



# AHLE FEDERN

## **New advantages for use of taper wire in suspension springs for lightweight design and side load control**

### **Automotive Applications**

**Vehicle Dynamics Expo  
16<sup>th</sup> to 19<sup>th</sup> June 2009, Stuttgart Messe, Germany**



# Agenda

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- 1) Spring design requirements**
- 2) Realization of Miniblock-Springs**
- 3) The Ahle manufacturing process**
- 4) Summary Miniblock-Springs**
- 5) New developments / potential of springs with non-constant wire diameter**
- 6) Summary**



# 1. Spring Design Requirements

## **Customer Requirements to Spring Design**

- 1. (Progressive) Deflection Curve**
- 2. Light Weight Design**
- 3. Packaging Minimisation**
- 4. No Coil Contact**
- 5. Super Progression**
- 6. Low Side Load**
- 7. Characteristic of the Load Deflection Curve**

# Spring Design Requirements



## Requirement:

- 1. (Progressive) deflection curve**
- 2. Light weight design**
- 3. Small installation space**
- 4. No coil contact**
  
- 5. Super progression**
- 6. Low side load**
- 7. Characteristic of the load-deflection curve**

## Solution:

### Non-constant pitch:

- Progression

### Non-constant wire diameter:

- Weight reduction: light weight design

### Non-constant coil diameter:

- Small block length (Miniblock spring)
- No coil contact (contact elimination)

# The Non-Constant Principle

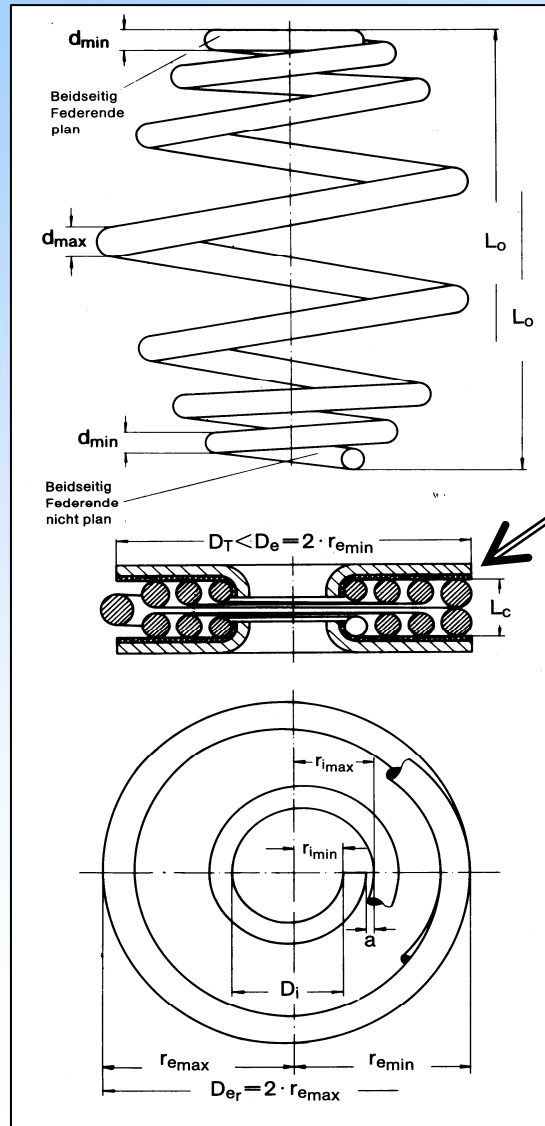


## Combination of:

- Non-constant pitch
- Non-constant coil diameter
- Non-constant wire diameter

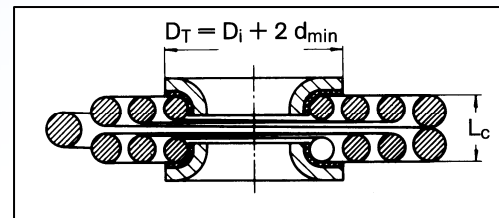
resulted in the design of the  
**Miniblock spring**

# Miniblock Spring Types



## Progressive Miniblock Spring

The spring is symmetrical.  
The coils are supported on both sides of the spring disks.



**And one-sided progressive spring!**

## Linear Miniblock Spring

The spring is symmetrical.  
The coils are not supported on the spring disks.

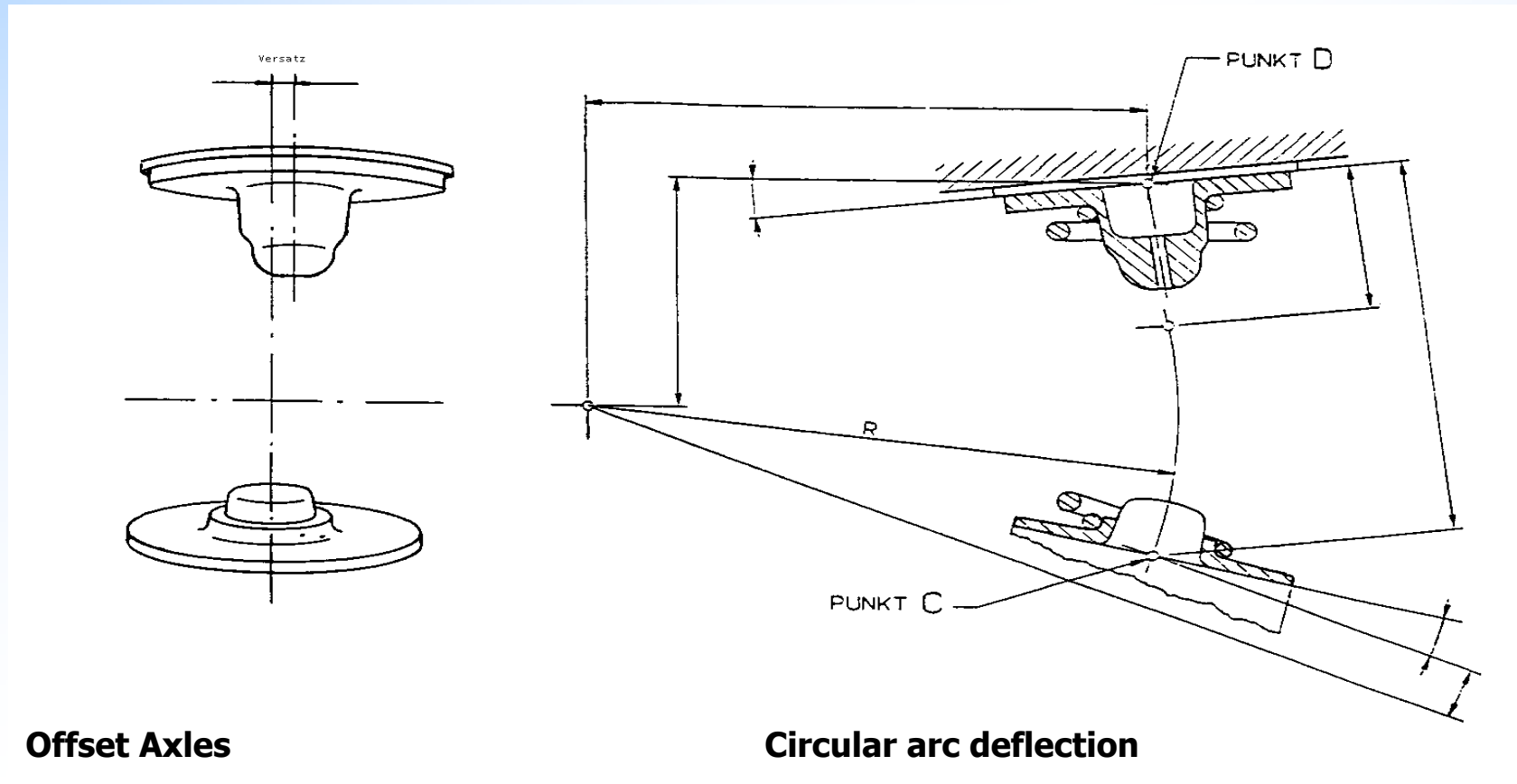
## 2. Miniblock Spring Design





# Complex Customer Requirements

## Example: realistic packaging and circular arc deflection



**Offset Axles**

**Circular arc deflection**

- **Ahle Spring Design Algorithm**
- **Ahle Tool Design Algorithm**
- **FEM (Femap/Nastran)**
- **CAD (ProEngineer)**
- **3-D Measurement (DEA/Hexagon)**
- **Integrated Tooling and Prototype Manufacturing**

# Spring Design Algorithm



Microsoft Excel - 13115969\_20.08.06.xls

Feder- und Werkzeugberechnungen

Berechnung einer progressiven Kennlinie

$F_{PA} = 3772,000 \text{ N}$      $F_{PE} = 5768,600 \text{ N}$   
 $R_A = 31,000 \text{ N/mm}$      $R_E = \text{ } \text{ N/mm}$   
 $S_{A-E} = 46,000 \text{ mm}$      $R_{E+} = 0 \%$   
 $n_{int} = 8$

zur Auto. RE Berechnung  
 FPA anpassen  
 FPE anpassen

$F_{PE2} = \text{ } \text{ N}$      $S_{A-E2} = \text{ } \text{ mm}$   
 $n_{int2} = 0$      $R_{E2} = \text{ } \text{ N/mm}$

Fpa : 3772,000 N  
 Fpe : 5768,600 N  
 Ra : 31,000 N/mm  
 Re : 0,000 N/mm  
 Re + x% : 0 %  
 Sa-e : 46,000 mm  
 nint : 8

