In-process Strain Measurement in Roll Forming

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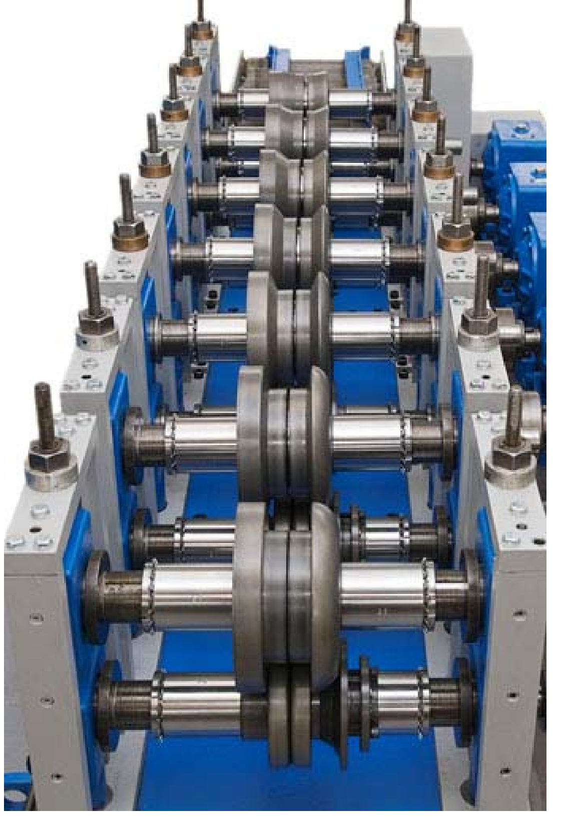
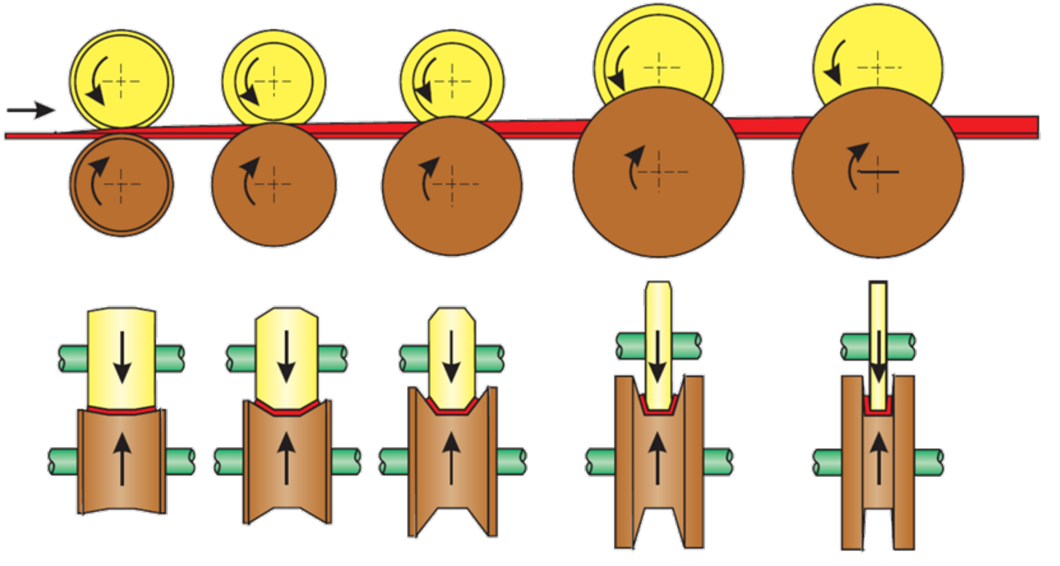
Roll Forming

- Bending process
- Angle introduced continuously along straight line
- Set of contoured rolls
- Strip motion applied by rotation of rolls (friction)
- Alternatively, pulling of strip
- Unlimited length



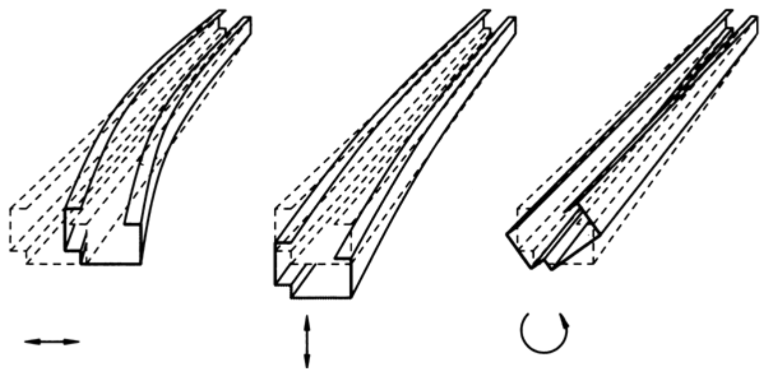


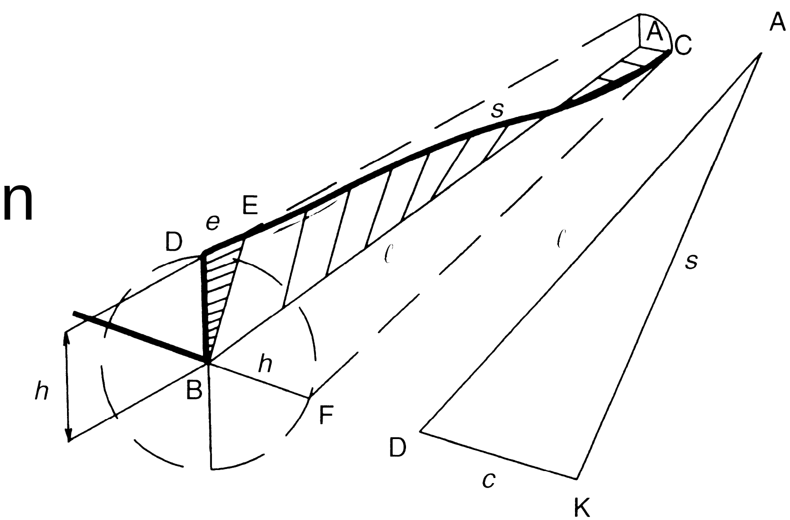
Source: Schuler

Motivation

- Geometric defects a frequent occurrence in roll forming
- Largely caused by plastic deformation outside the intended forming zone
- Verification of FEA-simulation of the process

→ Continuous, non-contact strain measurement in flange area

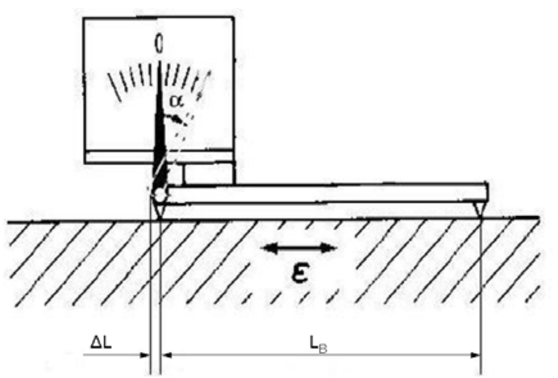




Source: Halmos

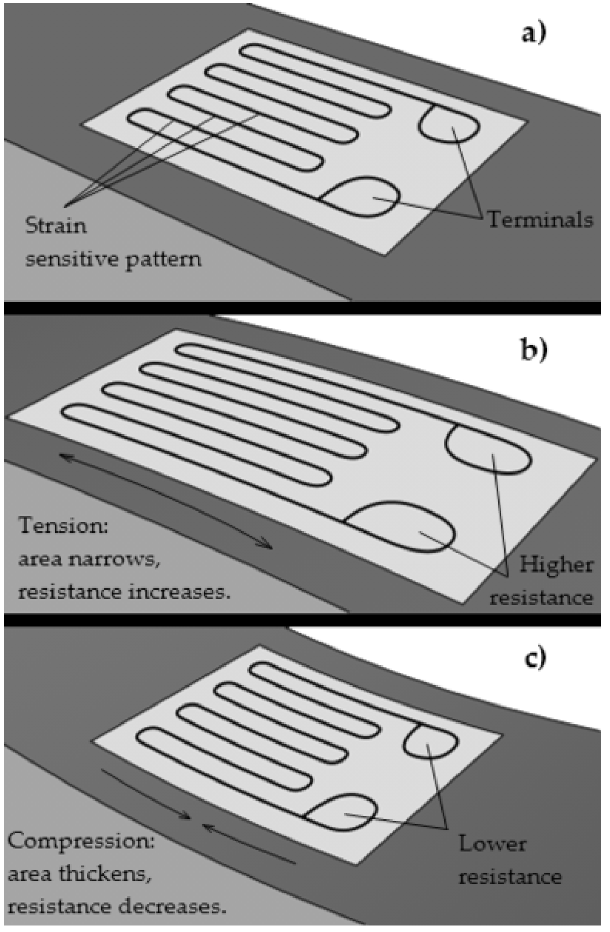
Strain Measurement Methods I

Mechanical	Strain Gauge



Source: Ferber

Mechanic longitudinal strain device

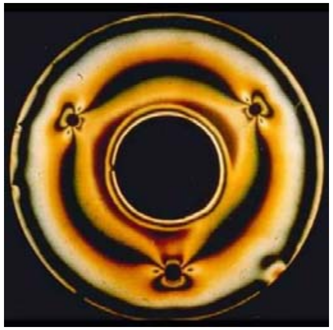


Source: Wikipedia

Electric conductor changes resistance when being compressed or elongated

Strain Measurement Methods II

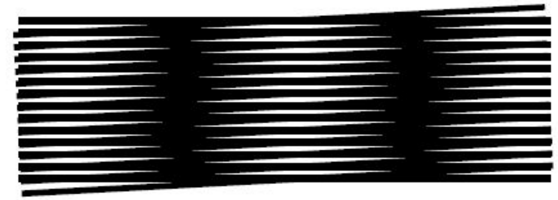
Photoelasticity



Source: Onera

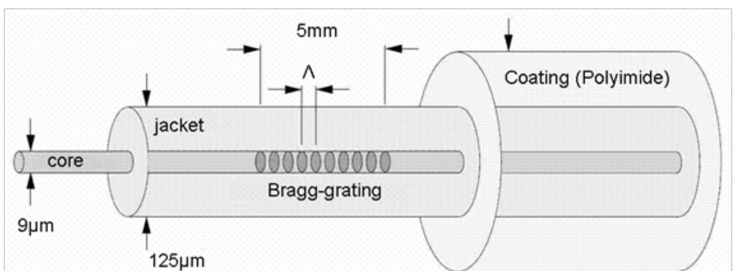
iso-chromatic and isoclinic lines in a specimen under load

