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RELAXATION OF HELICAL SPRINGS AND SPRING STEEL WIRES

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ABSTRACT

This is a lecture/paper on the initial thoughts, the experimental set up, the conduct of the experiments of in particular the relaxation tests on helical compression springs and steel spring wire, with their results.

Index Terms – steel spring wire, helical compression springs, relaxation, tempering temperature, presetting, spring index, shot peening

1. INTRODUCTION

Relaxation is the term used for the degree to which a spring of constant length loses its force over time [1]. Diagrams of the relaxation that takes place in cold-shaped helical compression springs are given in the European standard EN 13906-1 [2]. The questions to ask about it are how it comes about, which properties of the material are important for relaxation and, then, which steps in the manufacturing steps of the spring and/or which parameters have what effect on the force lost by relaxation of the spring. Answering these questions will mean it should be possible to improve spring quality systematically by reducing the loss of force from relaxation. A necessary procedure is to establish the relaxation behaviour of the wire used for the spring and then compare it with the relaxation behaviour of the spring made from the wire [3][4]. The investigations of the wire provide knowledge of relaxation affected only by the material properties and the conditions in which the relaxation takes place. The relaxation of the finished springs will, of course, also be influenced by the process stages to which the wire is submitted during spring manufacture.

2. MANUFACTURE OF HELICAL COMPRESSION SPRINGS

Helical compression springs are made of oil-hardened and tempered spring steel wire, stainless spring steel wire and patented-drawn spring steel wire. After drawing, the wire is coiled in a spring coiling machine. The residual stress developed in the spring wire during the cold shaping then has to be relieved by a tempering stage as the next step in manufacture. The degree of residual stress will be dependent on the spring index of the springs. After tempering, there are further possible manufacturing steps, basically grinding and deburring of the ends of the springs. Shot peening is used to extend fatigue life, followed by further heat treatment. The presetting introduces a form of stress into the spring wire that will be favourable for the later loadbearing, ensuring that the threatened shortening of the spring in use is all but avoided. The final stages of spring manufacture are surface coating and the measuring and testing of the spring properties.

The mechanical properties of the wire are affected by the coiling, the tempering, the shot peening and the presetting – and all these, in turn, affect the relaxation behaviour of the springs.

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3. STANDARDISED RELAXATION DIAGRAMS

In Fig. 1, the standardised relaxation diagrams from EN 13906 [2] as shown. The variables are the wire diameter, the wire material, the relaxation temperature and the relaxation stress.