Kräfte F <sub>FE</sub> F <sub>FE</sub> N	Hilfswege S <sub>mp</sub> S <sub>i</sub> mm	Einzelwege S <sub>p</sub> S <sub>i</sub> mm	S Einzelw. S <sub>p</sub> S <sub>i</sub> mm	Einzel-W*1/2 S <sub>mp</sub> S <sub>i2</sub> mm	S Einzel-W*1/2 S <sub>mp</sub> S <sub>i2</sub> mm	Gesamtrate R <sub>e</sub> R <sub>n</sub> N/mm	Einzelrate R <sub>p</sub> R <sub>n</sub> N/mm	Einzelrate*2 R <sub>pp</sub> R <sub>n2</sub> N/mm	
101	3772,000	6,293	8,505	8,505	4,252	4,252	31,000	443,511	887,021
102	3977,718	6,172	8,384	16,889	4,192	8,445	33,330	474,429	948,857
103	4194,656	6,052	8,264	25,153	4,132	12,576	35,848	507,607	1015,214
104	4423,425	5,931	8,143	33,296	4,071	16,648	38,572	543,221	1086,443
105	4664,671	5,810	8,022	41,318	4,011	20,659	41,520	581,462	1162,924
106	4919,074	5,690	7,902	49,220	3,951	24,610	44,713	622,536	1245,071
107	5187,352	5,569	7,781	57,001	3,891	28,500	48,173	666,666	1333,332
108	5470,261	5,448	7,660	64,661	3,830	32,331	51,925	714,096	1428,192
109	5768,600	5,328	7,540	72,201	3,770	36,100	55,987	765,091	1530,181

112 Re : 55,997 N/mm  
 113 F(HU) : 3576,921 N  
 114 x(0) : 1,055  
 115 S(prog.i.d) : 6,293 mm  
 116 Summe S(prog.i.d) : 50,343 mm  
 117 a : -0,121 mm

119 GEBRÜDER AHLE KARLSTHAL  
 120 Datum : 23.04.2009  
 121 Zeichen : Jahn

Start | Femap with NX Nastran... | Berechnung und Kalk | Federberechnung | Microsoft Excel - 1311... | Dokument1 - Microsoft W...

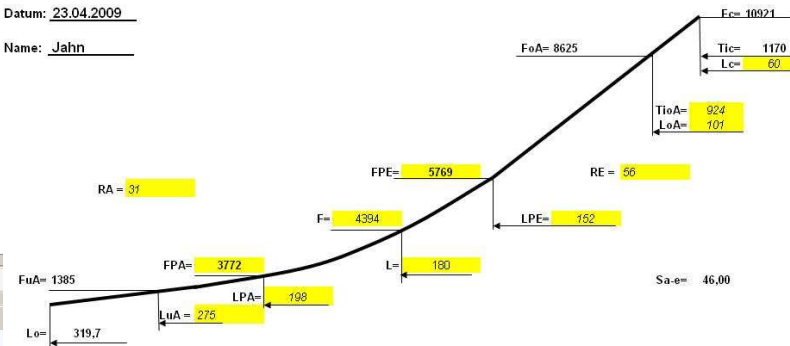


Kunde: \_\_\_\_\_

Nr.: \_\_\_\_\_

Datum: 23.04.2009

Name: Jahn



## Evaluation of geometry data and characteristic curve

# Tooling Algorithm



Unitechnik Stützpunkte 14:41:54 23.04.2009

Istposition Spindelstellung [Windungen] 5.80  
 Istposition Drahtführung [mm] 0.1  
 Istposition Hubachse [mm] 90.1

Feder in Bearbeitung: AHLE\_TEILE\_NR: 2596 - Entwicklungsstufe: 1 | Feder in Maschine: AHLE\_TEILE\_NR: 1445 - E-Stufe: 2 - Wdg: 5.8 - Länge: 239.0

**Bereich Zoomen**

Wdg-Startpunkt:   
 Wdg-Endpunkt:

Zurück Zoomen

**Progressive Feder entwickeln**

Stufe	Start(mm)	Ende(mm)	Wdg

Start (mm):   
 Ende (mm):   
 Windungen:

Feder entwickeln Verwerfen

**Bereich verändern**

Wdg-Startpunkt:   
 Wdg-Endpunkt:   
 +/- Distanz [mm]:

Bereich länger/kürzen Verwerfen

**Gummiband**

Wdg-Startpunkt:   
 Wdg-Endpunkt:   
 Mittenpunkt:   
 +/- Distanz [mm]:

Gummiband Verwerfen

**Anzahl Windungen**

Wdg-Startpunkt:   
 +/- Anzahl Wdg:

Anzahl größer/kleiner Verwerfen

**E-Stufe einbetten**

Stufe 1  Stufe 7  
 Stufe 2  Stufe 8  
 Stufe 3  Stufe 9  
 Stufe 4  Stufe 10  
 Stufe 5  Stufe 11  
 Stufe 6  Stufe 12

Kurve glätten

Federparameter	
Wdg	Steigung
0,00	0,00
0,10	1,00
0,20	2,35
0,30	3,71
0,40	5,64
0,50	8,04
0,60	11,42
0,70	15,25
0,80	18,45
0,90	21,65
1,00	23,97
1,10	25,05
1,20	26,09
1,30	27,30
1,40	28,20
1,50	29,10
1,60	30,63
1,70	31,75
1,80	32,88
1,90	35,50
2,00	38,50
2,10	41,08
2,20	43,20
2,30	46,57

**Stützpunkte**

**3. Achse**

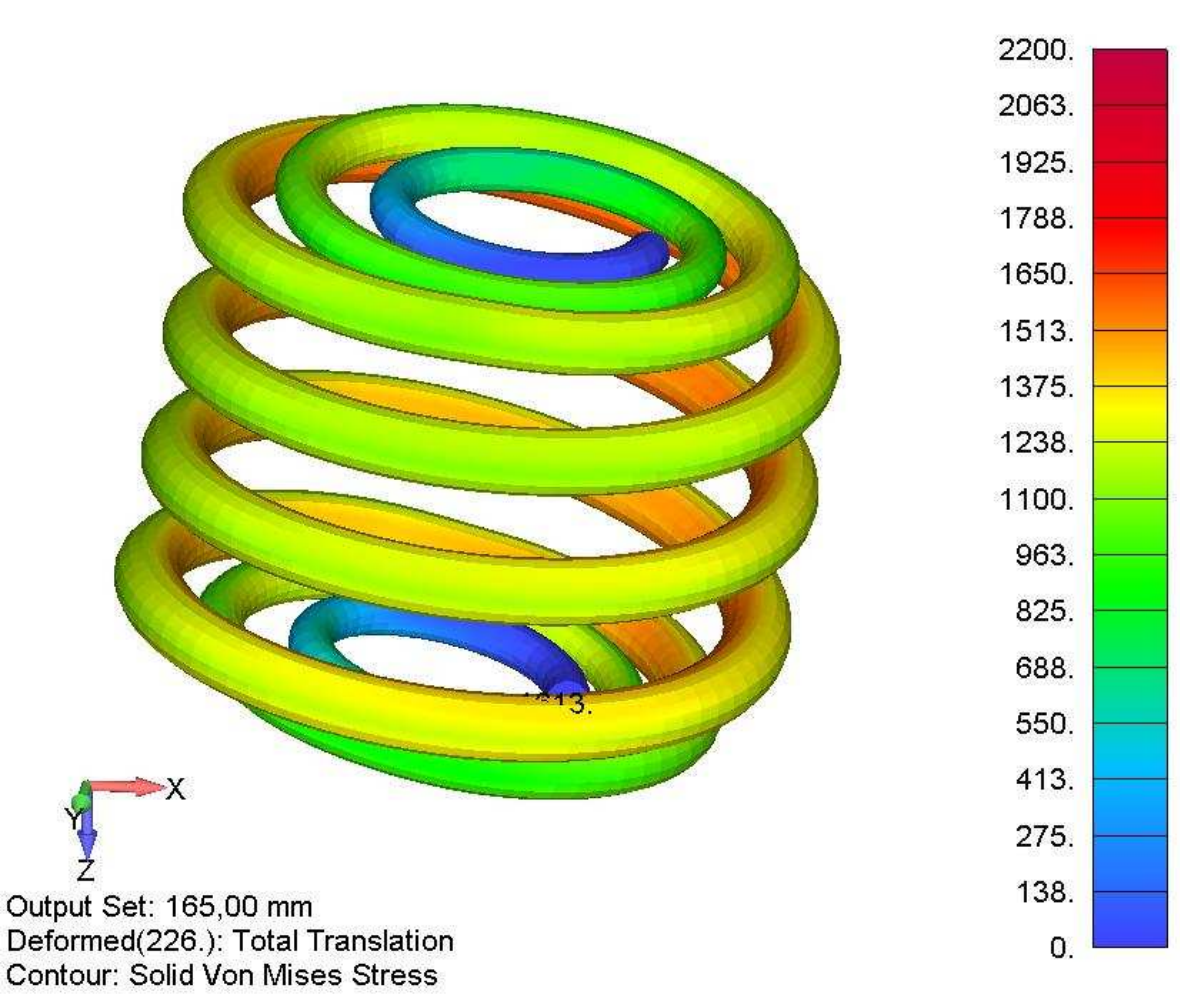
Federende	X[mm]	Y[mm]
240	14.7	
290	14.7	
280	12.9	
40	12.9	

F1 Federabbild	F2 Feder Parameter	F3 E-Stufe speichern	F4 E-Stufe löschen	F7 Zur Maschine
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## CAM link to tool design

