89	1.64
12	132.9	272.6	130.3	267.4	1.93	<b>1.90</b>
13	132.4	267.7	130.4	264.5	1.47	1.21
14	135.3	273.1	133.3	269.7	1.54	1.24
15	132.9	270.7	131.6	268.7	0.95	0.72
16	138.3	275.6	136.6	272.3	1.23	1.18
17	137.3	274.6	134.8	271.4	1.81	1.17
18	137.3	275.6	135.7	272.7	1.17	1.02
19	132.4	268.7	131.5	267.4	<b>0.67</b>	0.48
20	137.3	277.5	135.2	274.6	1.48	1.05
21	134.4	271.6	132.3	269.0	1.55	0.98
22	132.4	268.7	130.2	264.3	1.60	1.66
23	131.9	267.7	<b>129.2</b>	<b>262.9</b>	<b>2.07</b>	1.81
24	<b>140.2</b>	<b>278.5</b>	<b>139.3</b>	<b>277.5</b>	0.73	<b>0.35</b>
<b>min</b>	<b>131.4</b>	<b>266.7</b>	<b>129.2</b>	<b>262.9</b>	<b>0.67</b>	<b>0.35</b>
<b>max</b>	<b>140.2</b>	<b>278.5</b>	<b>139.3</b>	<b>277.5</b>	<b>2.07</b>	<b>1.90</b>
<b>X</b>	<b>134.6</b>	<b>272.0</b>	<b>132.7</b>	<b>268.7</b>	<b>1.39</b>	<b>1.19</b>
<b>R</b>	<b>8.8</b>	<b>11.8</b>	<b>10.1</b>	<b>14.6</b>	<b>1.40</b>	<b>1.55</b>

All the springs passed the test without failure. The value of operating load  $F_2$  of both serial and experimental springs is within limits of tolerance. The decrease of operating load made, on the average, 1.19%, that is comparable with the decrease of serial springs load at the analogous testing during  $6 \times 10^6$  cycles – 1.17%. The increase of the experimental springs resource up to 60% is noted.

### 3. Conclusion

A pilot lot of inner valve springs of automobiles' engines 2101-1007021 has been manufactured using a new method. The decrease of dispersion of operating load in experimental springs by 14.3%, compared to serial ones, has been proved.

It has been marked that when applying the new method of manufacturing, the resource of high load springs working at high loading speed with coils collision increases up to 60%.

#### 4. Acknowledgments

The reported study was funded by the Russian Fund of Assistance of Innovation according to research project No 4757GU1/2014.

#### References

- [1] Lavrinenko Y A, Belkov E G and Fadeev V V 2002 Strengthening of springs (Ufa: "Business-partner")
- [2] 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) 535–40
- [3] Edwards G D 1983 Valve-spring materials and design *Industrial Lubrication and Tribology* **35**(2) 44 – 51
- [4] Tebenko Y M 2007 Problems of production of high-velocity springs and methods of their solution (Stavropol: World of dates)
- [5] Pat RU 2464119 C1: IPC B21F 35/00, C21D 9/02 Method of manufacturing of high load compression springs