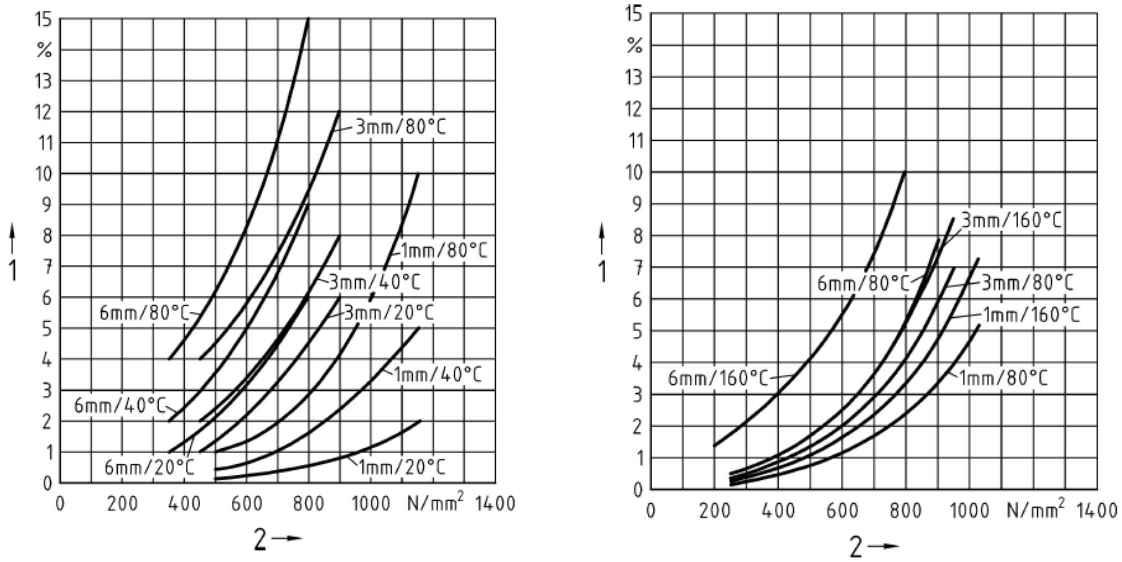

Fig. 1: Relaxation after 48 hours of cold-shaped springs made of SH and DH wire (left) and made out of oil-hardened and tempered SiCr alloy spring steel wire (right); preset at room temperature, depending on torsional shearing stress τ before relaxation started, at various temperatures in °C with (non-peened) wire diameters of 1 mm, 3 mm and 6 mm [2].

The standard only gives relaxation figures for non-peened springs. There is no way of finding out from the details and diagrams in the standard how the springs were heat-treated and preset and what the spring index of the spring is. It is these figures which are responsible for the residual stresses in the spring. As the difference between investigations of the wire and investigations of the spring lies precisely in the residual stress introduced during the cold shaping, it is the factors affecting residual stresses that have been varied in the experiments described below.

4. CONDUCT OF EXPERIMENT

5 springs and the 5 wires they were in each case made of were investigated in the relaxation experiments. The diagrams below show the respective mean values from the 5 experiments.

The variables modified for the investigation of relaxation were on the one hand the parameters of the spring or its wire: wire material, wire diameter, spring index, tempering temperature and duration, presetting stress. The other factors were the conditions in which relaxation was taking place: the relaxation temperature and duration and the relaxation stress.

Before helical compression springs are relaxed they are first prepared, tempered and, possibly, shot-peened with heat treatment after that. Then the springs are set up to block height or prestressed to the given setting load 3 times. The next thing is that the geometrical dimensions of the spring are measured, also the spring force and spring length at the working point given in each case. To investigate relaxation, the springs are loaded to the prescribed relaxation tension and stored in this state at the given relaxation temperature for the given time. At the end of this time, the load is taken off the springs and the spring force and length at the given working point again measured. This method provides the details of both the shortening and the reduction in force which are due to the relaxation.

5. RELAXATION RESULTS FOR HELICAL COMPRESSION SPRINGS

5.1. Effect of relaxation temperature, tempering temperature and spring index

In the experiments on springs made of VDSiCr wire, for which the results are summarised in Fig. 2 and Fig. 3, what was varied were not only the relaxation temperature and duration but also the tempering and pitch. The load applied in these experiments was 900 N/mm². The springs were closed solid three times.