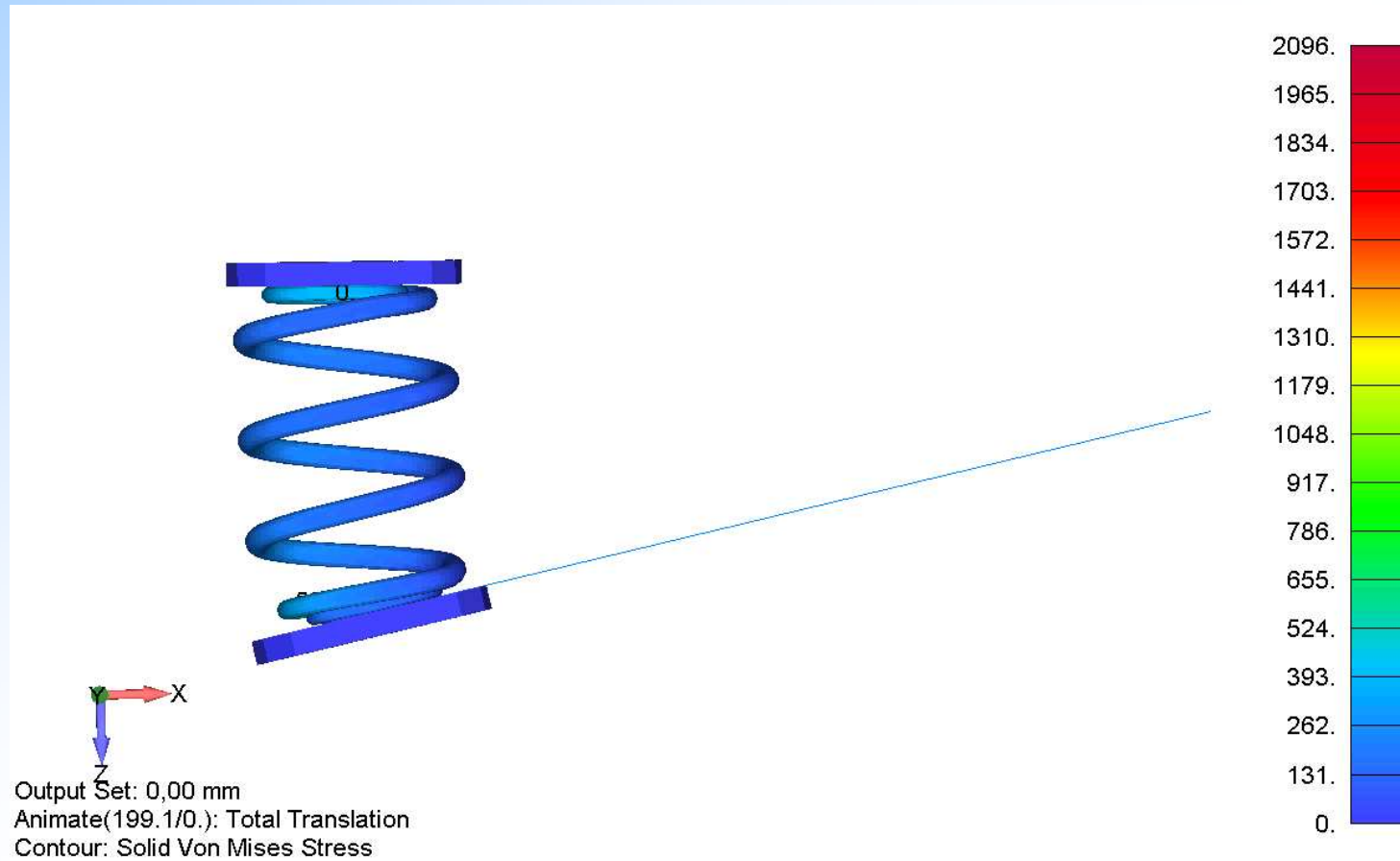
# Finite Element Simulation



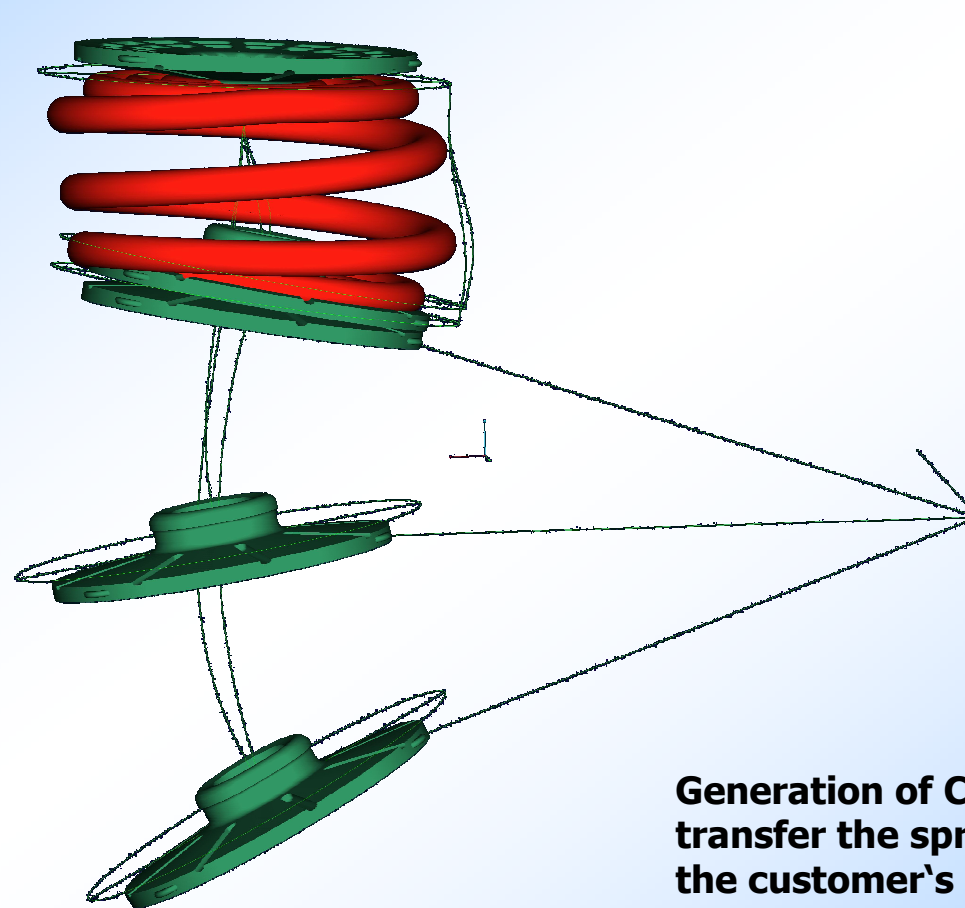
**Model of a Miniblock-Spring**

# FEM Simulation

**FEM simulation helps to analyse stresses (bending and torsion stresses) within spring wire during designing**



**FEM Simulation**

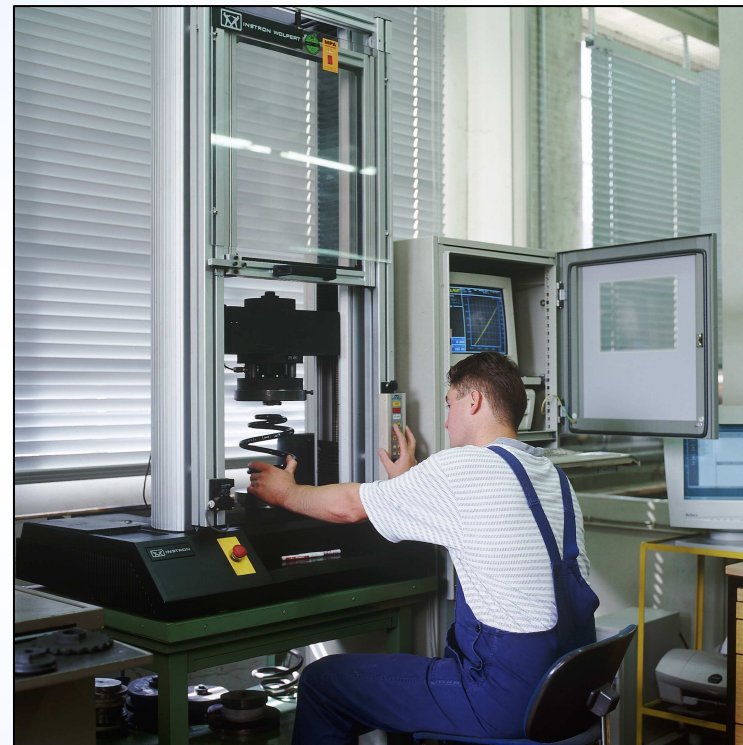


**Generation of CAD drawings to transfer the spring design into the customer's CAD system**

# Tooling / Prototype Development



**Product development is close to series production**



**Checking deflection curve and load during prototype development**



# 3-D Measurement; DEA/Hexagon

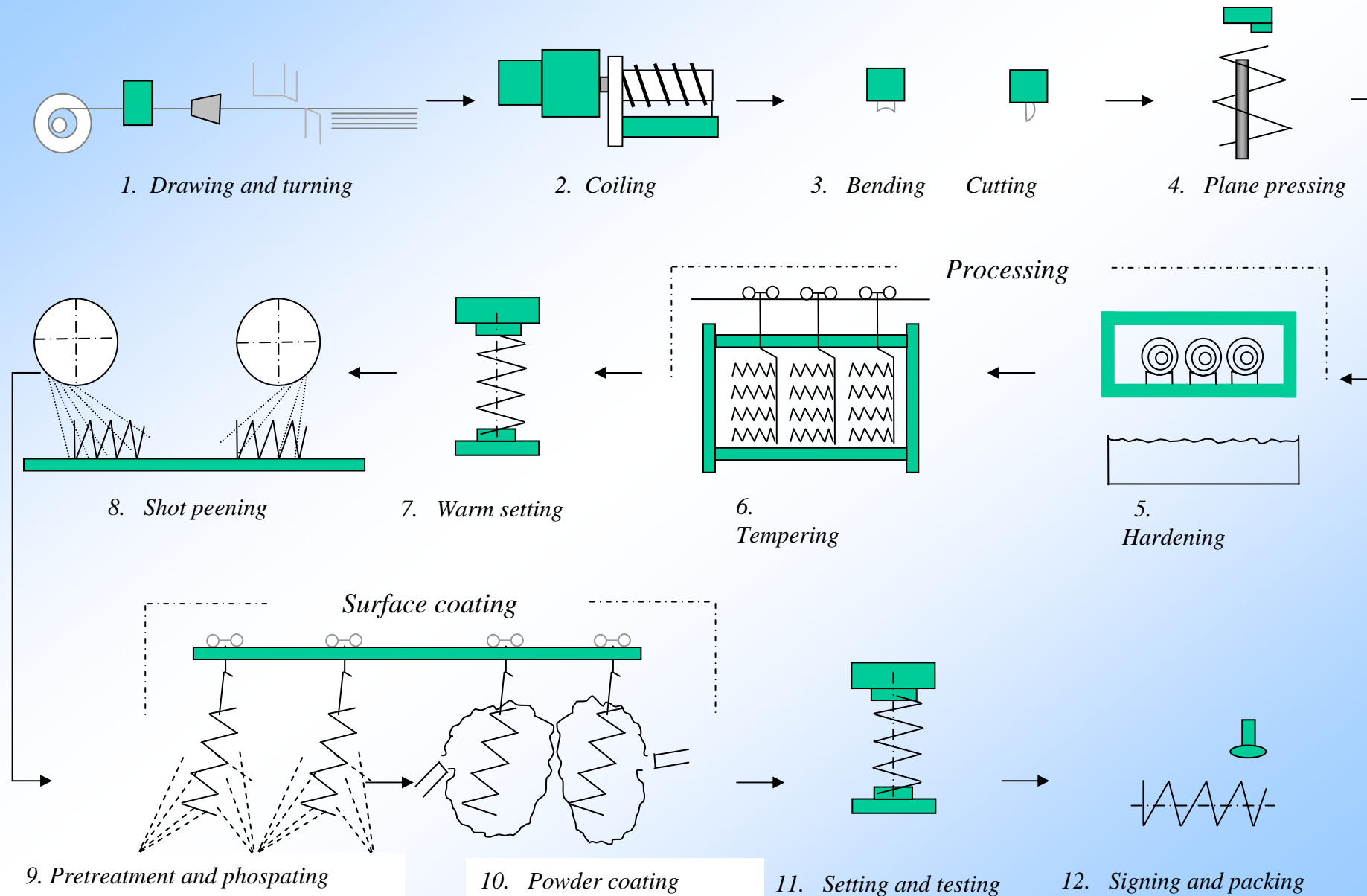


**Capturing geometry data of the real spring, feedback into FEM**



## **3. The Ahle Manufacturing Process**

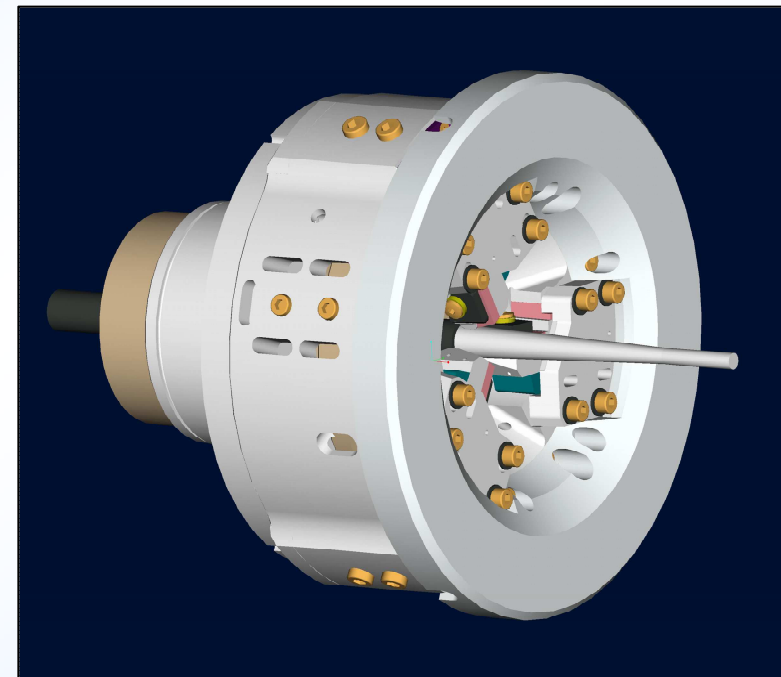
# Producing Springs from Steel Bars



# Taper Wire

<b>Chargen - Stempel</b>		n. Zeichn. Nr. - 1780.4	<b>Teile Nr.:</b>											
<b>Schrift:</b>		A 4 -16 DIN 30640												
<b>Kunden - Stempel</b>		n. Zeichn.-Nr. -1779.4												
<b>Text:</b>		Ch-Nr.	<b>Ahle Logo</b>											
<b>Schrift:</b>		DIN 30640	h = 4 mm											
<b>0,5 mm tief eingeprägt</b>		<b>ZD4</b>												
<input checked="" type="checkbox"/> kurz 7 40 <input type="checkbox"/> lang 32 70		(Stempelabstand):												
= wird nach dem Wickelvorgang abgetrennt														
<b>Stabkrümmung:</b>		<b>Toleranz für den:</b>												
		<b>kleinen Ø-Bereich im dünnen Teil</b> bis 12 mm Ø ± 0,08 bis 15 mm Ø ± 0,12												
