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„Prediction of Presetting Value for Helical Compression Springs“

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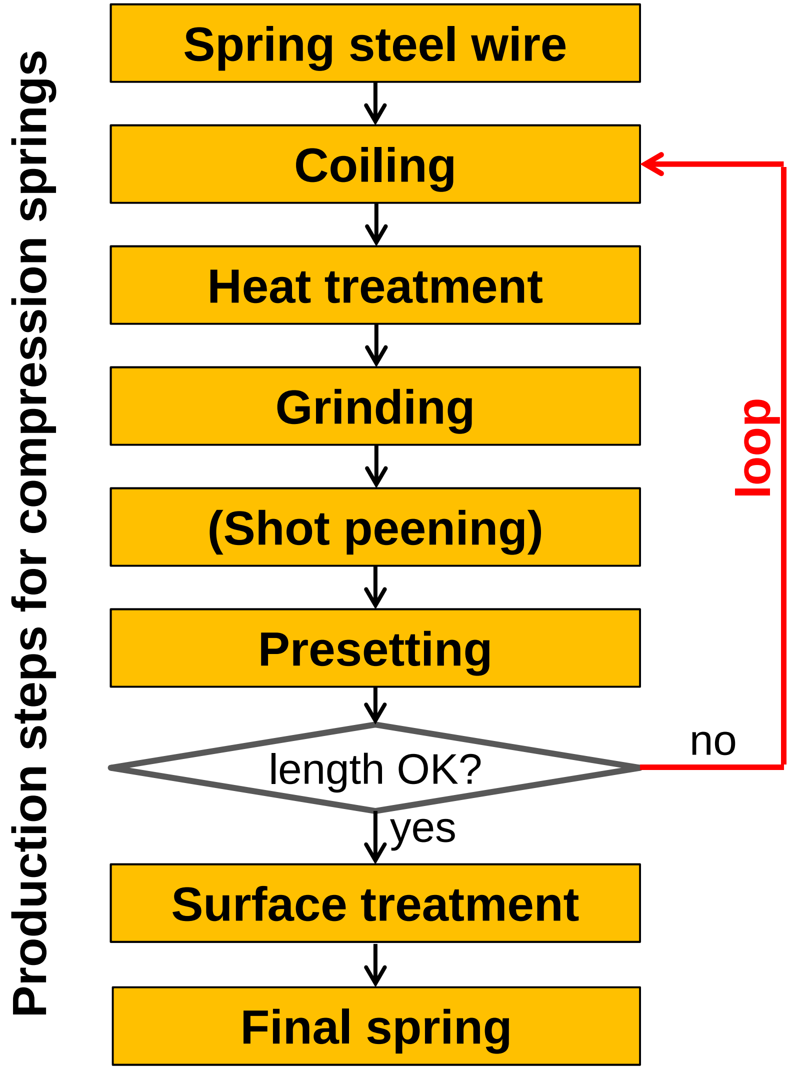
Content

Motivation



Length is not OK:

- **Necessary to repeat the production steps Coiling, Heat treatment, Grinding, Shot peening and Presetting**
- **Costs a lot of time and money**
- **Important to know the Presetting value before**

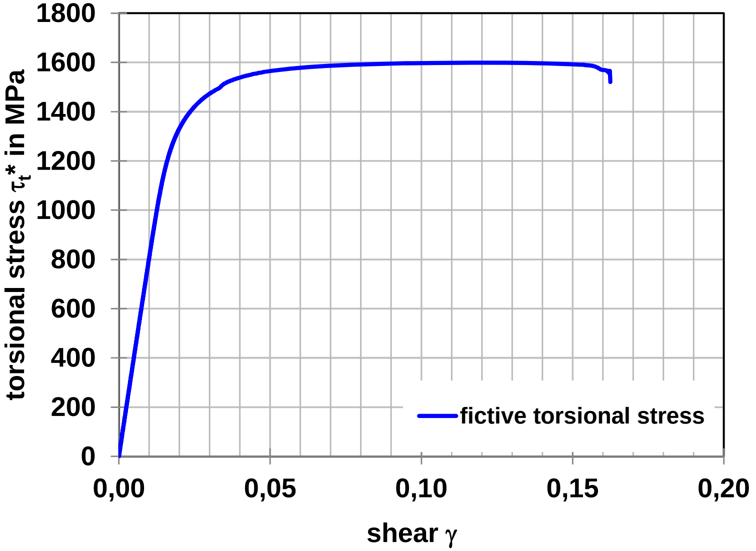
Torsion Test

- Main stress of the wire in helical compression springs is torsion

  ➔ Torsion test is best suited to determine the static material behaviour
- Result: torsional Moment M_t dependent on the torsion angle φ, the wire diameter d and the wire length l
- Results can be used for calculation of a

  fictive torsional stress: $$\tau_t^* = \frac{16 \cdot M_t}{\pi \cdot d^3}$$

  maximum shear: $$\gamma_{max} = arctan\left(\frac{\varphi \cdot d}{2 \cdot l}\right)$$
- **Problem:** valid for elastic deformations and not for elastic-plastic deformations
- With torsional stress shear characteristic, it is not possible to predict the Presetting value
- Real shear stress shear characteristic of the material is necessary