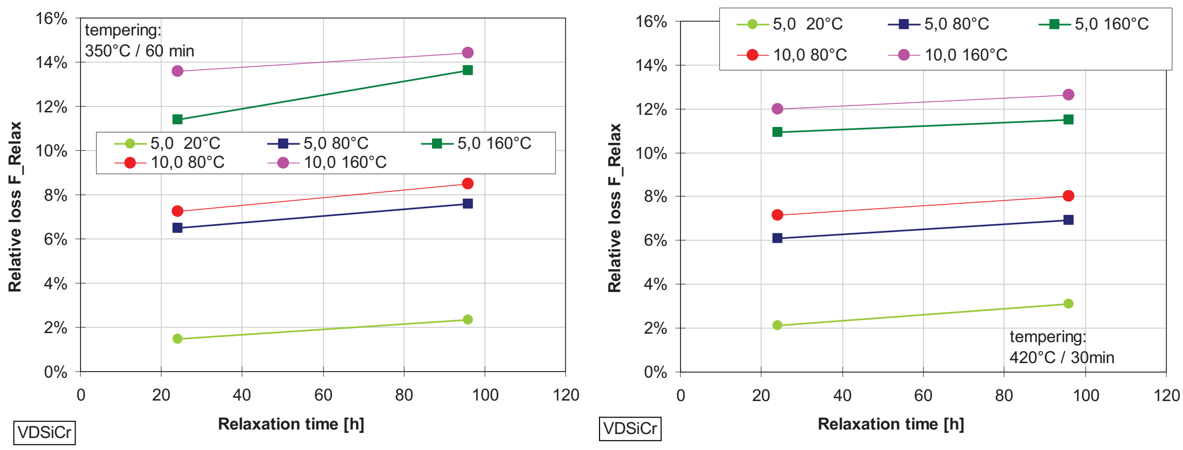

Fig. 2: Relative force lost by relaxation in springs $d = 6$ mm made of VDSiCr after different tempering procedures,
left: 350°C / 60 min; right 420°C / 30 min, applied load: 900MPa
Variation: Spring index ($w = 5$ / 10), relaxation temperature (20°C / 80°C / 160°C) [4]

It is the relaxation temperature which has the greatest effect on the loss of force through relaxation; the variables applied were 20°C, 80°C and 160°C. Different relaxation times (24h / 96h) had a similar effect on the loss of force through relaxation (approx. 1 %) to the effect of the spring index w: The springs with $w = 10$ relax about 1 % more than the springs with $w = 5$. The variation of the tempering of the springs (350°C / 60 min; 420°C / 30 min) had only a little effect on the loss of force through relaxation (approx. 0.5 %) in the variation selected. The figures for loss of force on relaxation confirm those which it would be possible to estimate from the diagram in the EN 13906 1 standard (Fig. 1).

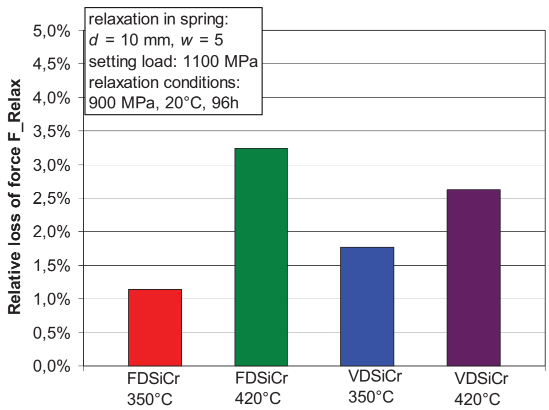

Fig. 3: Relative loss of force at the working point for springs made of oil-hardened and tempered wire FDSiCr / VDSiCr of $d = 10$ mm after varied tempering of springs [4]

Figure 3 shows the effect of the variation of tempering of the springs on the loss of force through relaxation, but also, indirectly, the effect of the temperature of relaxation on the loss of force. Relaxation carried out at room temperature (20°C) is associated with less loss of force in the case of springs tempered at 350°C, which is shown by the fact that the yield point under torsional stress is higher than in the case of tempering at 420°C. The reverse is true if relaxation is carried out at higher temperatures 80°C or 160°C (see, for example, Fig. 2, Fig. 5).