Moiré Pattern



Moiré effect of two rotated superimposed line pattern

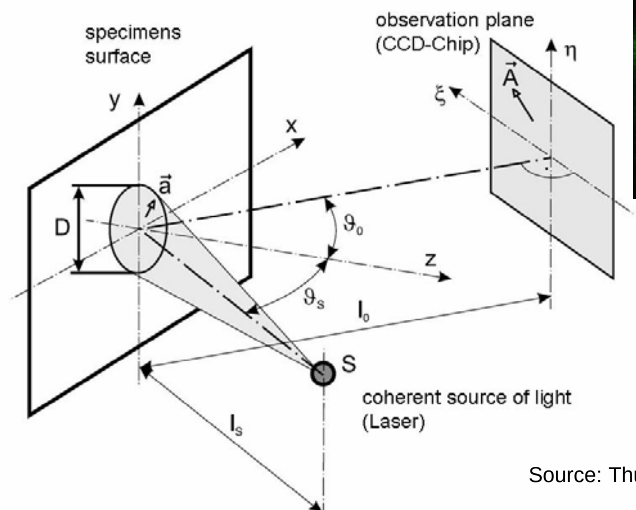
Fibre Bragg Grating



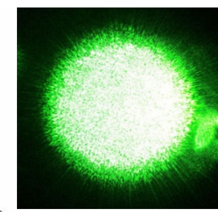
Source: Marti

$$\Delta\varepsilon = \frac{1}{1-p_e} \cdot \left(\frac{\Delta\lambda_B}{\lambda_B} - (\alpha - \zeta) \cdot \Delta T \right)$$

Laser Speckle



Source: Thurner



Source: Wikipedia

Principle geometry for strain measurement with objective Speckles

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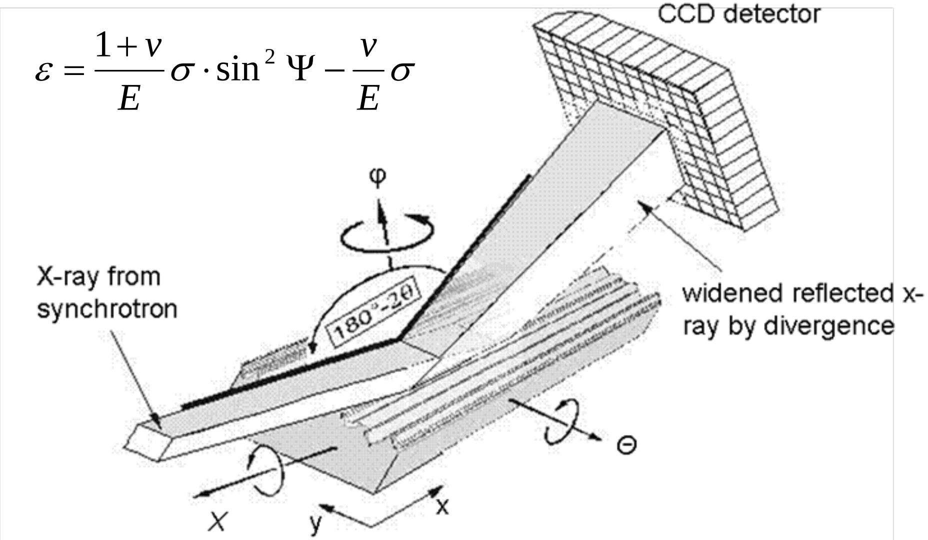
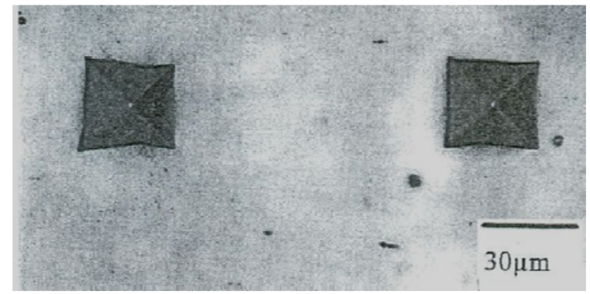
Strain Measurement Methods IV

X-ray Diffraction	Optical



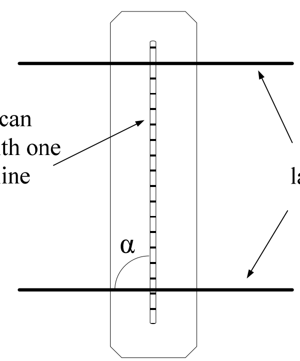
Source: Tönshoff

Set-up to measure strain in the surface zone of a specimen



Source: Ziebs

Vickers micro hardness indentations



Line camera

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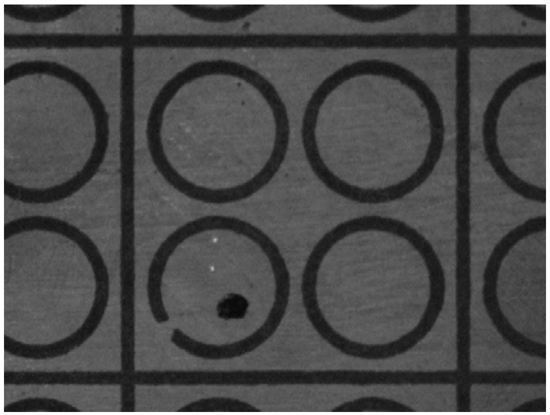
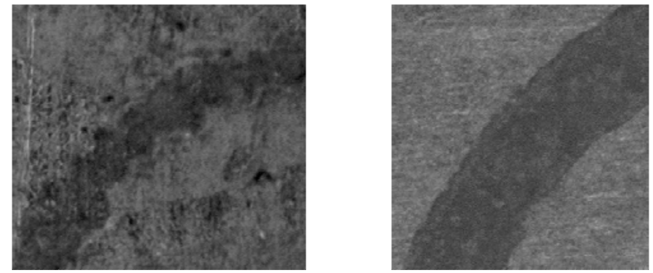
Strain Measurement Methods IV

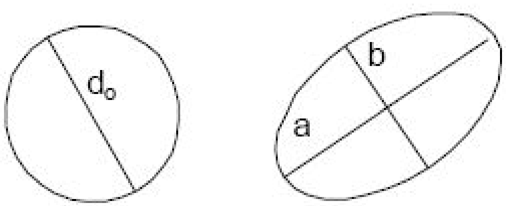
Grid Analysis



Undeformed Ø 2.5mm laser grids with straight laser lines



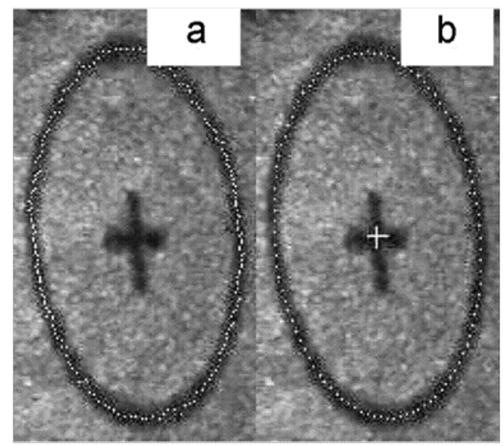
Etched (left) and laser (right) grids shown at 50x magnification, circle radius of 2.5mm



Deformation of a circle grid

$$e_{major}(\%) = \frac{a - d_0}{d_0} \times 100$$

$$e_{minor}(\%) = \frac{b - d_0}{d_0} \times 100$$



Source: Hsu

Fitted ellipses
a: automatic grid acquisition
b: elliptic grid for a MRA

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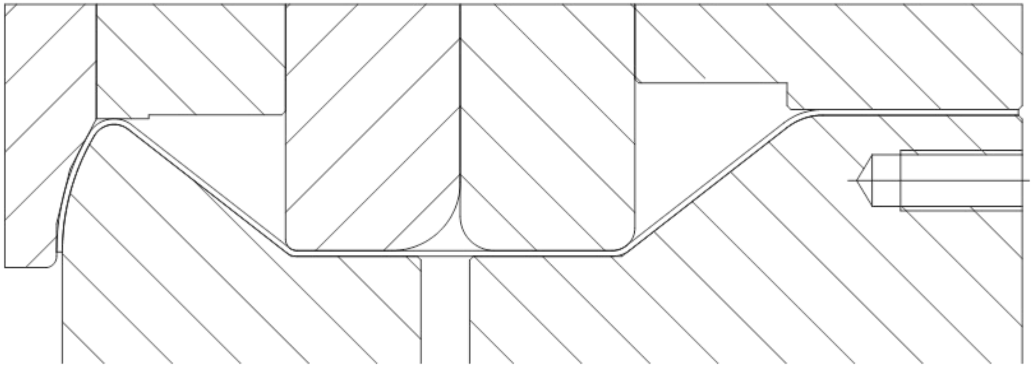
Strain Measurement - Conclusions

Balance between accuracy and cost

Compromise: Strain gauge

laborious preparation, but:



•continuous data
•inexpensive (in comparison)
•well established
•accurate (compared to other inexpensive solutions)
•delivers full set of data (3 directions)

Problem: How to acquire bending strain with one side of the strip inaccessible?