Real Shear Stress Shear Characteristic

- Real shear stress shear characteristic in the wire was determined by simulating the torsional moment angle characteristic
- material law according to Ramberg-Osgood-Equation was used

$$\gamma = \gamma_{el} + \gamma_{pl} = \frac{\tau}{G} + \left(\frac{\tau}{k'}\right)^{\frac{1}{n'}}$$

- Describing variables:
  - G (shear Modulus)
  - n' (solidifying exponent)
  - k' (solidifying coefficient)
- Describing variables were determined by a solver calculation using Excel program

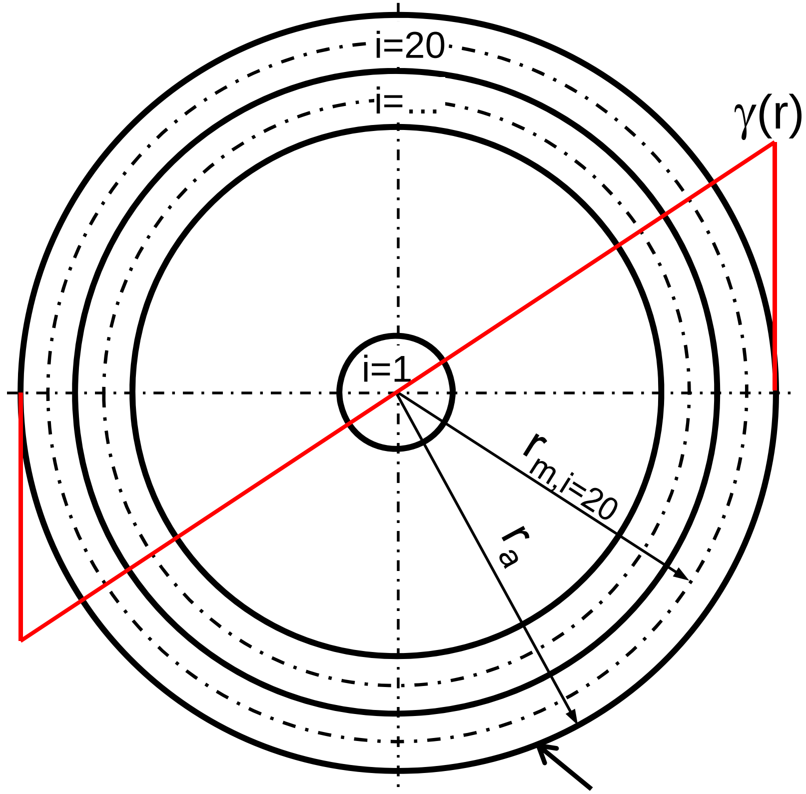
Real shear stress shear characteristic

- *1st Step*: Wire cross section was divided into 20 circular rings
- *2nd Step*: shear γ was assigned to each of the rings

$$\gamma(\varphi, r_{m,i}) = \gamma_{max} \cdot \frac{r_{m,i}}{r_a}$$

- *3rd Step*: According to Ramberg-Osgood-Equation the existing mean shear stress can be assigned to each circular ring
- *4th Step*: by multiplication of the mean shear stress with corresponding circular ring area a force $F_{\varphi,i}$ results