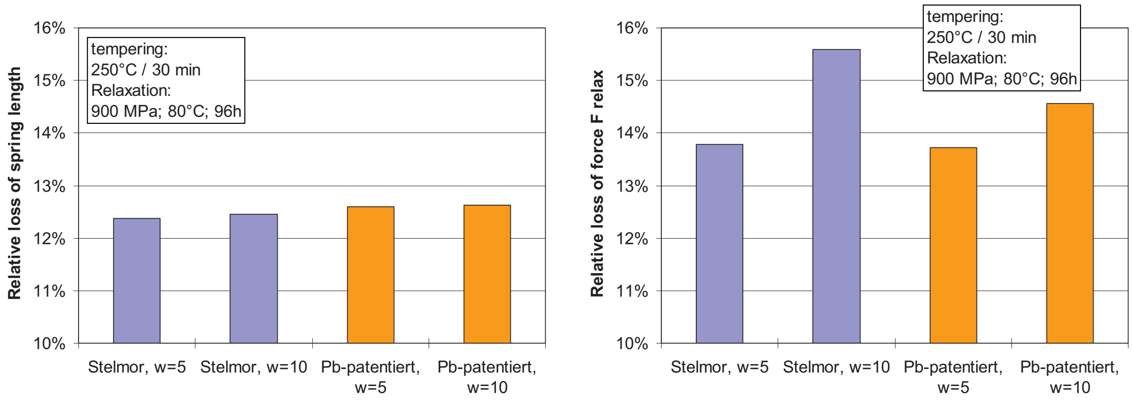

Fig. 4: Relative shortening (in relation to stroke of spring) on the left, and relative loss of force at the working point on the right – for springs made of patented-drawn spring steel wires with $d = 6$ mm; variation: Stelmor / lead bath; spring index w [4]

Investigations of the relaxation of spring made of patented-drawn spring steel wires with $d = 6$ mm are shown in Figure 4. On the left the relative shortening is to be seen and on the right the relative loss of force. As the diagrams make clear, the two are not bound to behave similarly.

5.2. Effect of presetting condition

Figure 5 shows the relaxation results for springs set up to block height compared with springs set to a particular level of force. The springs set to a particular level of force were considerably less effectively preset than were those blocked. This lower prestress figure then, as would be expected, leads to greater loss of force on relaxation if both springs are loaded with the same relaxation stress (900 MPa).

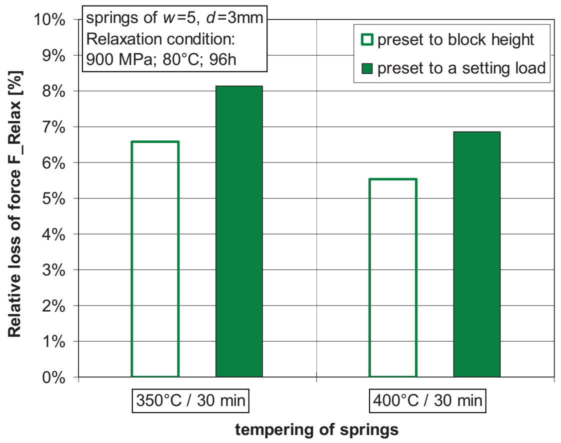

Fig. 5: Relative loss of force at the working point for springs set to a particular setting load and springs preset to block height
Variation: tempering of springs [4]

5.3. Effects of shot-peening

The effect of shot-peening on the loss of force through relaxation is not uniform for the two different relaxation temperatures (Fig. 6). While it can be seen that the non-peened springs of both spring index at a relaxation temperature of 80°C relax about 0.5 % more than the peened wires, the relationship is reversed at 160°C for the relaxation temperature. At this temperature, the non-peened springs relax least. The total effect of shot peening on the loss of force from relaxation is low (approx. 0.5 %)