<table border="1"> <tr> <th>L</th> <th>h</th> </tr> <tr> <td>bis 2000</td> <td>0 - 30</td> </tr> <tr> <td>bis 3000</td> <td>0 - 60</td> </tr> <tr> <td>bis 4000</td> <td>0 - 90</td> </tr> <tr> <td>bis 5000</td> <td>0 - 120</td> </tr> </table>		L	h	bis 2000	0 - 30	bis 3000	0 - 60	bis 4000	0 - 90	bis 5000	0 - 120	<b>großen Ø-Bereich</b> bis 15 mm Ø ± 0,05 bis 25 mm Ø ± 0,07		
L	h													
bis 2000	0 - 30													
bis 3000	0 - 60													
bis 4000	0 - 90													
bis 5000	0 - 120													
Ziehstein-Ø	Einsatz-	Werkstoff	Festigkeit	Gefüge										
Spantiefe Vorschneider S1	material-Ø		N/mm²											
Spantiefe Fertigschneider S2		Ø 64 SiCr V6	680-800	GKZ										
Spantiefe Fertigschneider S3		Ø 55 Cr 3	660-770	GKZ										
Einsatzgewicht des Stabes	kg	mm	Ø 50 Cr V4	660-770 GKZ										
Fertiggewicht des Stabes	kg	Oberflächengüte : nach Grenzmuster ZD												
Lineal-Nr. / Progr.-Nr.	-	Rundheitsabweichung : 0,05 mm												
Änderungen:		Ersatz für:												
		Gehört zu:												
		Kunden-Nr.:												
		Teile-Nr.:												
		Zeichn.-Nr.:												
		Datum:												
		Name:												
Schutzvermerk	A H L E FEDERN Gebrüder Ahle GmbH & Co. Karlsthal 51789 Lindlar													
nach DIN 34														
beachten	<b>Stabskizze</b>													
Maßstab:	<b>Beidseitig konischer Stab</b>													
ohne														

## Production of taper wire



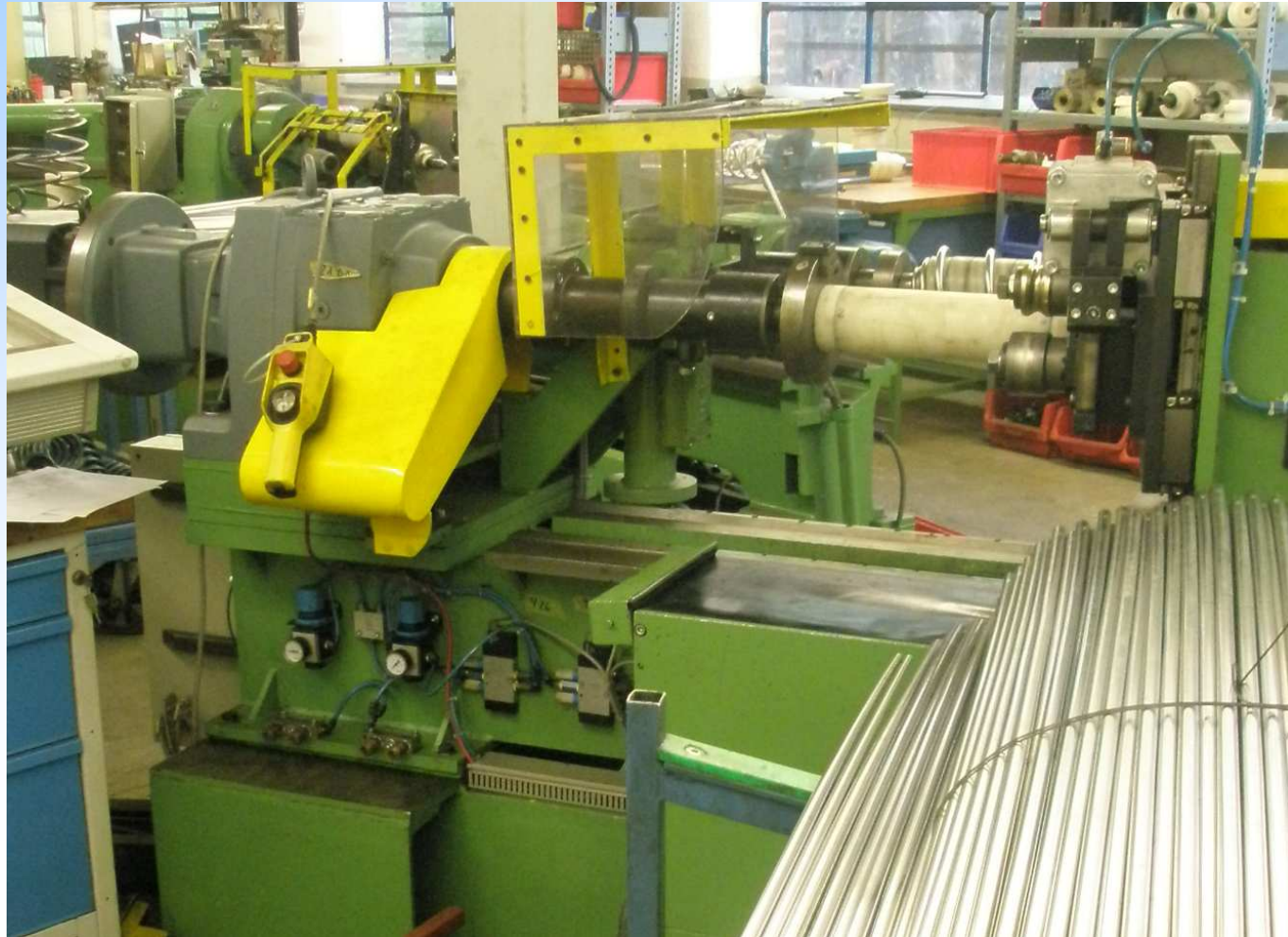
Reducing the material in a combination of drawing and peeling processes