$$F_{\varphi,i} = \tau_{\varphi,i} \cdot A_i$$



wire cross section

Real shear stress shear characteristic

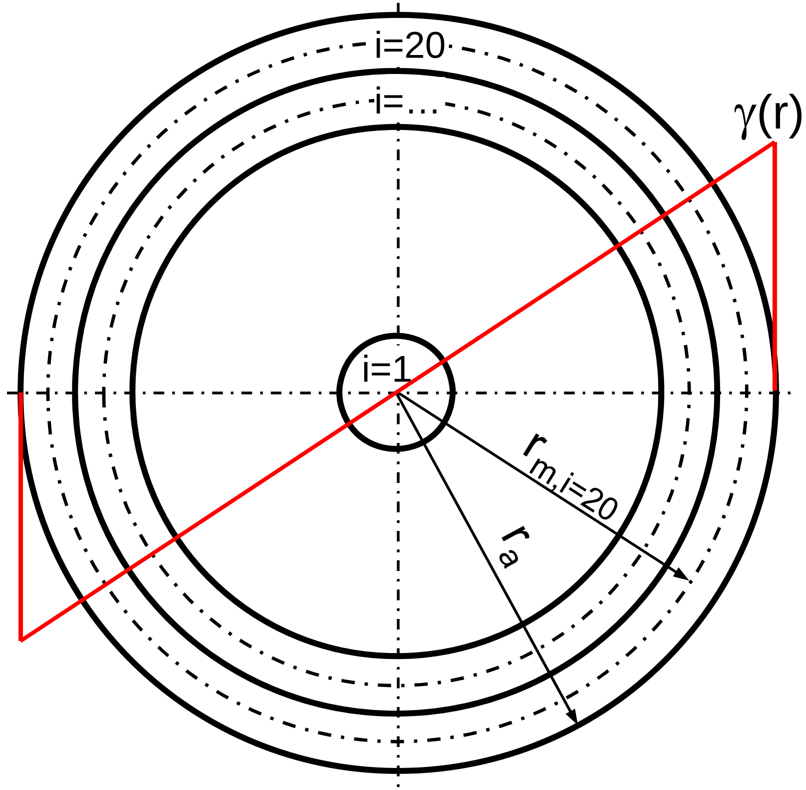
- *5th Step*: after multiplication by the corresponding average radius, a partial moment generated by the circular ring results

$$M_{\varphi,i} = F_{\varphi,i} \cdot r_{m,i} = \tau_{\varphi,i} \cdot A_i \cdot r_{m,i}$$

- *6th Step*: summation of all partial moments

$$M_{\varphi} = \sum_{i=1}^{20} M_{\varphi,i} = \sum_{i=1}^{20} \tau_{\varphi,i} \cdot A_i \cdot r_{m,i}$$

- *Result*: torsional moment depending from angle, wire geometry and parameters of the Ramberg-Osgood-Equation (G, n’, k’)