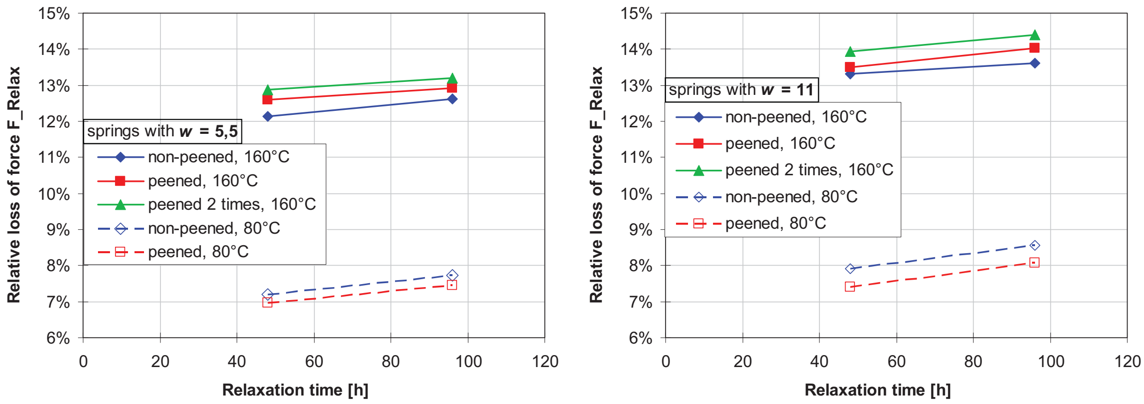

Fig. 6: Relative loss of force at the working point for springs made of VDSiVr oil-hardened and tempered wire of d = 4.5 mm; tempering of springs: 350°C / 30 min, preset stress: 900 MPa, relaxation stress: 900 MPa; Variation: spring index w (w=5.5 on the left, w=11 on the right); shot-peening, relaxation temperature

6. RELAXATION INVESTIGATION OF SPRING STEEL WIRES

Relaxation, or creep, is generally determined in accordance with the standard on the component itself, i.e. on the helical spring. The variables investigated are spring dimensions such as wire diameter and spring index but also the wire material. Diagrams of the relaxation have been produced for peened [5] and non-peened springs [2].

No relaxation investigations have previously been carried out on the wire before it is shaped into the spring as far as the authors know. The practice is to make springs of varied geometrical shape for which the relaxation tests, always taking a considerable amount of time, are required, from the wire of a particular lot with particular dimensions. There is, therefore, a need to clarify whether relaxation investigations on wire permit conclusions to be drawn about the relaxation of springs made from this wire.

In such a case the relaxation experiments should be carried out on wires prepared in a way matching the processing stages of the component: tempering, shot-peening, heat treatment, presetting. This makes it possible to investigate experimentally the influence exerted on the relaxation behaviour by the processing stages which follow coiling.

The wire in a helical spring is placed under torsional load. It is therefore necessary to place the wire to be used for helical springs under torsional load for the investigations of relaxation at the wire stage.

7. EXPERIMENTAL DEVICE FOR INVESTIGATING STEEL SPRING WIRE RELAXATION

A device was designed and constructed for thin wires $1 \leq d \leq 6$, to put the wire under torsional stress and keep it so for the relaxation time (Fig. 7). In order to maintain the necessary torsional moment in wires with $d > 6$ mm for the whole relaxation time, it is necessary to place these under torsional stress in a 500 Nm-torsion testing station.

Fig. 7: Relaxation device for thin wires under torsional stress [3]

To test the relaxation, the prepared wire in the torsion testing station is twisted to reflect one of the prescribed levels of torsion stress.

Preliminary investigations using the relaxation device for wire have shown that the elastic deformation of the sensor for the torsion moment and inadequacies in the fixing of the wire are causes of systematic error in the determination of the relaxation. It is not possible to find a means of measuring the degree of sensor deformation. The overall systematic error can be estimated by pre-tensioning and then relaxing the wire without a relaxation time and without temperature changes. This estimation of the systematic error has to be carried out anew for each range of torsion moment.

8. EXPERIMENTAL RESULTS, RELAXATION OF SPRING STEEL WIRES

The percentage of loss of force in the spring is similar to the percentage of torsional stress loss in the wire as the force is in linear relation to the calculation of the torsional stress.

Fig. 8 shows the relative stress loss of relaxation of wires which have been treated to different tempering, presetting and relaxation variants. It is of interest that the wires under the greatest load at a relaxation temperature of 80°C relax after tempering at 400°C less than those tempered at 350°C; on the other hand, the reverse is true for the two wires subjected to less loading.