## Typical bar drawing (taper wire)

Karsten Landwehr, Key Account

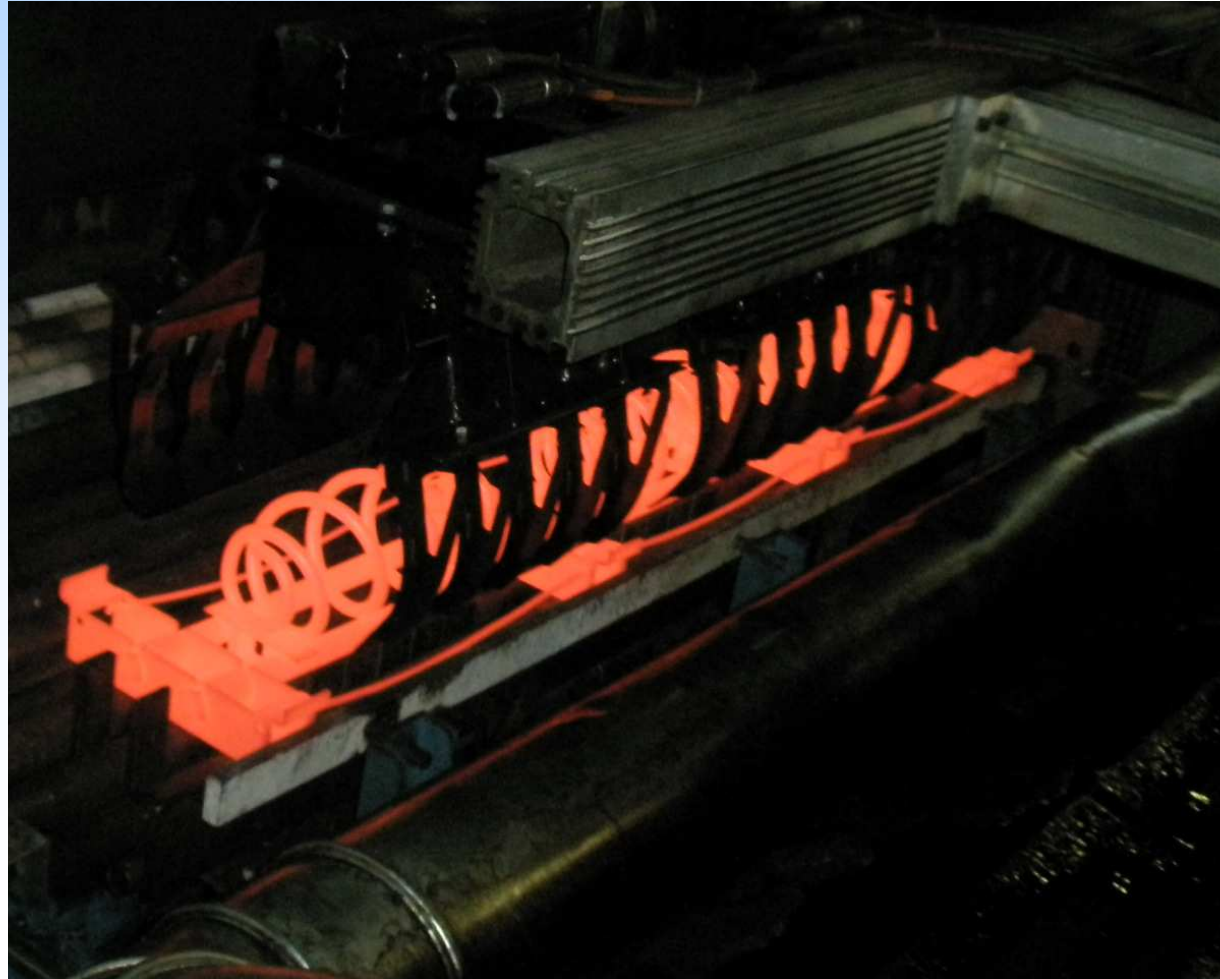
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# Coiling Process



**Coiling of springs**

# Heat Treatment



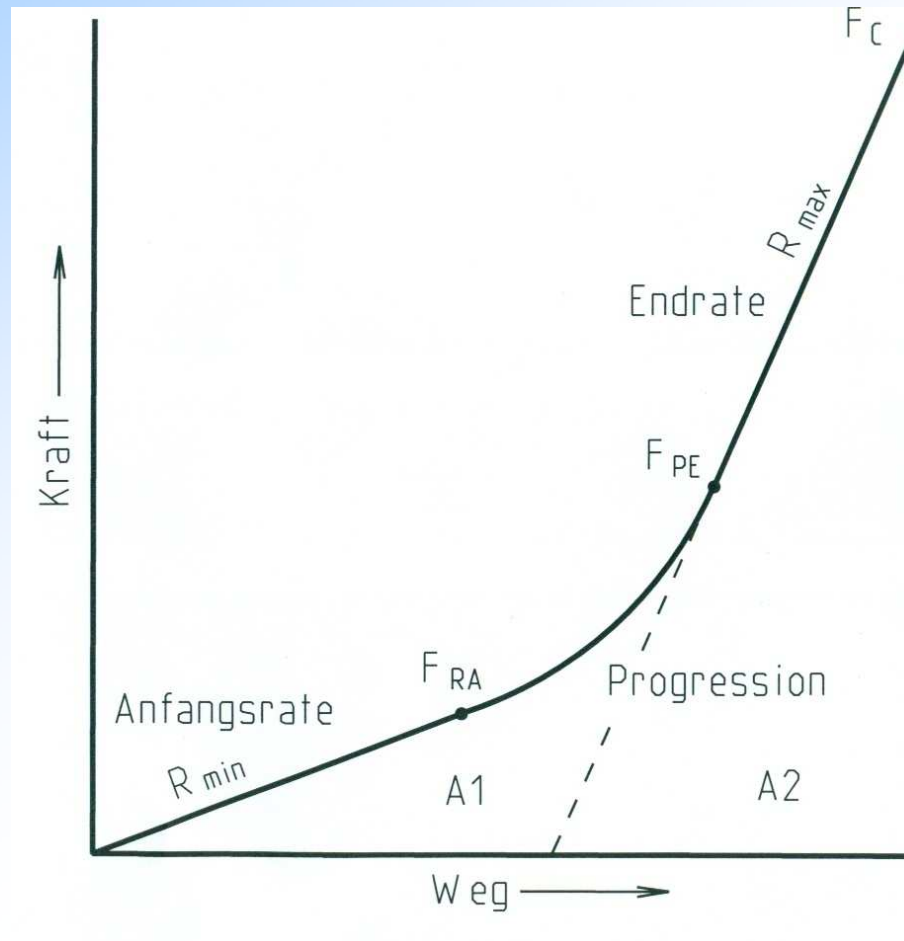
**Heat treatment furnace with controlled atmosphere**



## 4. Miniblock Springs, Summary

# Requirement: Deflection Line

## Execution of every required deflection curve



**The Ahle process enables the development and production of chassis springs with a rate ratio of 1:3!**

$$Rate = \frac{F}{S} = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n}$$



# Requirement: Light-Weight Design



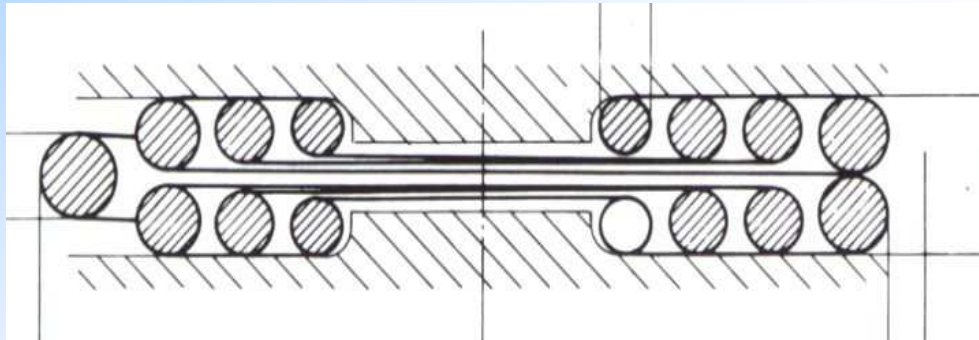
**Solution:** The wire diameter can be adjusted to the stress in this area. As soon as smaller coils have settled, the stress in these coils is reduced. The wire diameter of these coils is thus designed with a smaller diameter.