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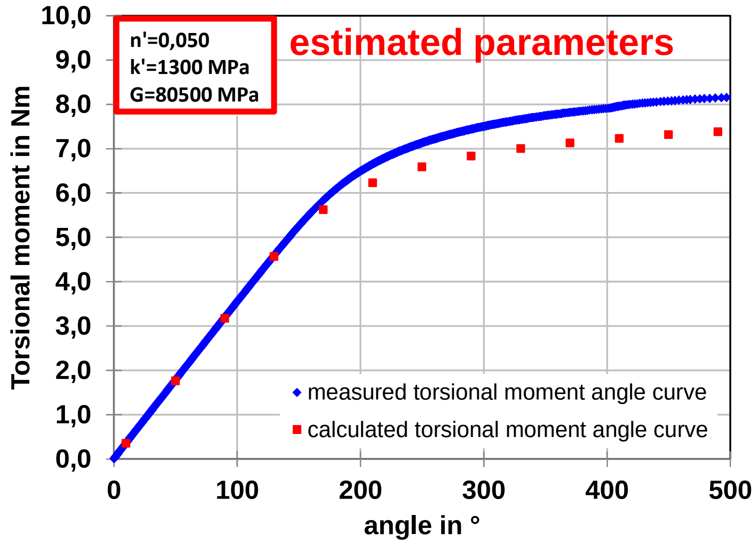
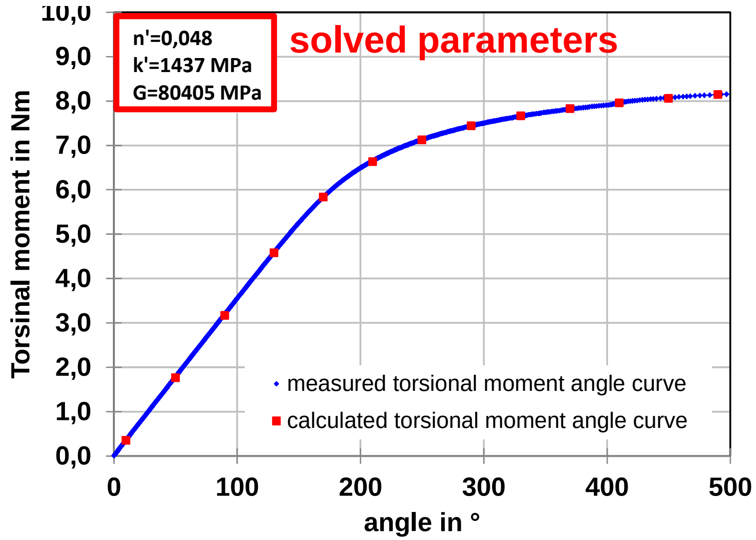
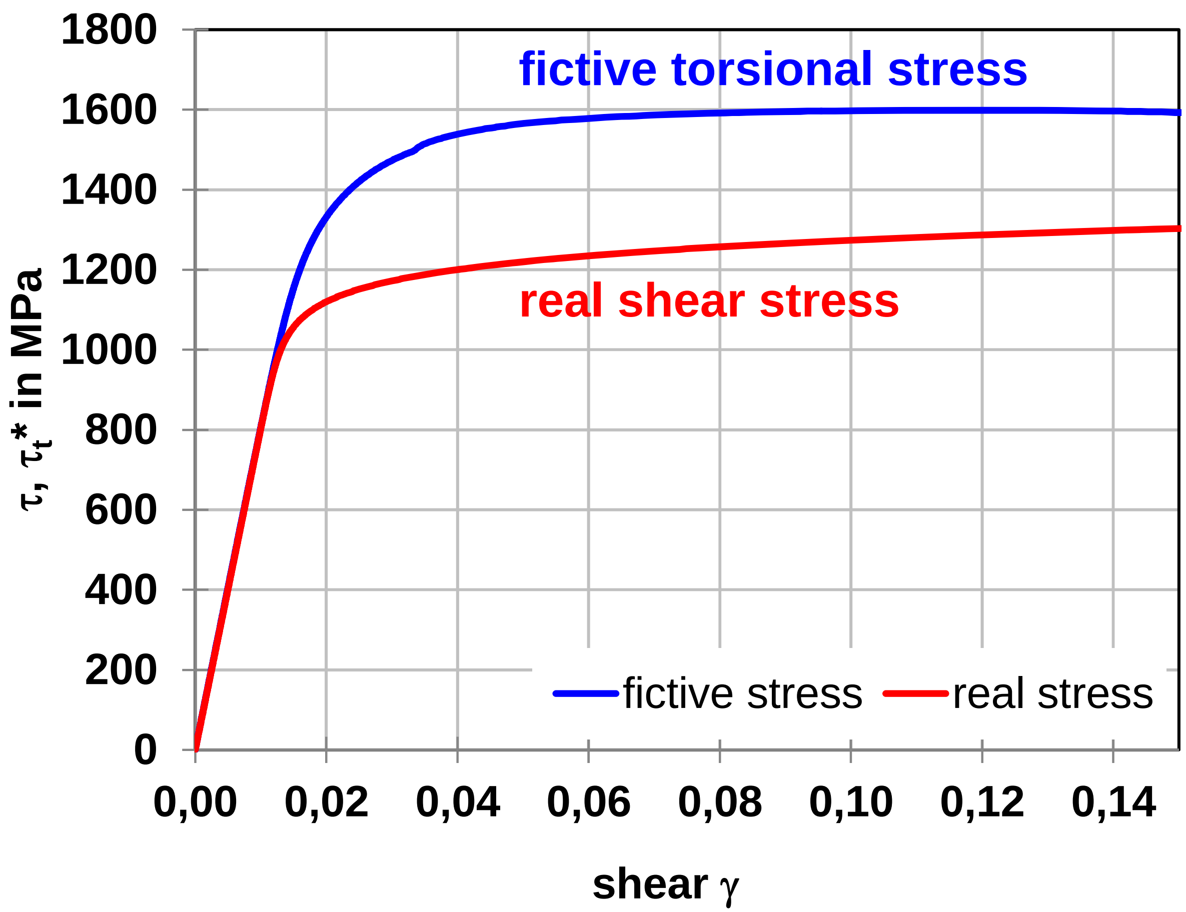
- *Result*: torsional moment depending from angle, wire geometry and parameters of the Ramberg-Osgood-Equation (G, n’, k’)
- *Problem*: parameters of the Ramberg-Osgood-Equation (G, n’, k’) are unknown
- *Solution*: determine the parameters by using the solver integrated in Excel in order to minimize the deviations





Real Shear Stress Shear Characteristic



- *elastic deformation range*: no difference between fictive torsional stress and real shear stress
- *elastic plastic deformation range*: significant deviation between the two kinds of stress