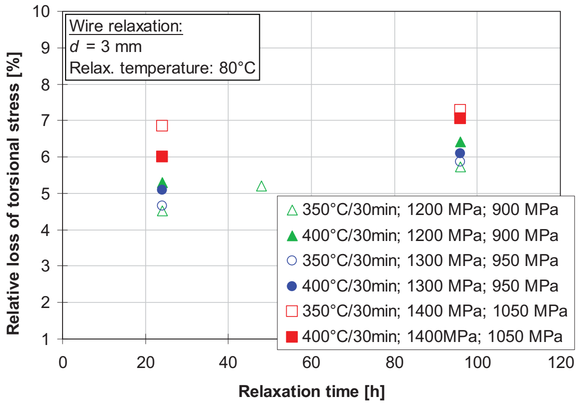

Fig. 8: Relative loss of torsional stress at relaxation of VDSiCr wire *d*=3 mm; variation: tempering , preset stress, relaxation stress [4]

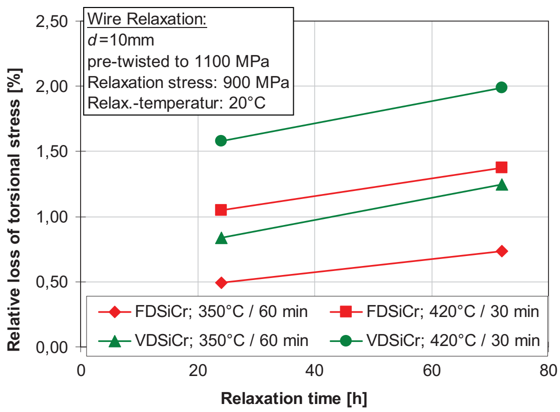

Fig. 9: Relative loss on relaxation (tension) of oil-hardened and tempered wires VDSiCr, FDSiCr, *d* = 10 mm [4]

If relaxation takes place at room temperature, both wires tempered at 350°C show lower loss on relaxation than do those tempered at 420°C. The reason lies in the higher yield point under torsional stress already mentioned in sect. 5.1. applicable to wires tempered at 350°C compared with tempering at 420°C.

9. COMPARISON OF RELAXATION RESULTS FOR HELICAL SPRINGS AND SPRING STEEL WIRES

To compare relaxation results for the wire and the springs it is necessary to make springs out of the wire used for the experiments. The difference between the experiments on wires and on helical springs lies in the coiling stage which has as its result the curvature of the wire in the spring. In order to establish the influence of wire curvature and the residual stresses caused of cold bending on relaxation and to find the differences from the straight wire, the experiments are carried out on springs of two different spring index' (e.g. $w = 5$; $w = 10$).

The most difficult question to answer in conducting relaxation experiment on wires is what tension to set: what levels should be selected for the preset stress and the relaxation stress. It is, after all, the intention to compare the relaxation experiments on the wires with similar ones on springs. However, as is well known, the torsional stress in the wire of a helical spring is not constant but, depending on the spring index, considerably higher on the inside of the coil than on the outside. It is also difficult to decide the actual preset stress of the spring: if the presetting is to the block height, the force actually taking effect as torsional stress in the wire is unknown. This problem can be avoided by presetting to a particular level of force (setting load).

Table 1: Calculation of preset and relaxation tension

w	k faktor	k' faktor	Uncorrected preset τ_c [MPa]	Preset stress corrected with k' $\tau_{k'}$ [MPa]	Uncorrected relaxation stress τ_{relax} [MPa]	Relaxation stress $\tau_{k'}$ corrected with k' [MPa]
5	1.3	1.15	1200	1389 (1400)	900	1035 (1050)
10	1.13	1.06	1200	1272 (1300)	900	954 (950)

The right-hand side of Fig. 10 shows the relaxation results for wires with force raised by the factor k' (see Table 1) in association with tempering (350°C / 30 min, 400°C / 30 min), preset stress of 1200 MPa and relaxation stress of 900 MPa for purposes of comparison with springs of spring index $w = 5$ and $w = 10$. It is of particular interest to note the comparison of these losses of relaxation force with those in springs made of the same wires (Fig. 10 left). The springs were designed for presetting to block height at 1200 MPa with no correction.