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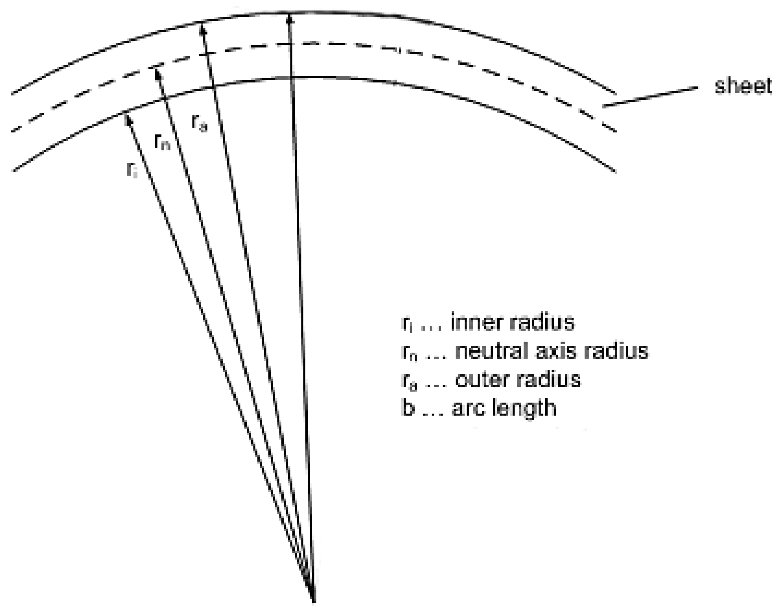
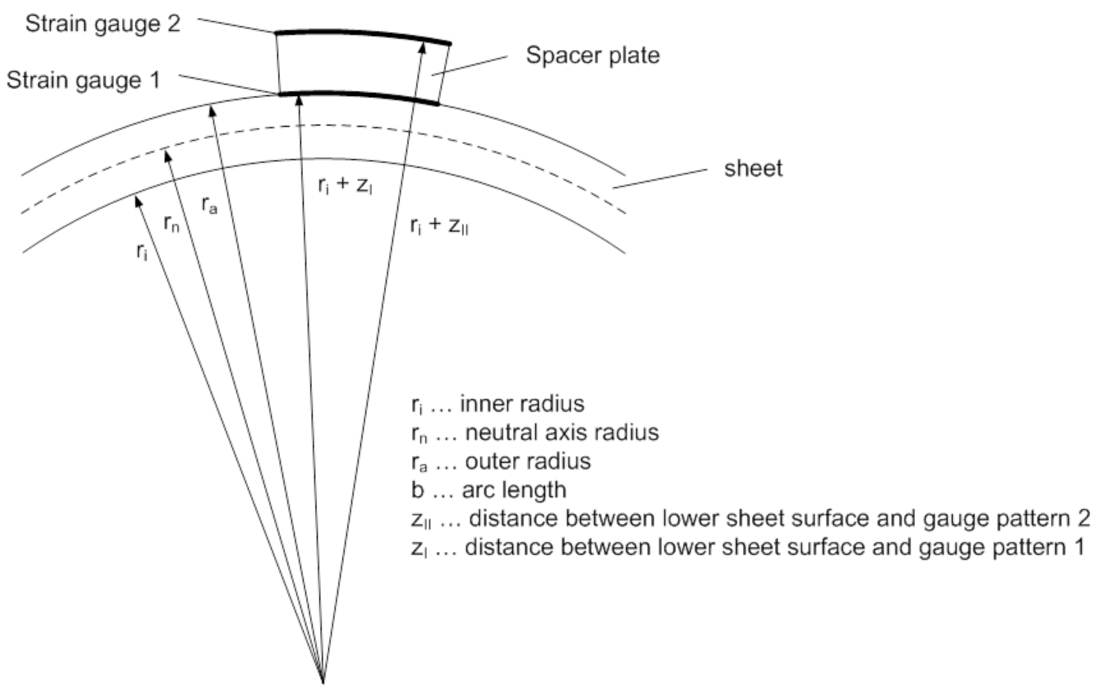
Spacer Plate – Principle I



$$\varepsilon_O(z) = z\left(\frac{\varepsilon_{II} - \varepsilon_I}{z_{II} - z_I}\right) + \left(\varepsilon_I - z_I \frac{\varepsilon_{II} - \varepsilon_I}{z_{II} - z_I}\right)$$

Spacer Plate – Principle I



$$\varepsilon_O(z) = z\left(\frac{\varepsilon_{II} - \varepsilon_I}{z_{II} - z_I}\right) + \left(\varepsilon_I - z_I \frac{\varepsilon_{II} - \varepsilon_I}{z_{II} - z_I}\right)$$

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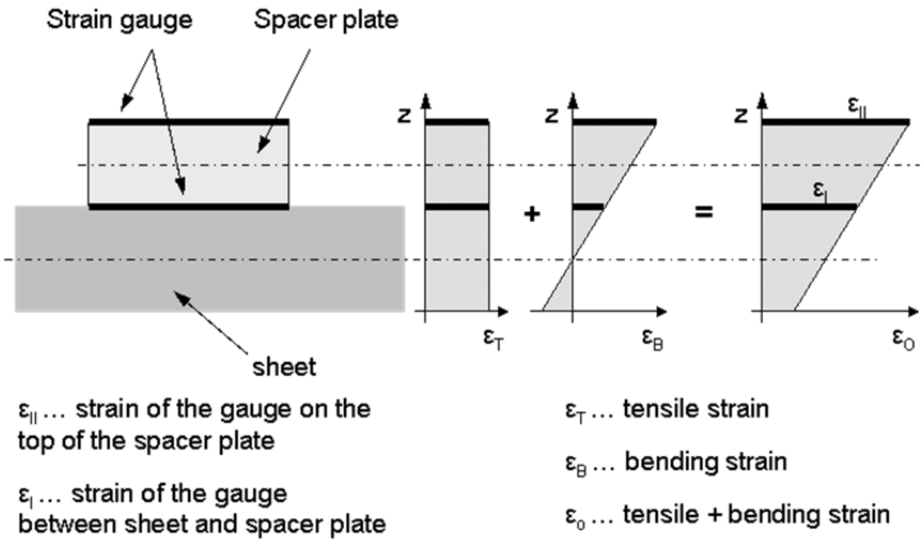
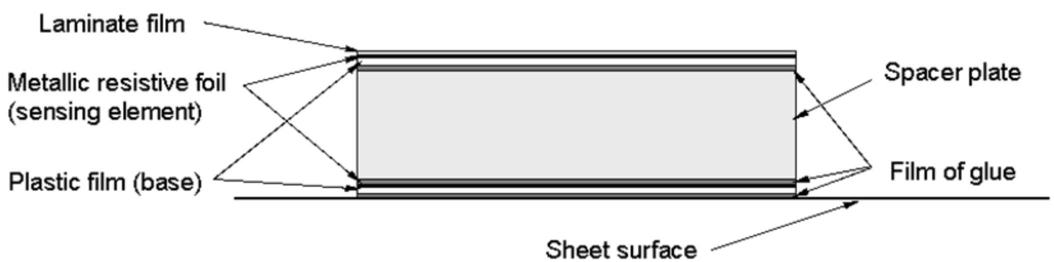
Spacer Plate – Principle II

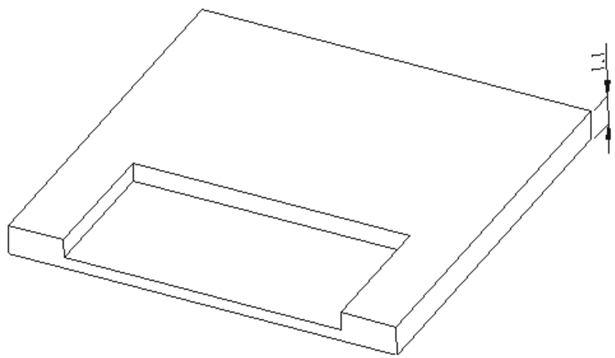


Trend of the strain in a cross-section of sheet and spacer plate

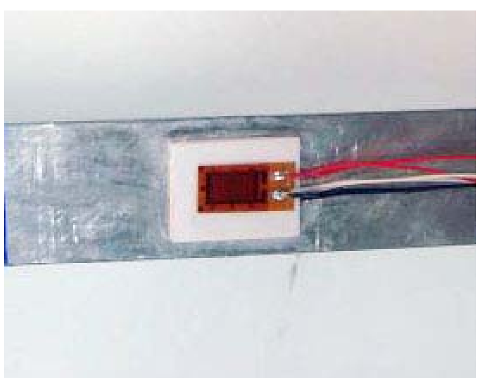


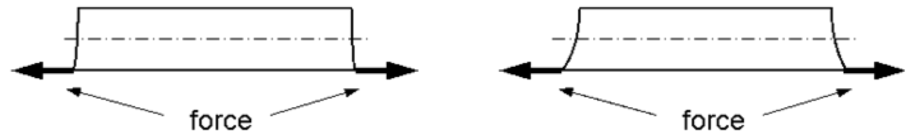
Strain measurement from one side of the sheet