Transfer on Helical Compression Springs

- Nonlinear shear distribution across the wire cross-section
- Taken into account by using the stress correction factor k

$$k(r,\alpha) = a \cdot r^2 \cdot cos^2\alpha + b \cdot r \cdot cos\alpha + c$$

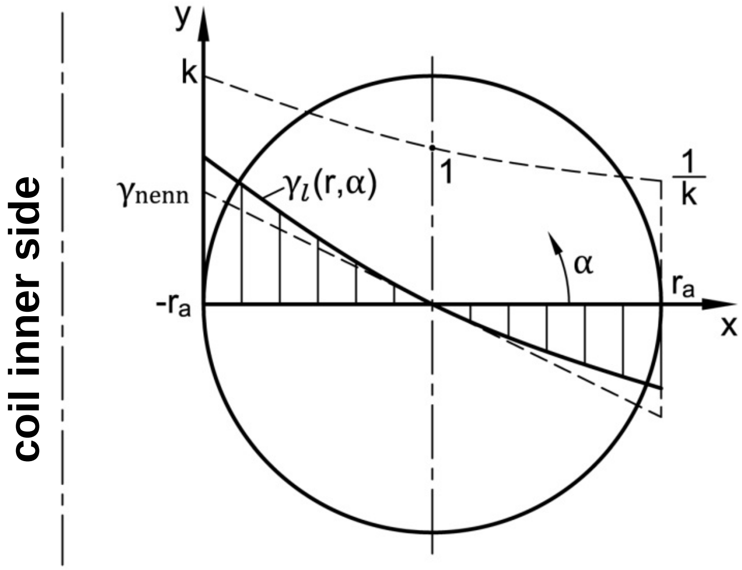
$$a = \frac{k}{2r_a^2} + \frac{1}{2kr_a^2} - \frac{1}{r_a^2} \qquad b = -\frac{k}{2r_a} + \frac{1}{2kr_a}$$

$$c = 1$$

- Elastic deformation range:
  - Linear relationship between spring deflection and spring load as well as between spring deflection and shear
- Elastic-plastic deformation range:
  - Only linear relationship between spring deflection and shear

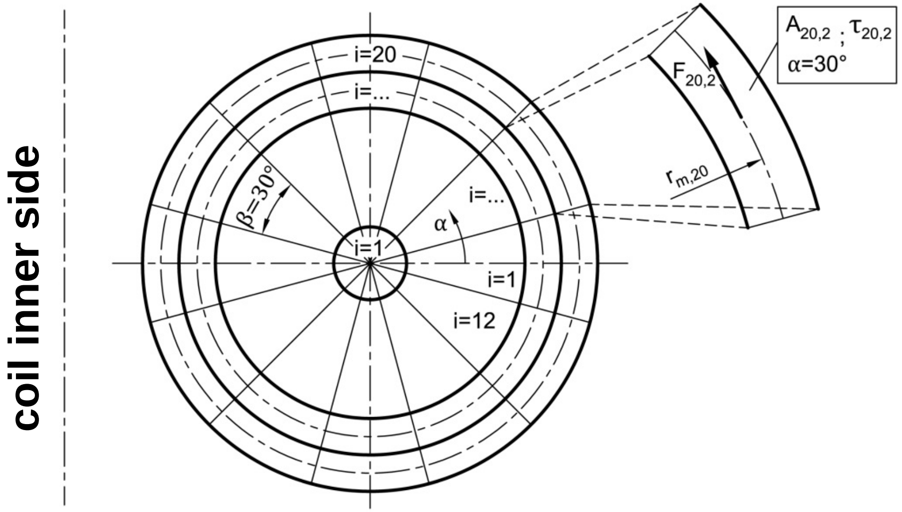
$$\gamma_l(r,\alpha) = \left(a \cdot r^2 \cdot cos^2\alpha + b \cdot r \cdot cos\alpha + c\right) \cdot \frac{r}{r_a} \cdot \gamma_{nenn}$$

with: $\gamma_{nenn} = \dfrac{s_{pl}}{w^2 \cdot d \cdot \pi \cdot n_f}$



Transfer on Helical Compression Springs

- *1st Step*: Wire cross section was divided into circular ring segments $A_{i,j}$



- *2nd Step*: an average local shear was assigned to each circular ring segment

$$\gamma_{i,j}(r_{m,i}, \alpha_j) = (a \cdot r_{m,i}^2 \cdot \cos^2\alpha_j + b \cdot r_{m,i} \cdot \cos\alpha_j + c) \cdot \frac{r_{m,i}}{r_a} \cdot \gamma_{nenn}$$