**Result: light-weight design**



**The Miniblock-Spring is the lightest spring from a physical point of view and offers the lowest block length.**

# Requirement: No Coil Contact



**No coil contact – no noise, no surface damage!**

# Requirement: Small Installation Space



315.00mm

here:

**Block length:  
47.30mm**

***=15% of the free  
length  $L_0$***



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**47.30mm**



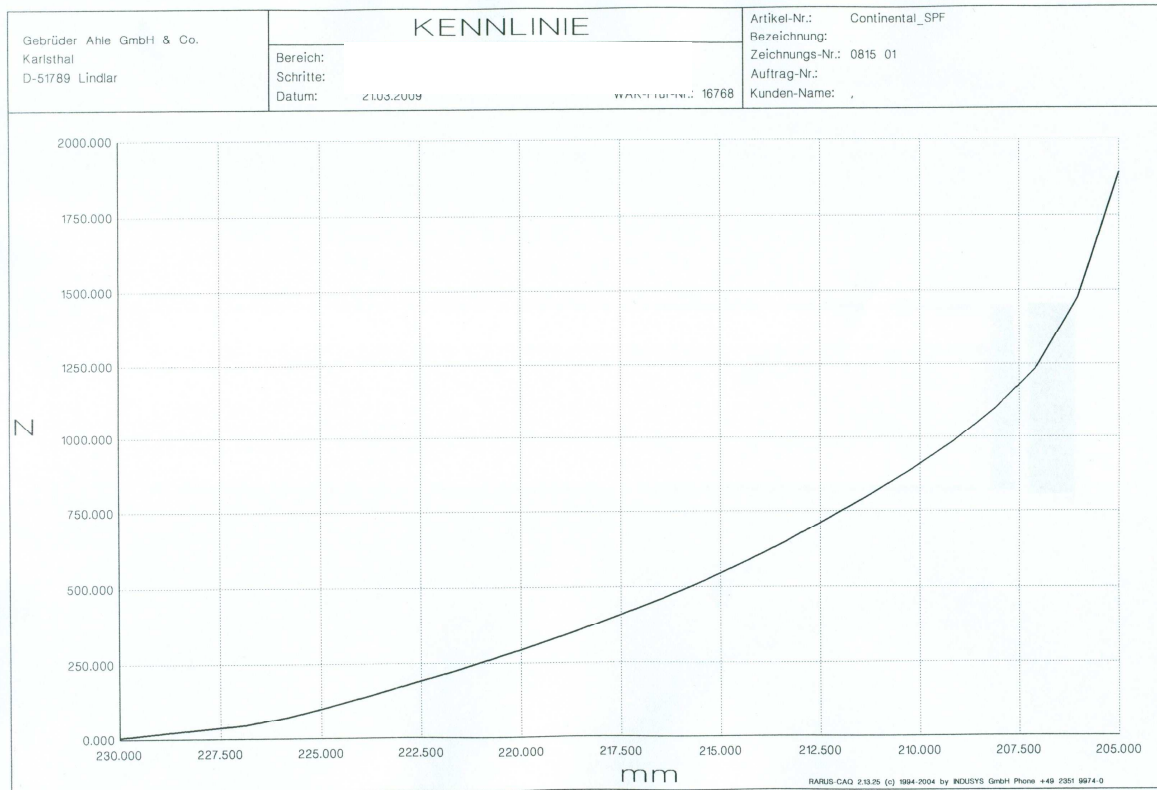
**315.00mm**

1. (Progressive) Characteristic Curve ✓
2. Light Weight Design ✓
3. Packaging Minimisation ✓
4. No coil contact ✓
5. **Super Progression**
6. Defined Force Line Piercing Points ✓
  - Side load minimisation (piercing points in the spring axis)
  - Offset (piercing points are outside of the spring axis)



## **5. New Developments/ Potential of Springs with Non-Constant Wire Diameter**

# New Development: Mini SPF (Super-Progressive-Springs)



**Applications (e.g.):**

**Rebound spring  
Simulator spring**

**The Ahle process  
makes it possible  
to develop and  
produce super-  
progressive-  
springs with a rate  
ratio of up to zu  
1:10!**

**Characteristic curve of a Mini –Super-Progressive Spring (Mini-SPF)**

# Comparison: Mini SPF vs. Helical Compression Spring

	Mini SPF (Super progressive spring)	Helical compression spring
<b>Weight</b>	71 %	100 %
<b>Free length</b>	66 %	100 %
<b>Solid length</b>	58 %	100 %

**Different springs with identical properties:**

**Material, force, initial rate, end rate, outer diameter = constant**

**Benefit of non-constant wire diameter!**





# Requirements

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1. (Progressive) Characteristic Curve ✓
2. Light Weight Design ✓
3. Packaging Minimisation ✓
4. No coil contact (noise elimination) ✓
5. Super Progression ✓ ✓
6. **Defined Force Line Piercing Points**
  - **Side load minimisation (piercing points near spring axis)**
  - **Offset (piercing points outside of spring axis)**

# Objectives / Benefits of AHLE Solution

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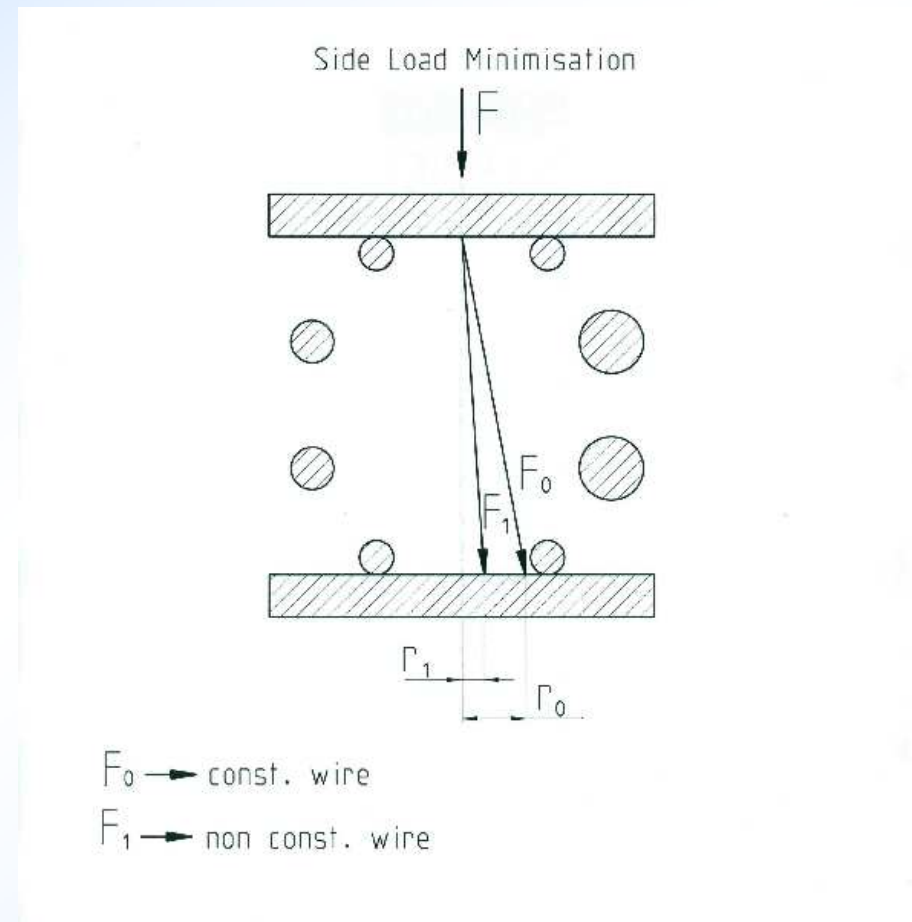


- **Reduction of friction within the spring system**
- **Reduction of height / length of the spring (improved pedestrian protection!)**
- **Optimised positioning of the shock absorber system**
- **Reduced weight of spring**
- **Easier assembly of the shock absorber system**