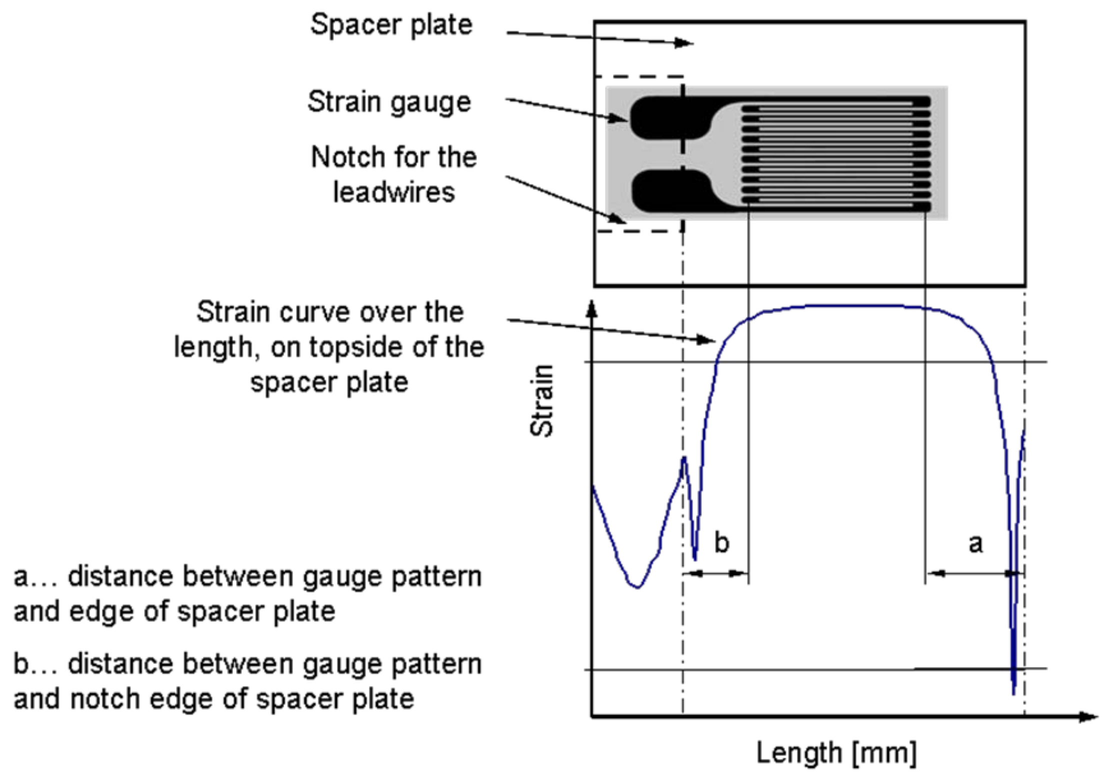
Design of Spacer Plate



ABS spacer plate





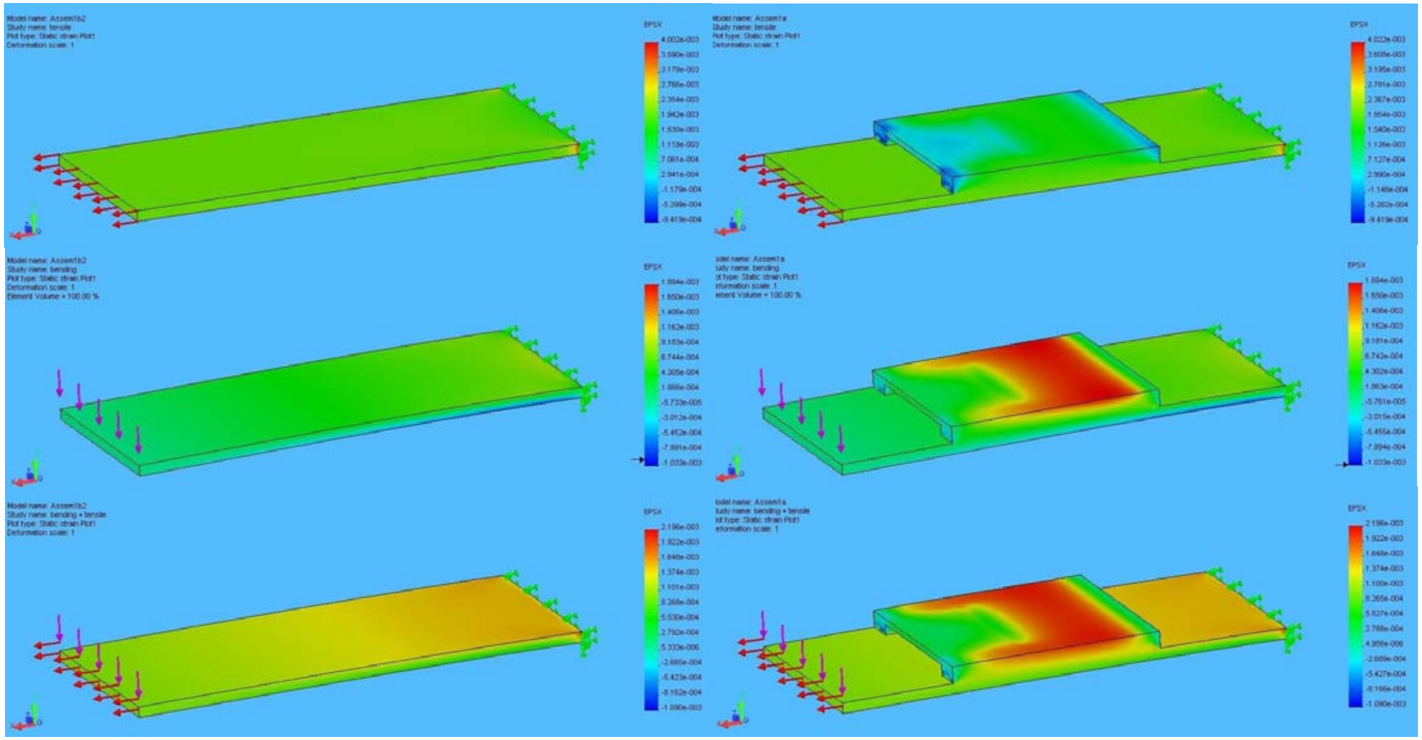


Simulation of Spacer Plate I

tensile

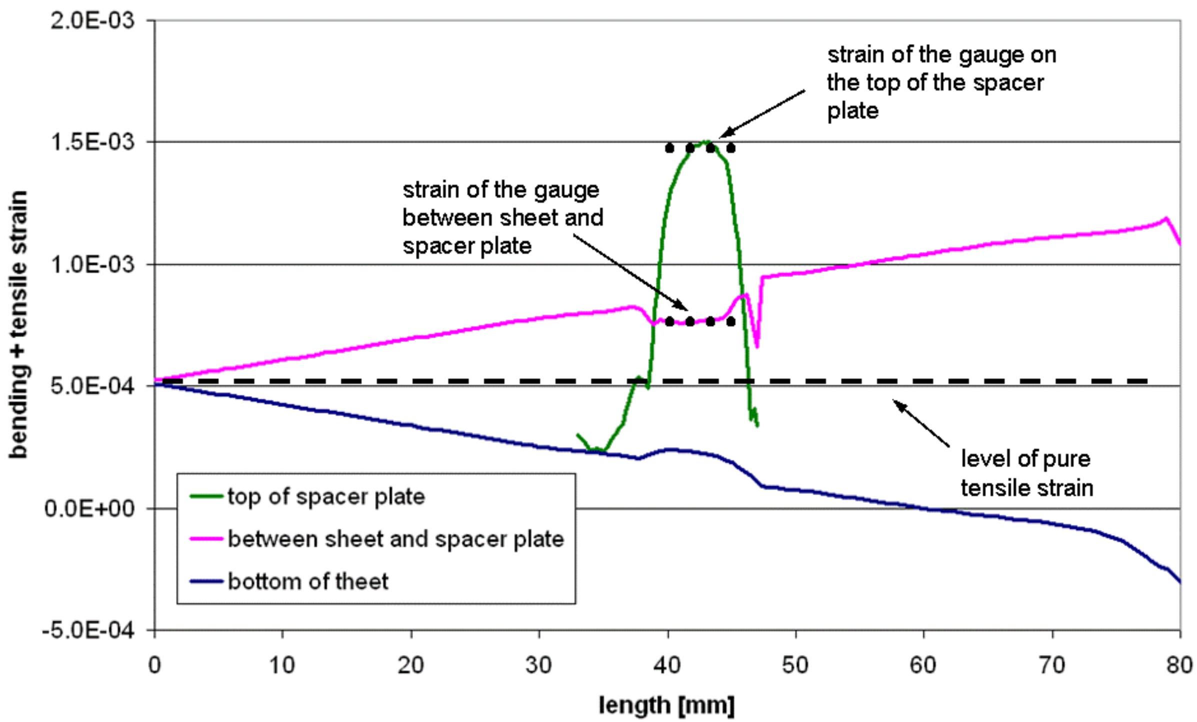
bending

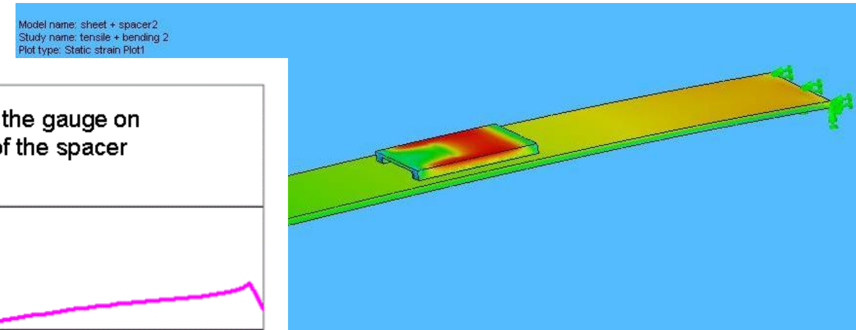
tensile + bending



Simulation of the strain layout during deformation with and without applied spacer plate on the sheet

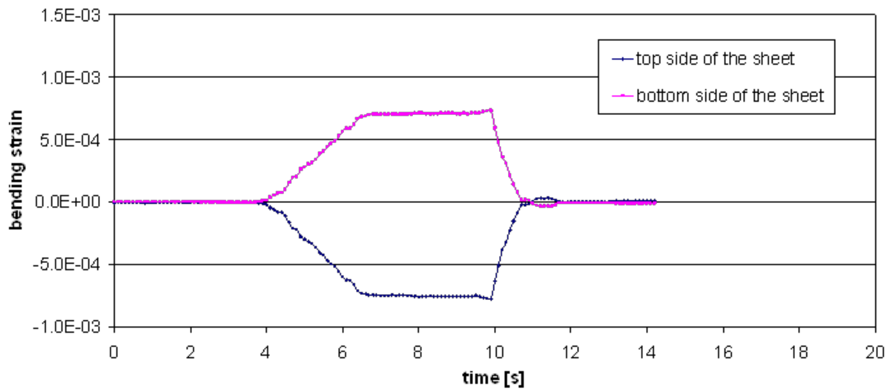
Simulation of Spacer Plate II



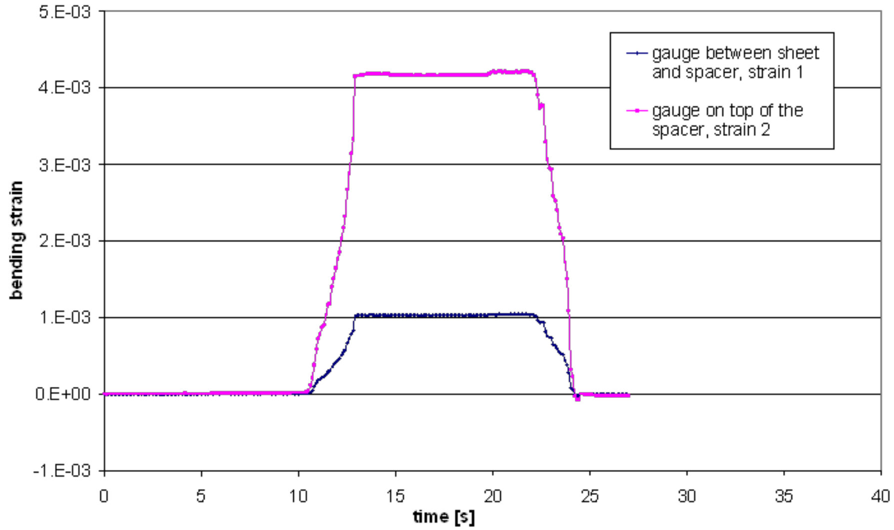