- *3rd Step*: real shear stress shear characteristic was used to assign a shear stress to each circular ring segment

$$\tau_{i,j} = f(\gamma_{i,j})$$

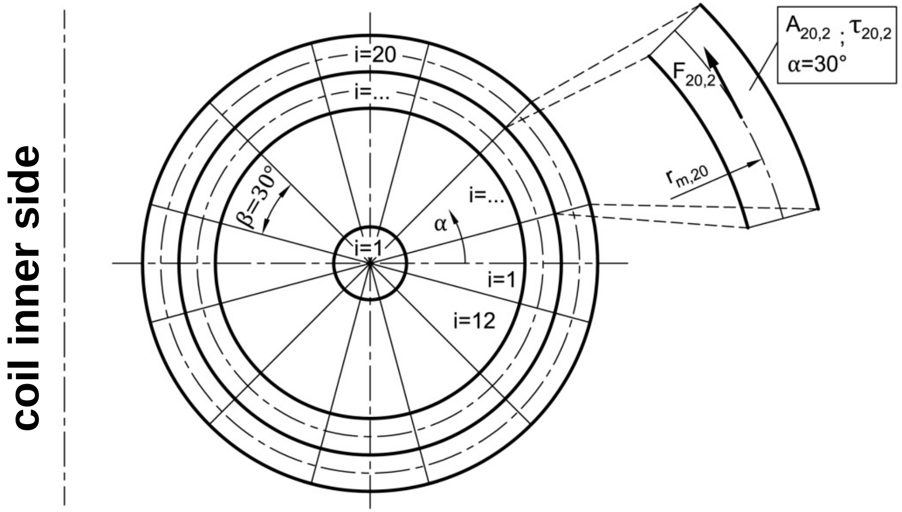
- *4th Step*: multiplication by area of circular ring segment $A_{i,j}$ and the average radius $r_{m,i}$, a partial moment $M_{i,j}$ generated by the circular ring segment results

$$M_{i,j} = \tau_{i,j} \cdot A_{i,j} \cdot r_{m,i}$$

Transfer on Helical Compression Springs

- *5th Step*: summation of all partial moments $M_{i,j}$

$$M = \sum_{i=1}^{20}\left(\sum_{j=1}^{12} M_{i,j}\right)$$



- *Result*: total required torsional Moment M and also the setting force F as a function of spring deflection s_{pl}
- *Spring back*:
  - elastic material behaviour was assumed
  - same moment M, which was necessary for the spring deflection s_{pl} is also present

$$s_{el} = \frac{16 \cdot M \cdot D^2}{G \cdot d^4} \cdot n_f = \frac{8 \cdot F \cdot D_m^3}{G \cdot d^4} \cdot n_f$$

- *Presetting value*: $\Delta s = s_{pl} - s_{el}$

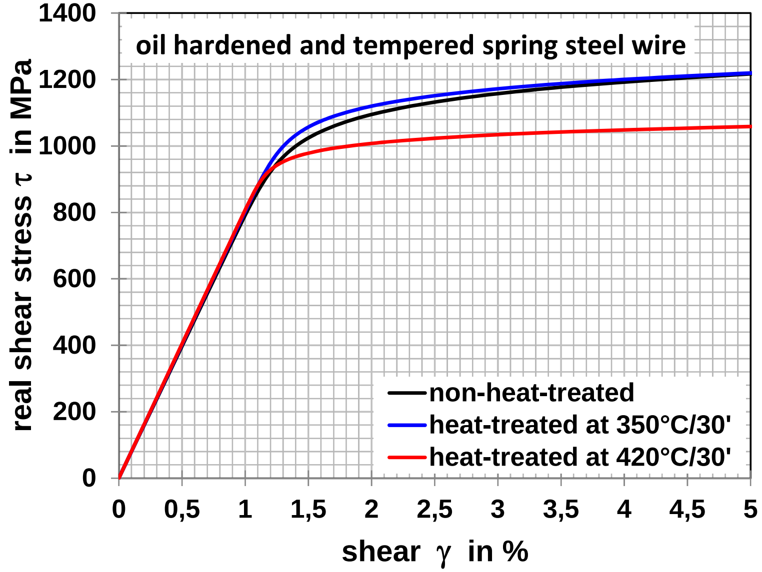
Experimental Investigations
- Materials used and their Characteristics -

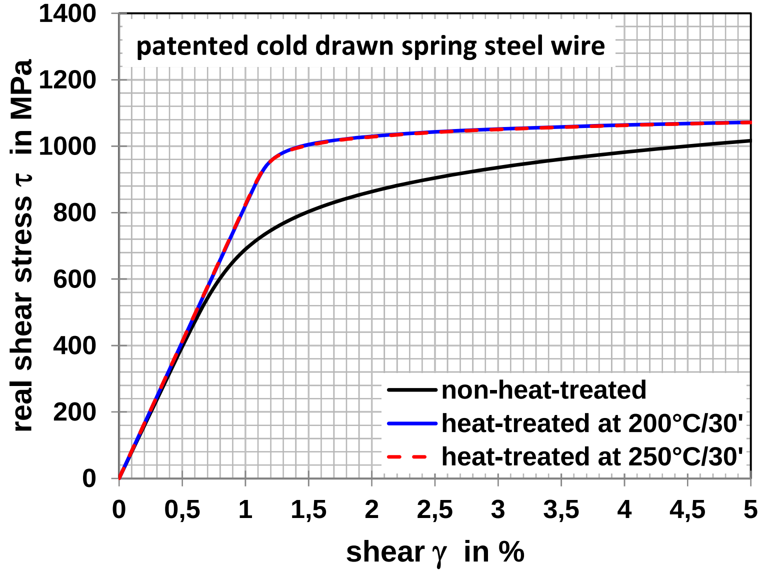
- Oil hardened and tempered and patented cold drawn spring steel wire of diameter d=3.0 mm were used
- Wires have been heat-treated depending on material
- Real shear stress shear characteristic was determined using the procedure described in the previous slides