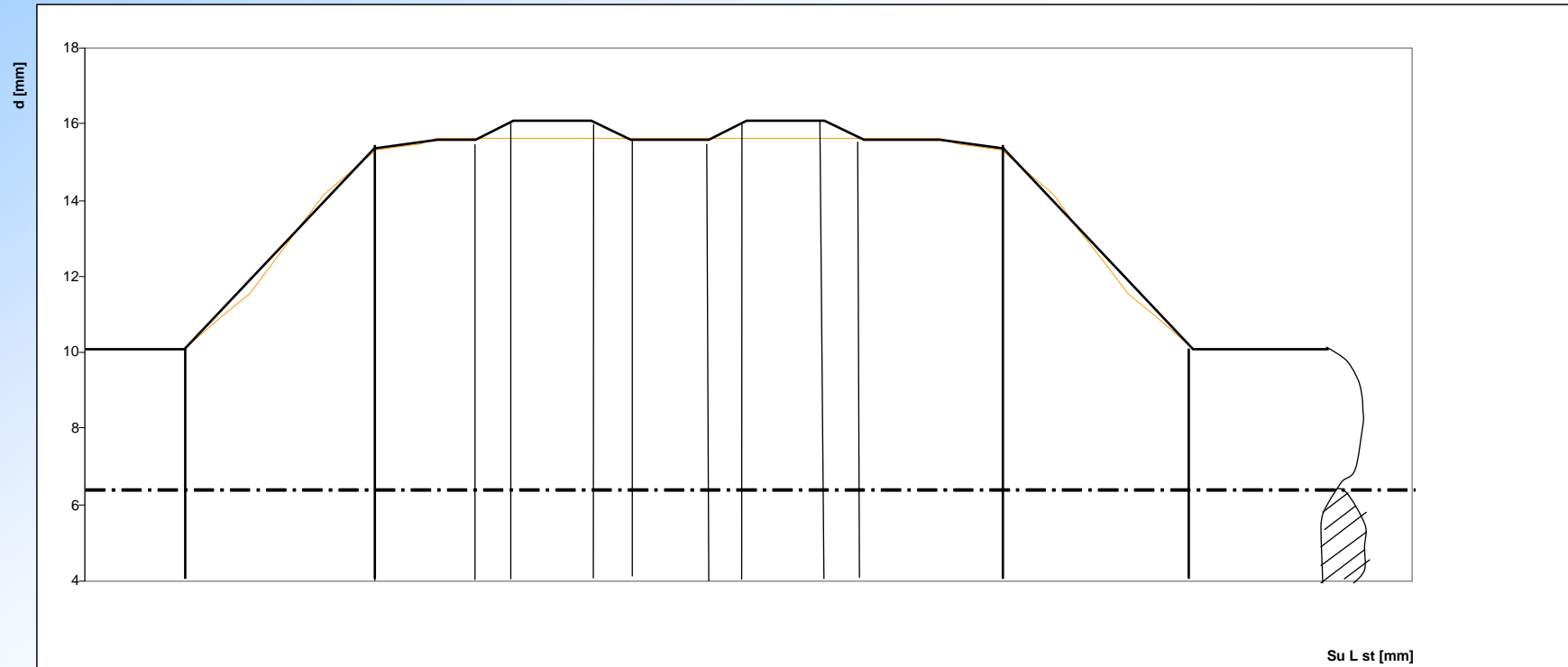
# Side Load Correction

**Objective achieved by:  
Non-constant wire diameter**



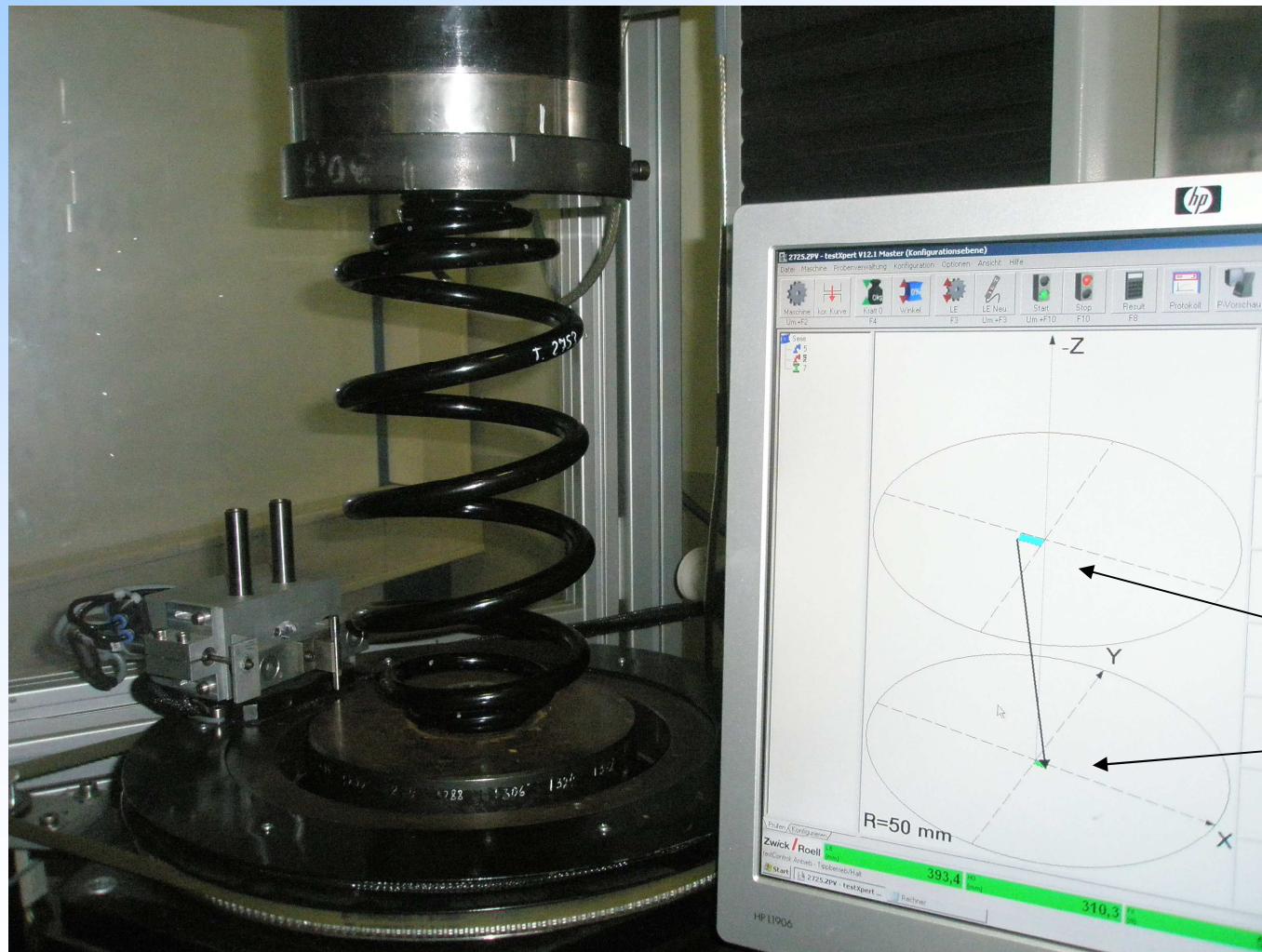
**Sketch: modified Miniblock-Spring**

# Side Load Correction



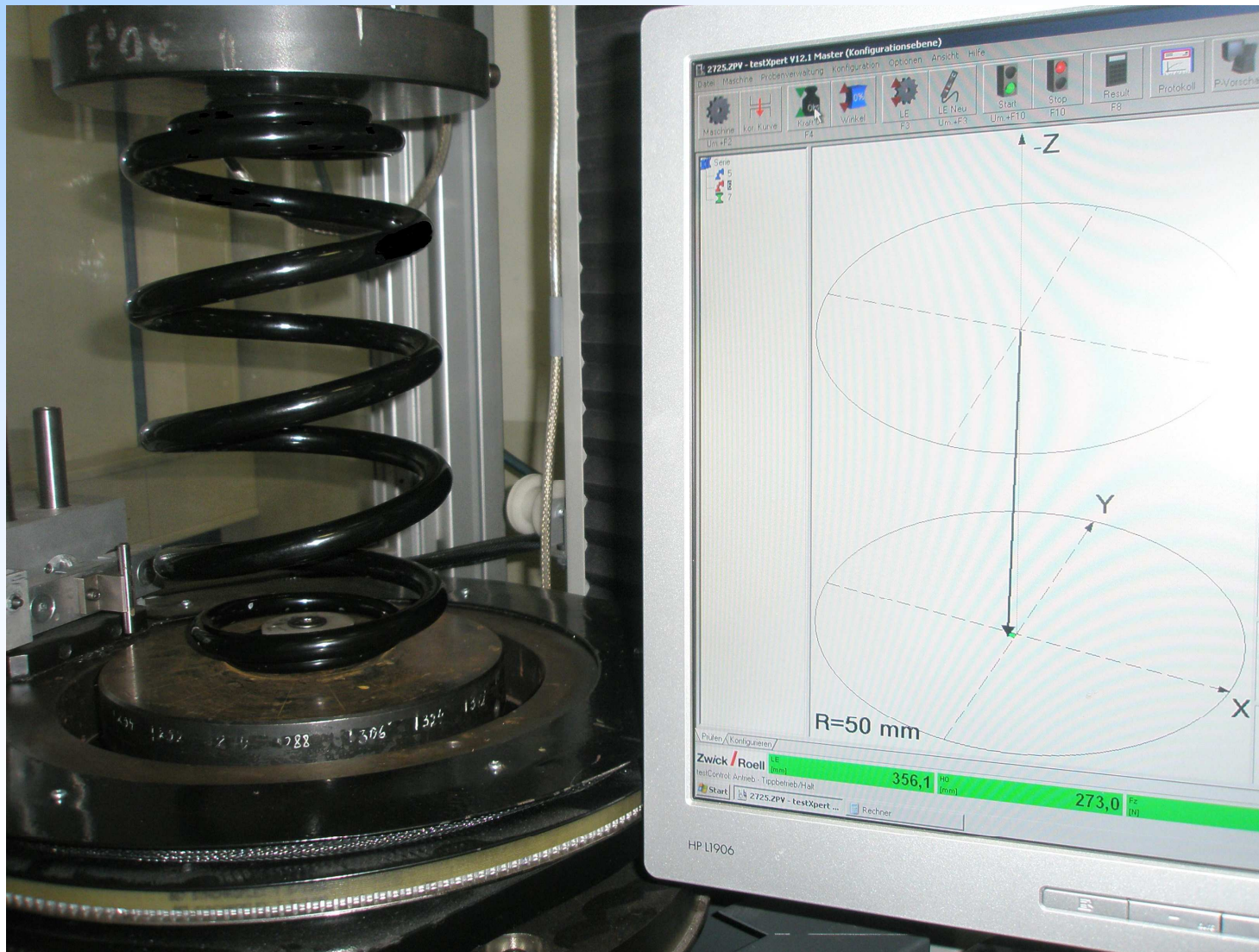
**Schematic drawing of a bar with partially thickened wire sections**