Strain in x direction (xy-plane, centre)
3.5N shear force, 1625N tensile force,
14mm long spacer plate

Accuracy of Measurement



Bending, one strain gauge on each side



Bending, two strain gauges and spacer plate on one side of the specimen

Bending strain can be measured with accuracy of ±3%

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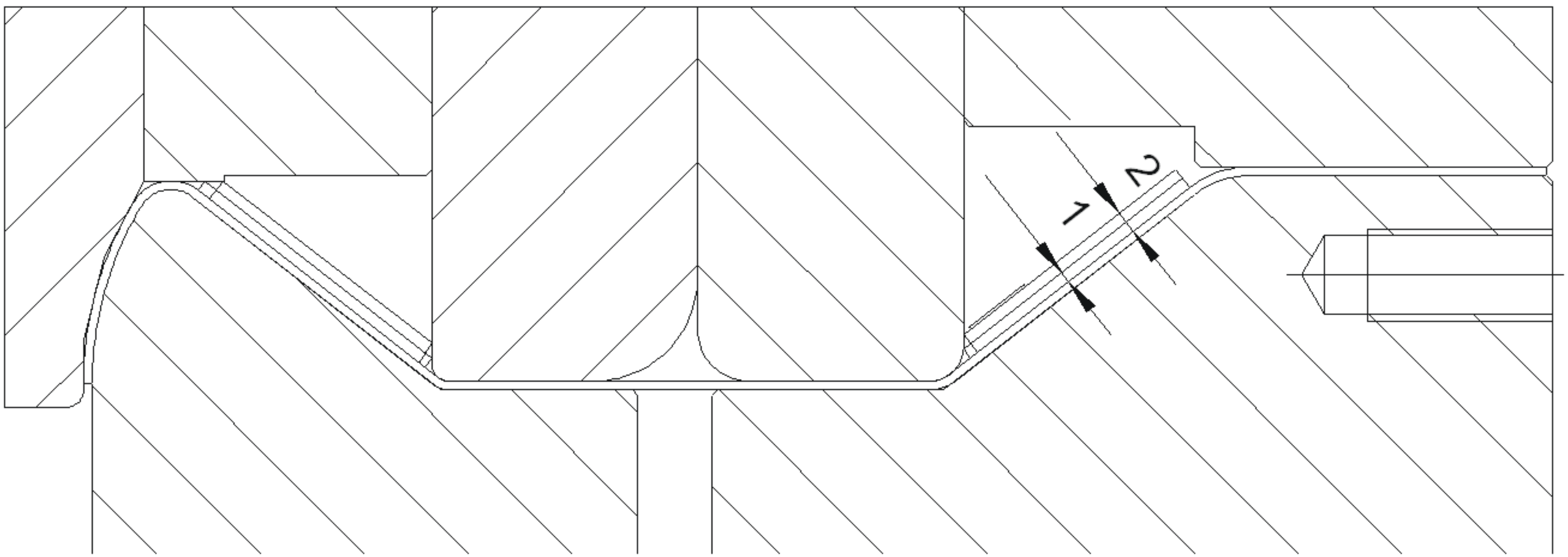
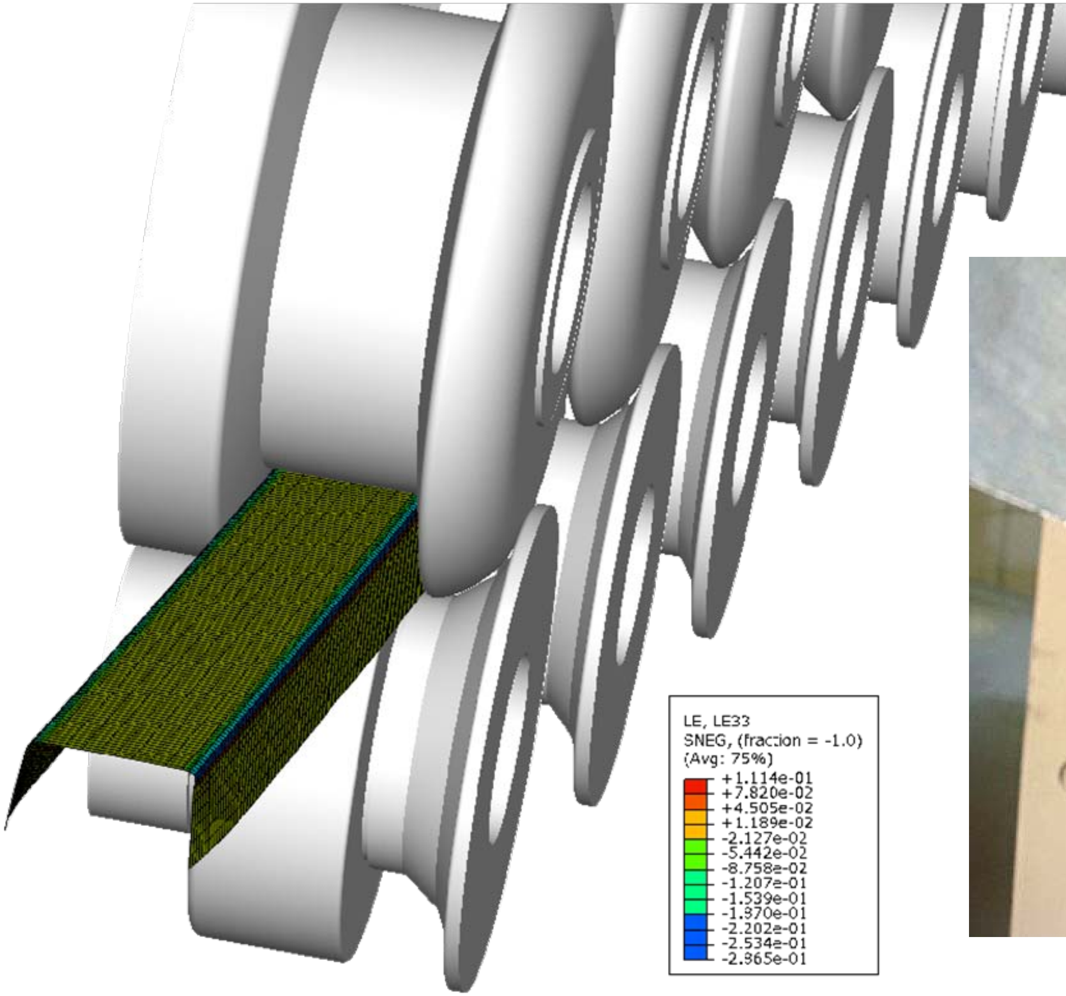
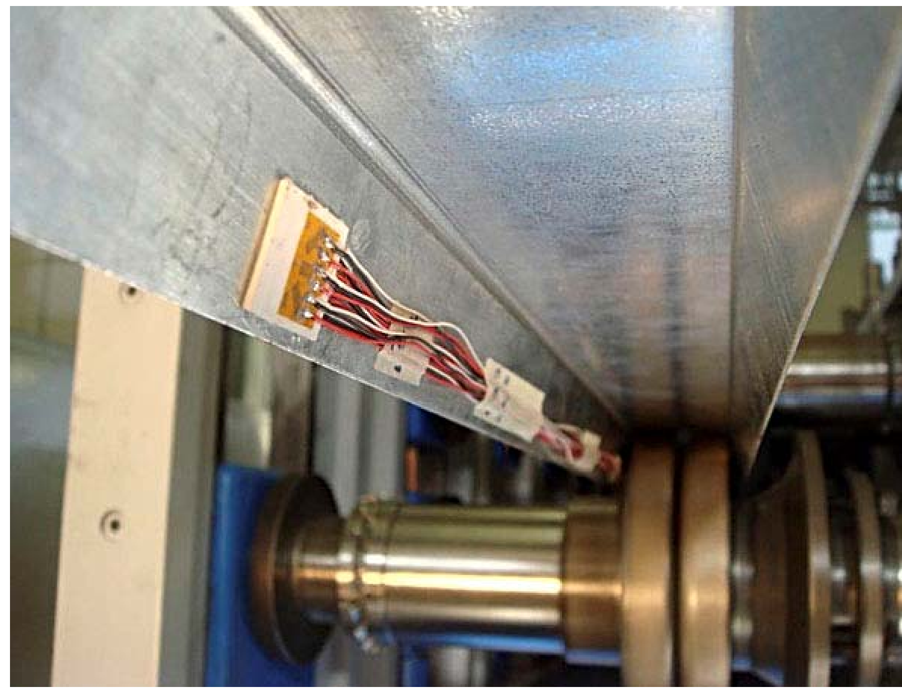
Spatial Constraints in Roll Former