material	heat treatment	G in GPa	n‘	k‘ in MPa
Oil hardened and tempered spring steel wire	non-heat-treated	79.396	0,0615	1496
	350°C/30‘	80.405	0,0489	1437
	420°C/30‘	80.823	0,0310	1172
Patented cold drawn spring steel wire	non-heat-treated	79.422	0,1162	1490
	200°C/30‘	82.414	0,0251	1164
	250°C/30‘	82.434	0,0257	1166

Experimental Investigations
Materials used and their Characteristics

- Parameters of the Ramberg-Osgood-Equation allow to describe the material behaviour of the wires for shear stresses





350°C/30': yield point increases with respect to the non-heat-treated wire

420°C/30': a significant reduction in the yield point was observed.

non heat treated: the yield point is significantly lower than with heat-treated wires

heat treated: no differences in the real shear stress shear characteristic of the wires

Experimental Investigations
- Spring Variation -

- Total number of coils of the spring was not varied (n_t=6,5)
- Heat treatment was similar to that of the wires
- Spring index was varied between 3 and 12 for oil hardened and tempered and between 5 and 12 for patented cold drawn wire

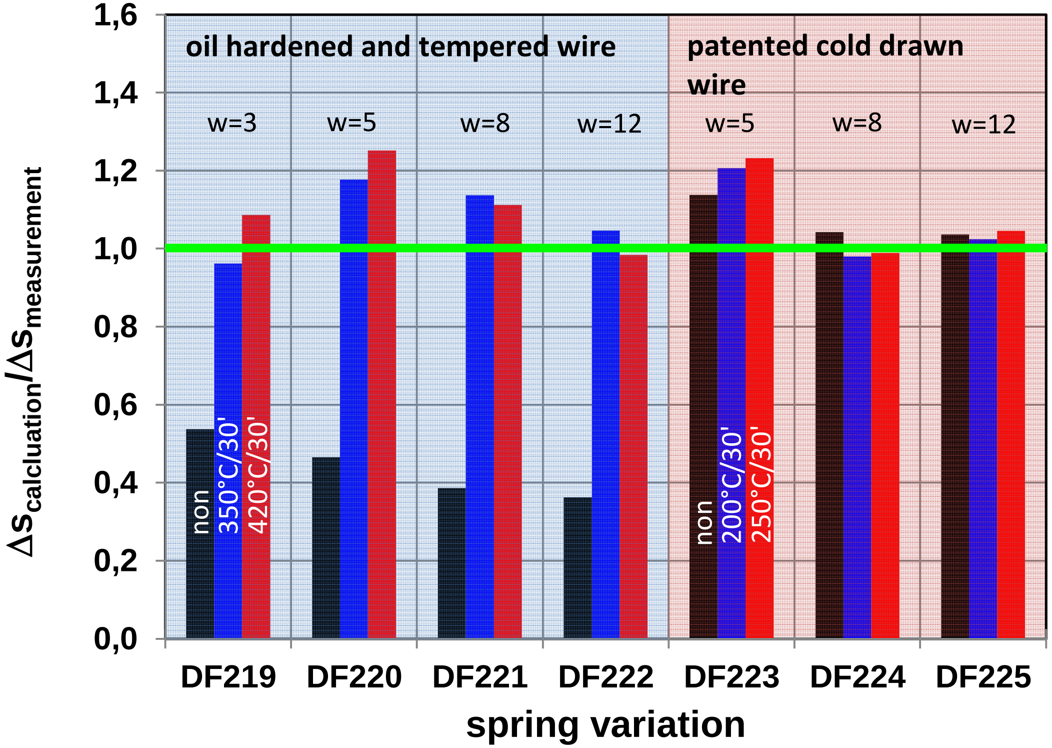
name	**material**	**w**	**L_0 in mm**
DF219	54SiCr6	3	25,9
DF220	54SiCr6	5	36,7
DF221	54SiCr6	8	62,9
DF222	54SiCr6	12	117,2
DF223	DH	5	36,8
DF224	DH	8	63,0
DF225	DH	12	126,0