# Side Load Determination



Position of piercing points based on the direction of the force line of action

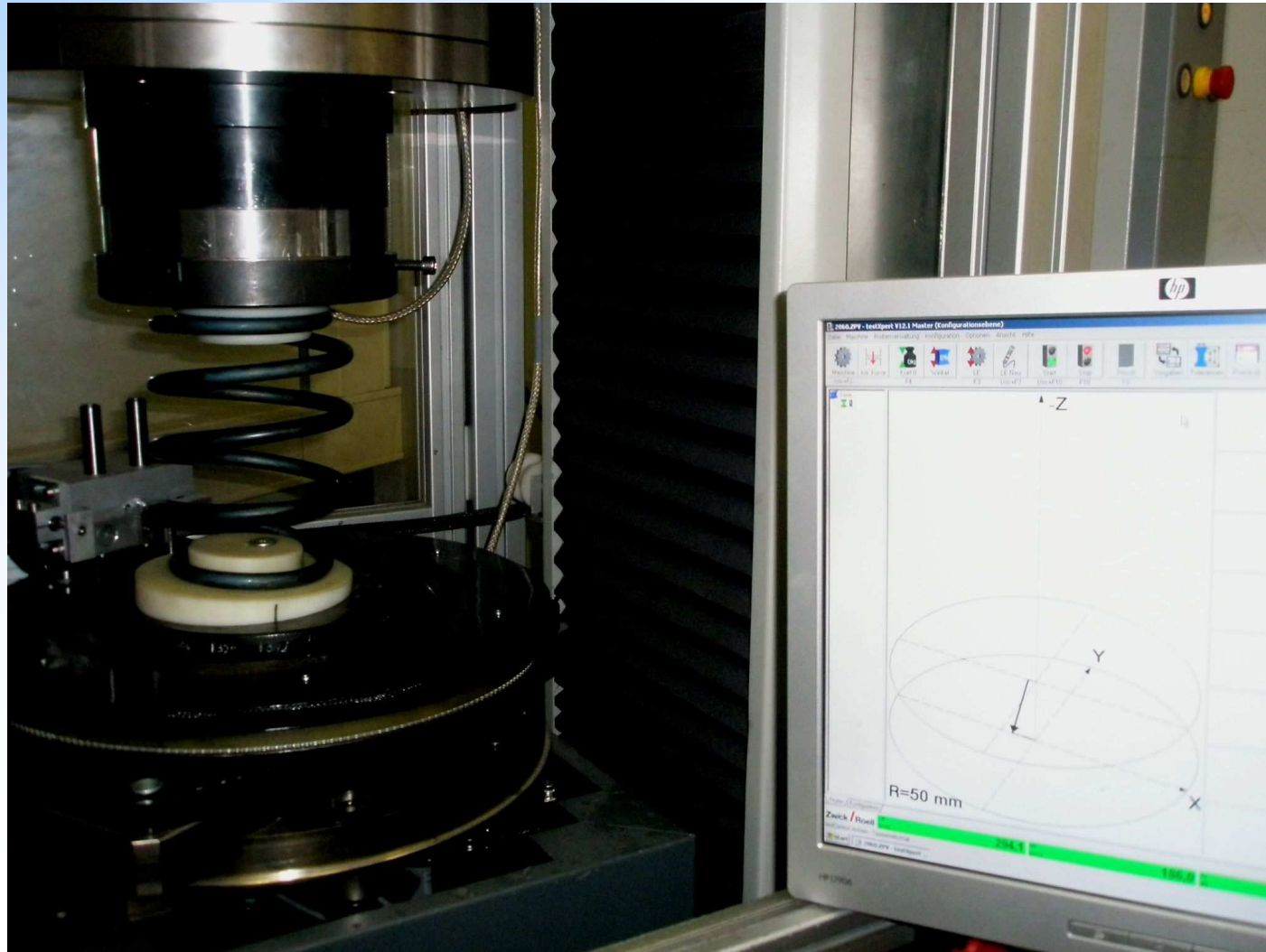
# Side Load Minimization



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**Optimized force line of action of a modified Miniblock-Spring)**

# Influencing the Force Line of Action

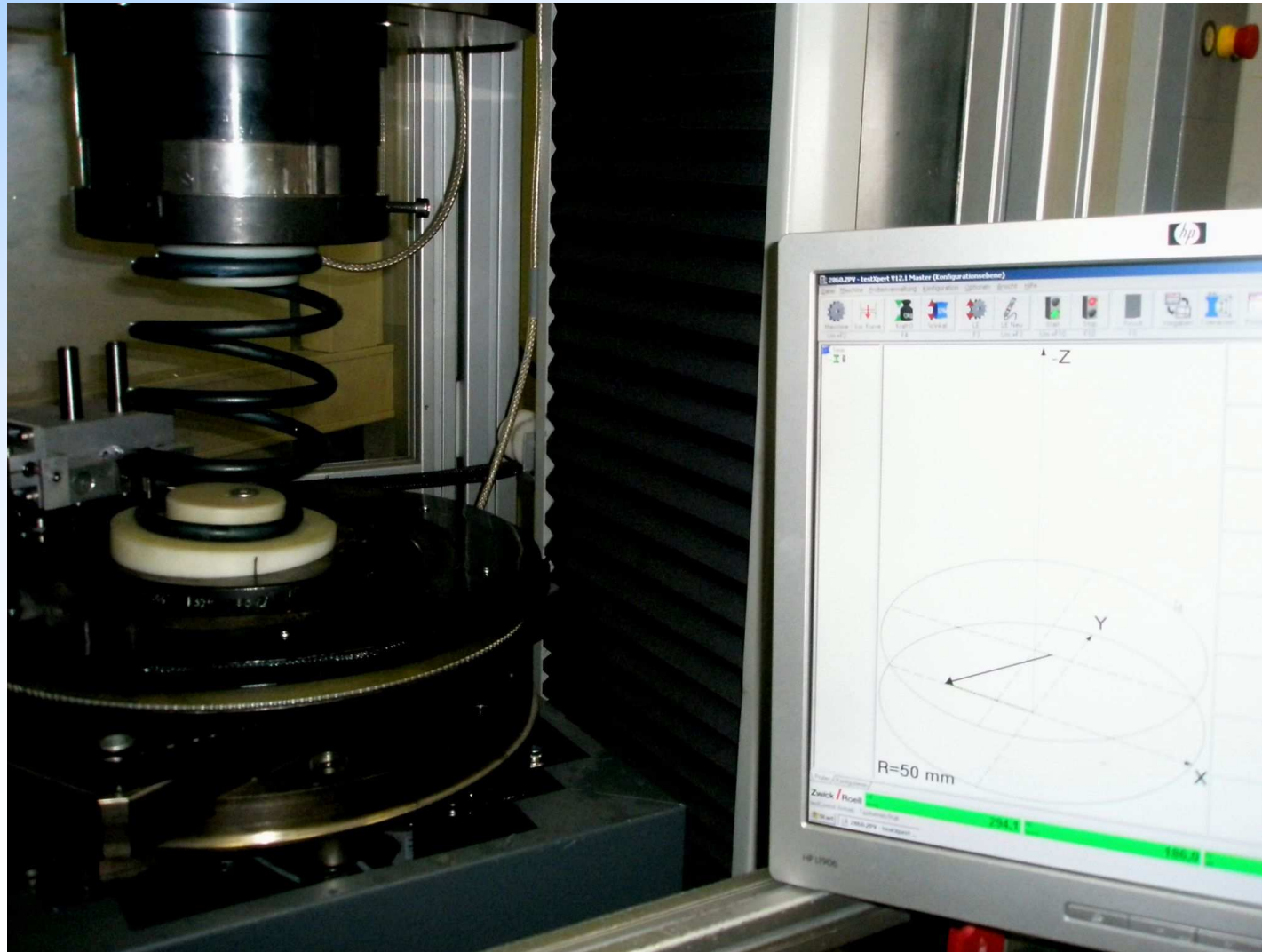


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**Ahle – Side-Load Spring without bar modification**



# Influencing the Force Line of Action

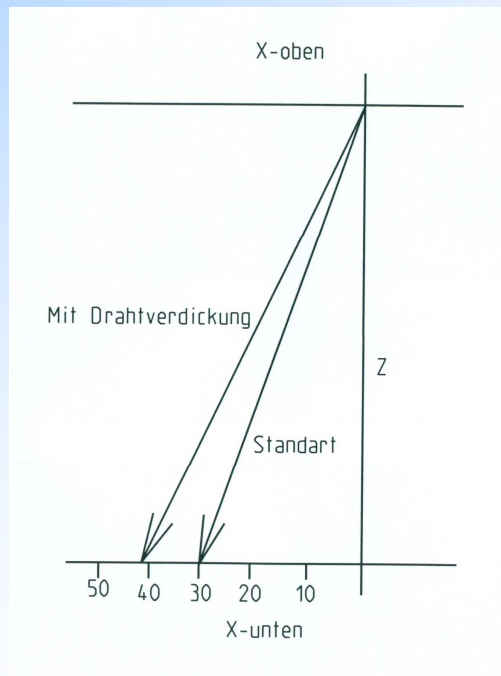


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**Ahle – Side-Load Spring with bar modification**

# Current Status of Developments

- **Series production of partially thickened bars is possible**
- **Confirmed functionality of the Ahle – Side-Load Spring**



Lower piercing point		Upper piercing point		Side load	Wire
Xunt [mm]	Yunt [mm]	Yob [mm]	Xob [mm]	Fq [N]	
-32.73	-2.86	-6.37	-3.61	577.53	No thickened sections
-32.02	-2.01	-8.98	-3.89	541.61	
-33.05	-1.51	-5.71	-2.93	508.58	
-44.81	0.49	-1.57	2.12	859.93	With thickened sections
-47.59	0.63	-2.32	1.02	825.46	
-48.02	0.79	-2.79	0.78	808.82	

**Further development of a competitor's side load spring**

- **Compared with series side-load springs the Ahle-Solution shows up to 50% larger shifts of the piercing points**

## 6. Summary



**(Progressive) helical compression springs with taper wire show the following properties:**

- **Optimum use of material**
- **Low weight**
- **Small packaging**
- **No coil contact**
- **High progression in only one component**  
**possibility to influence the force line**



# AHLE FEDERN

**Thank you for your attention**