Application of strain gauge device





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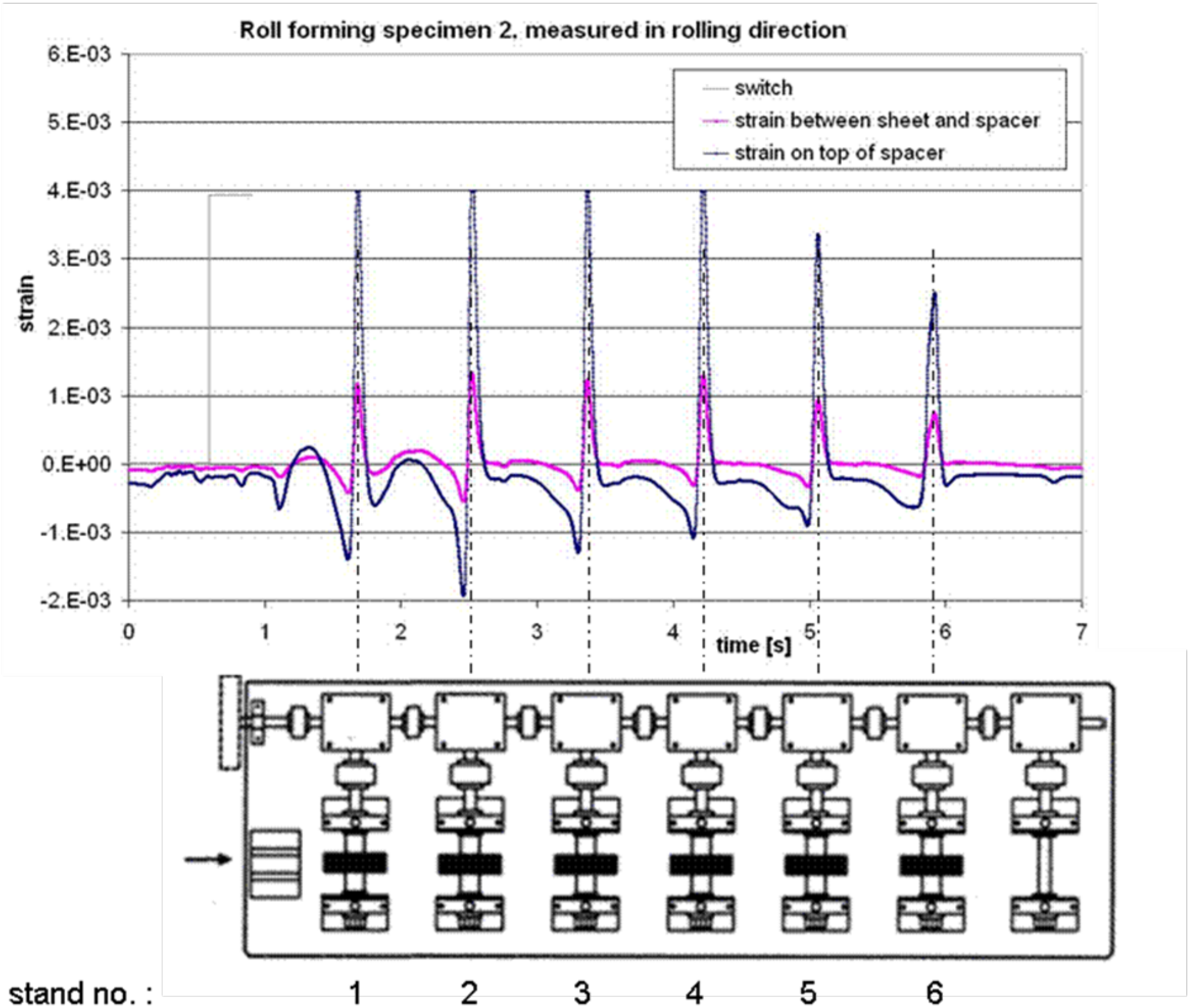
Measured Longitudinal Strain