Experimental Investigations
- Presetting Experiments and Results -

- Spring variants were preset three times by controlled deflection
- Presetting tests were made with three springs of the same geometry
- Presetting value was determined by forming the arithmetic mean value

	Experimental results					Results of calculation	
name	**L_o in mm (before)**	**s_{pl} in mm**	**L_o in mm (after)**	**Δs in mm**	**F in N**	**Δs in mm**	**F in N**
DF 219	25,92	6,22	25,38	0,55	1340	0,5	1316
	25,9	6,22	25,39	0,5	1336		
	25,84	6,22	25,34	0,51	1335		

Experimental Investigations
- Presetting Experiments and Results -



Relation between calculation and experiment

- Calculated presetting values were between 96 and 125% (exception of non heat treated springs made of oil hardened and tempered material)
- On average, deviation of 10% between calculation an experiment
- Significant deviations from non heat treated springs made of oil hardened and tempered steel can be explained by the residual stress after coiling process

Summary

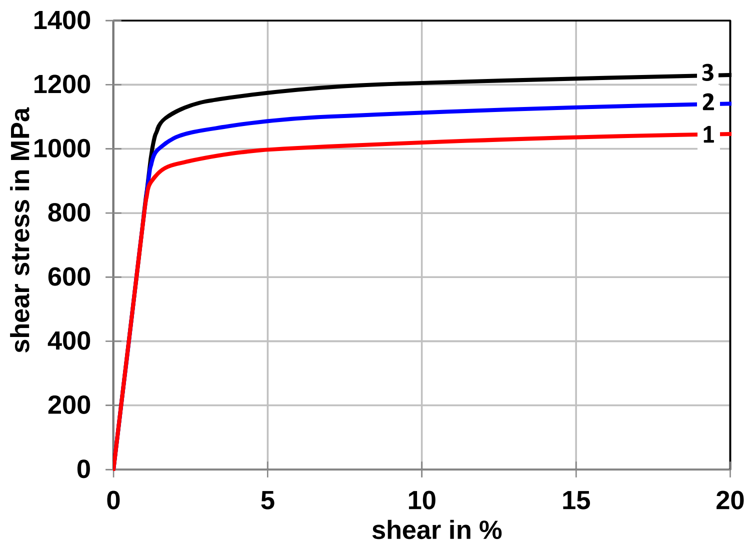
- The approach presented is a simple, fast and inexpensive way to determine the presetting value based on the real shear stress shear characteristic of the material
- The input of spring geometry and material parameters as well as the calculation of the presetting value require only a few seconds with relatively good result quality as opposed to time and cost-intensive simulations using FE models
- In addition, it is possible to estimate realizable spring lengths depending on the properties of the material.
- The feasibility of a spring with the corresponding material properties can be demonstrated without great effort.

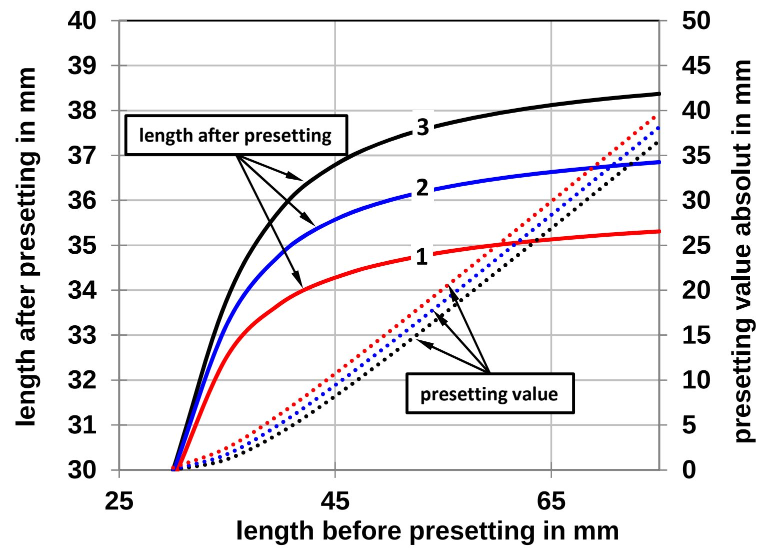
Thank you for your attention!

Theoretical Considerations
- Realizable Spring Length -

sample calculation:

- three different materials were used
- Geometry of the spring was not varied
  (number of coils: n_t=6.5; spring index: w=5; wire diameter d=3.0 mm)
- Presetting to solid length





From a certain setting way, the length of the helical compression spring only increases slightly after presetting process.