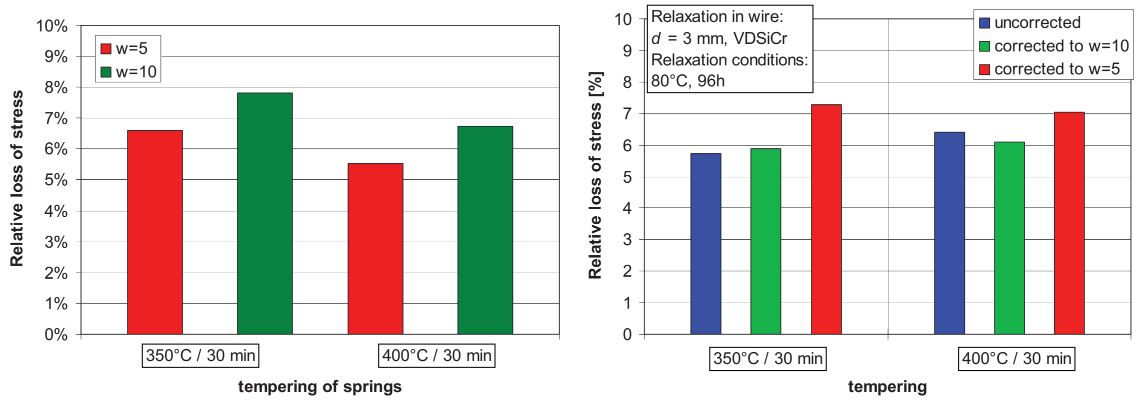

Fig. 10: Relaxation losses in springs (left) and their wire (right); variation: tempering

For the springs of spring index $w = 10$ which had been tempered at 400°C the relaxation losses agree very well for wires and springs (approx. 6%). In contrast the springs of $w = 5$ which had been preset to block height show less relaxation loss than the springs of spring index $w = 10$. As the corrected stress used as relaxation stress is greater for the springs of spring index $w = 5$ than for the springs of spring index $w = 10$, the relaxation losses in the wire are also higher. Here the relaxation losses for wires and springs where stress is corrected for spring index $w = 5$ diverge more clearly.

The result for the non-corrected stress is particularly interesting: at tempering temperature of 400°C and the considerably higher loss of residual stress associated with this, the relaxation losses of springs and wires are in very close agreement (approx. 6.5 %).

The experimental relaxation results for the springs in Fig. 3 (FDSiCr / VDSiCr of $d = 10$ mm) and the investigations on the wires in Fig. 9 belong together. The experiments were in each case carried out on the same wire at room temperature. The experimental relaxation results for wires and springs agree remarkably closely.

10. ACKNOWLEDGMENT

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11. REFERENCES

[1] Meissner, M.; Schorcht, H.-J.: Metallfedern. 2. ergänzte Auflage, Springer Verlag 2007
[2] DIN EN 13906
[3] Geinitz, V.; Weiß, M; Braunschweig, M.: „Funktions- und fertigungsrelevante Kennwerte für Federstahldraht und Federband. Tischvorlage zum Projekttreffen am 07.10.2010“, IGF 16217 BR, TU Ilmenau 2010
[4] Geinitz, V.; Weiß, M.; Braunschweig, M.: „Funktions- und fertigungsrelevante Kennwerte für Federstahldraht und Federband. Tischvorlage zum Projekttreffen am 24.03.2011“, IGF 16217 BR, TU Ilmenau 2011
[5] Kaiser, B.; u.a.: Ermittlung von Dauerfestigkeits- und Relaxationsschaubildern für hochbeanspruchte Schraubendruckfedern. Abschlußbericht zum AiF-Forschungsthema 12 287 N, TU Darmstadt 2002.