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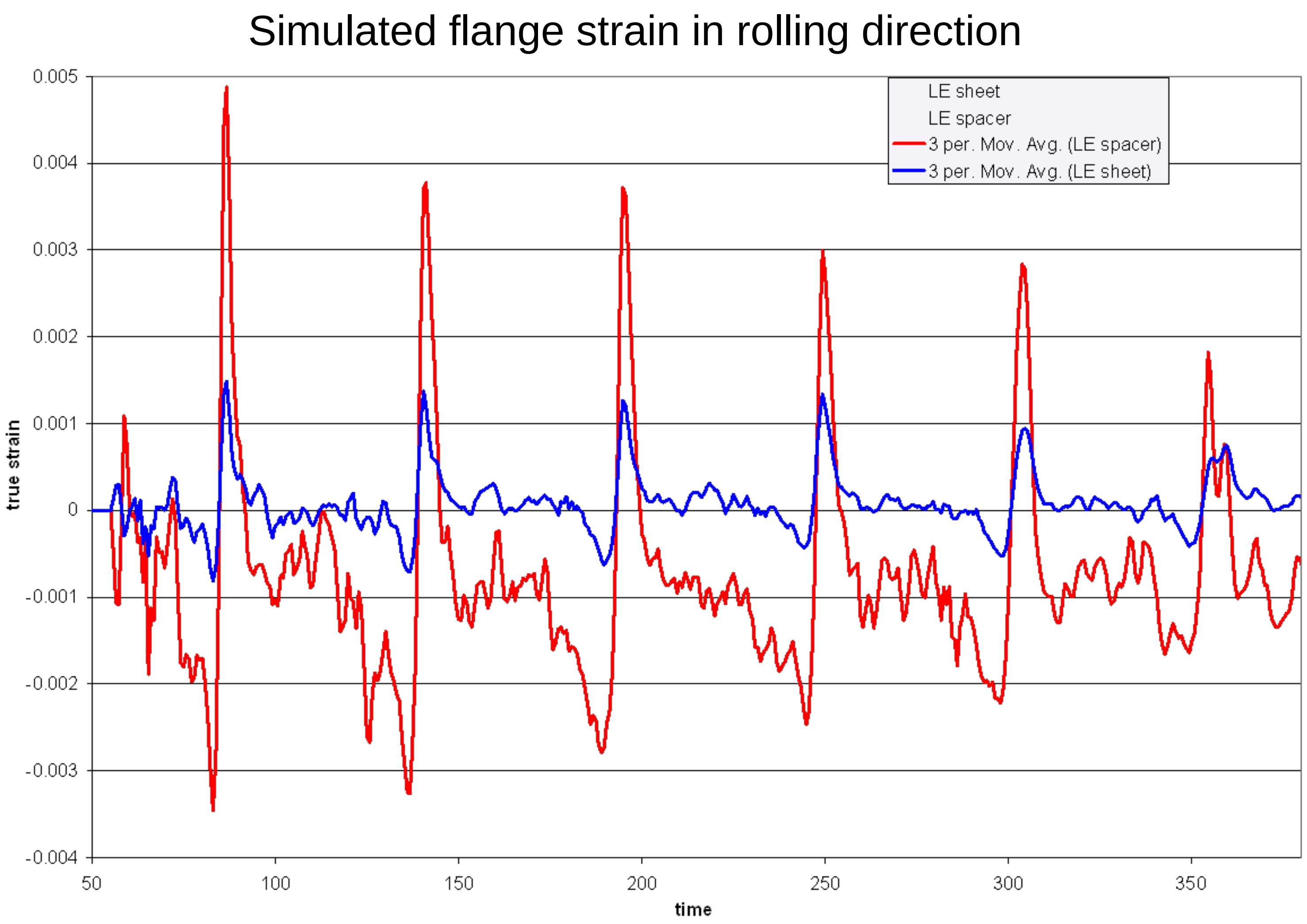
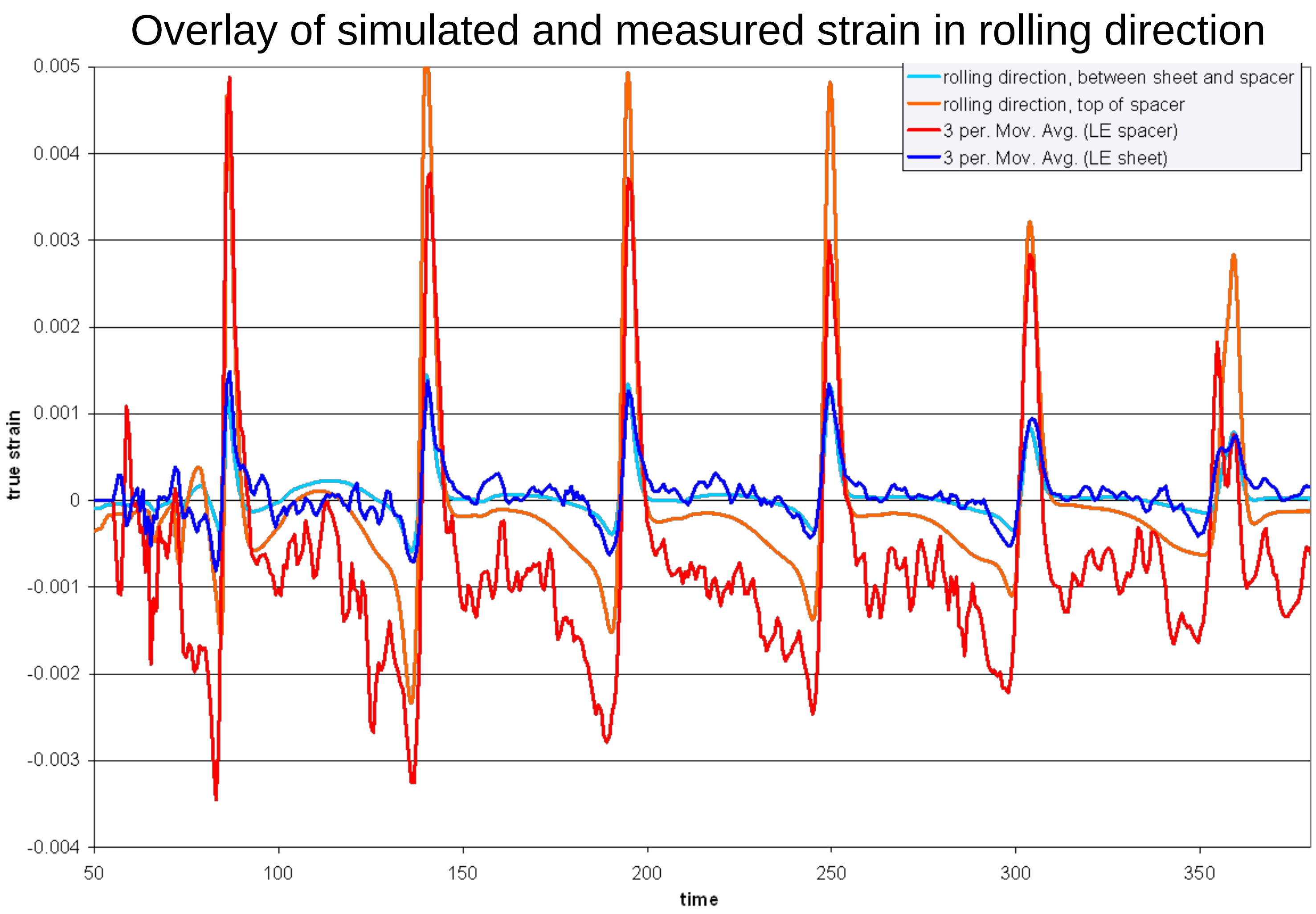
Simulated Longitudinal Strain



Longitudinal Strain



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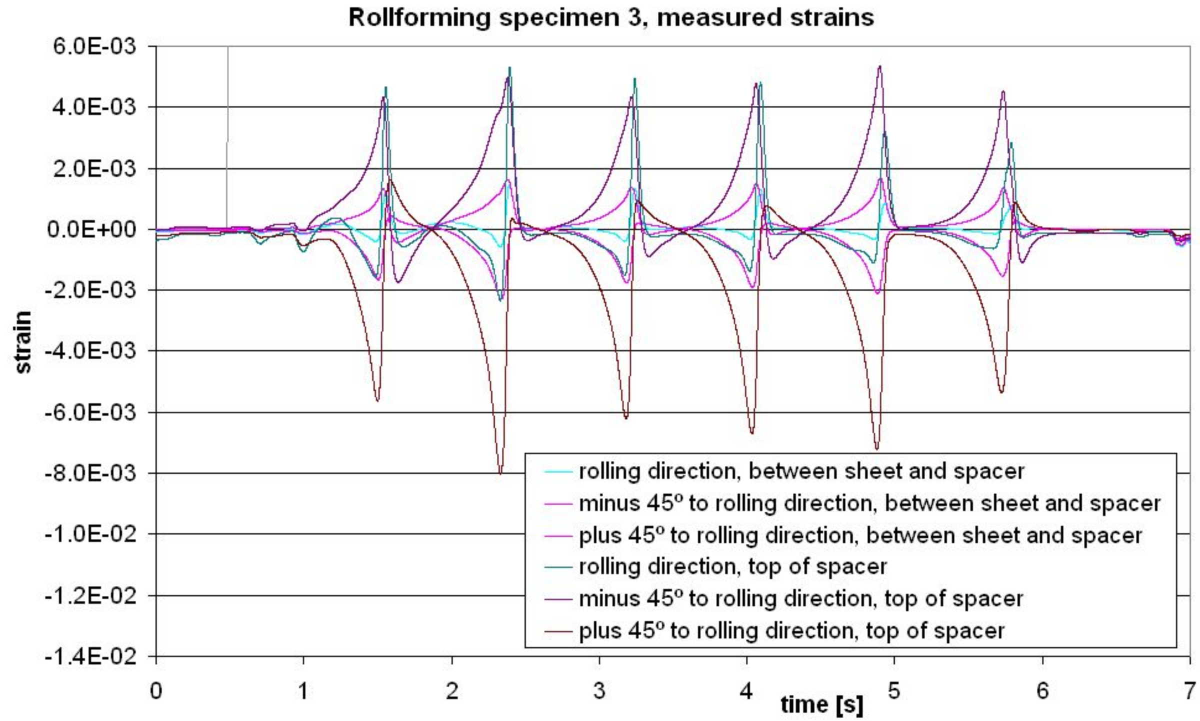
Principal Strain



$$\varepsilon_{\mathrm{I,II}} = \frac{\varepsilon_A + \varepsilon_C}{2} \pm \frac{1}{2}\sqrt{2}\sqrt{\left(\varepsilon_A - \varepsilon_B\right)^2 + \left(\varepsilon_B - \varepsilon_C\right)^2}$$

$$\tan 2\phi = \frac{\varepsilon_A - 2\varepsilon_B + \varepsilon_C}{\varepsilon_A - \varepsilon_C}$$

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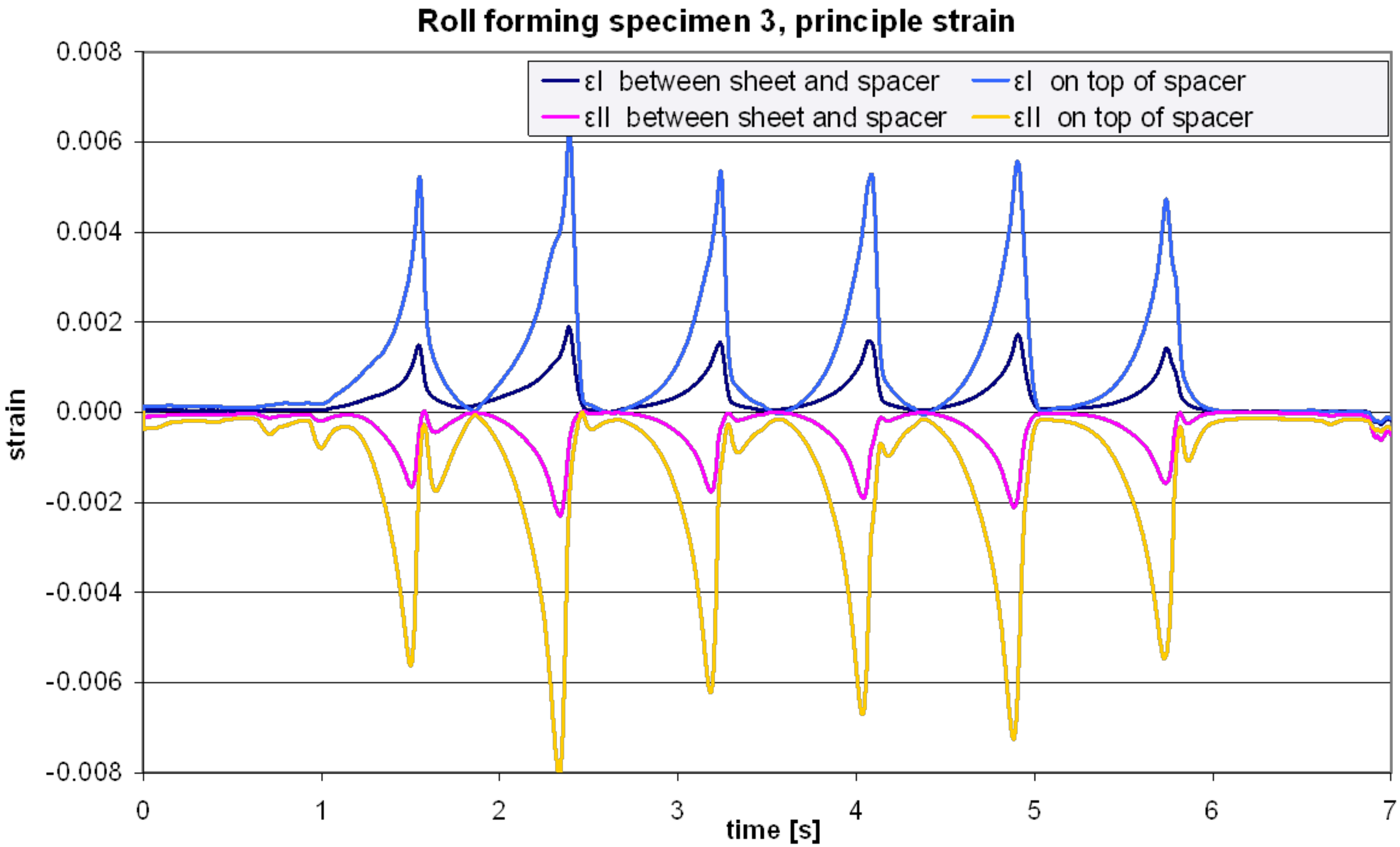
Principal Strain - Measured



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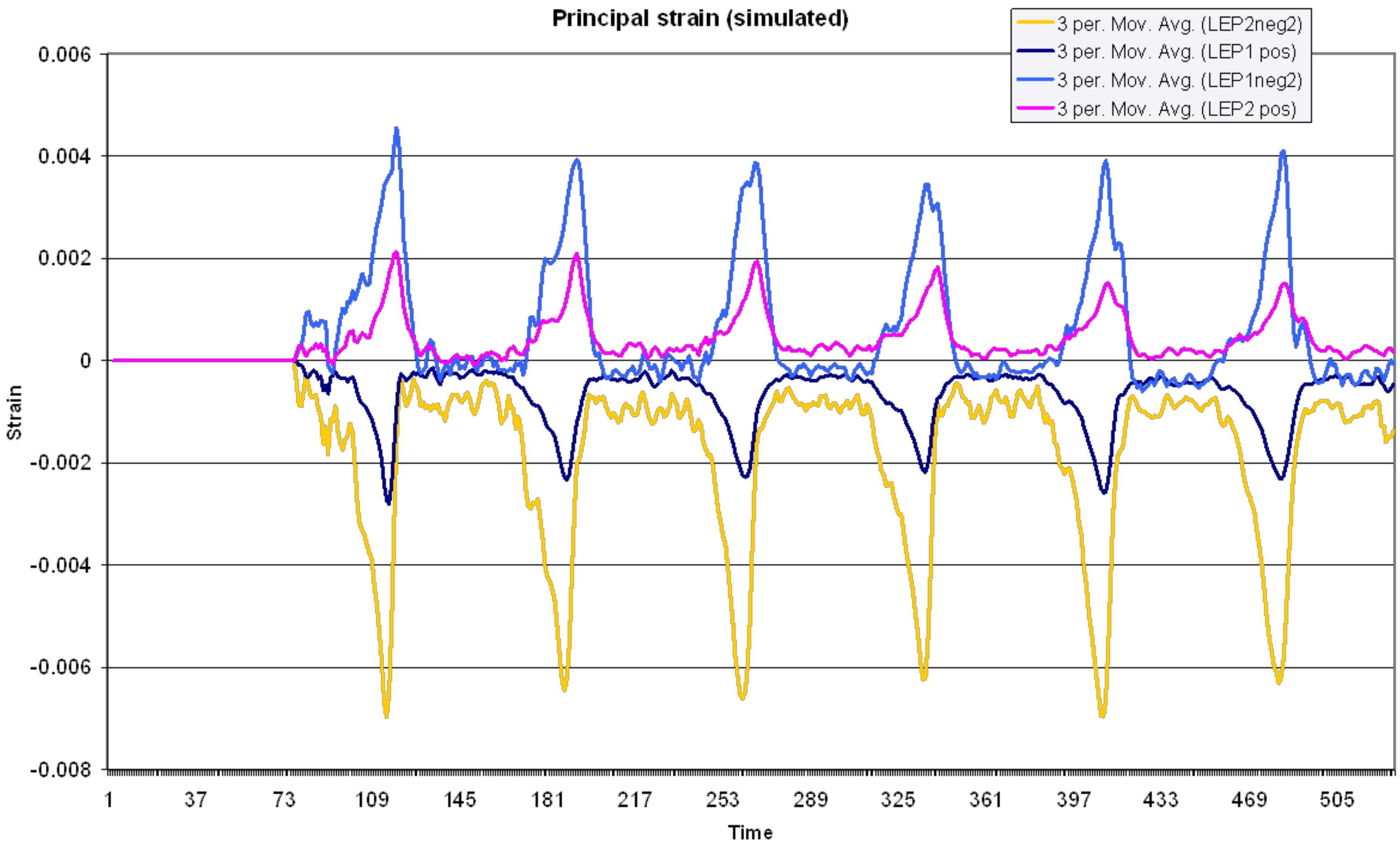
Principal Strain - Simulated



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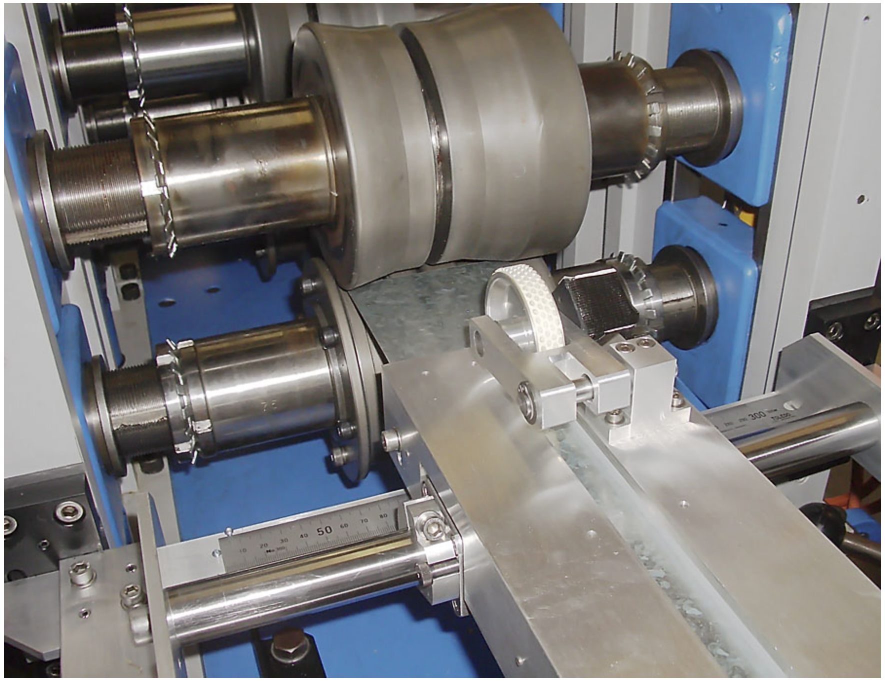
Summary and future work

- Review of strain measurement methods
- Design of strain gauge device that acquires all desired data from one side of the strip
- Agreement between measurements and simulation

- Gather data under conditions that generate geometric deviations
- Develop rules for corrective intervention



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