ESPI assisted Hole Drilling Method

for

Residual Stress Measurement

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Hole Drilling Method

- Measurement of the in-plane strain relaxation produced by hole drilling
- Estimation of the residual stress by evaluating the strain relaxation data
- Incremental drilling and measurement provides an estimate of the variation of stress with depth

Advantages

Advantages of the ESPI assisted strain relaxation measurement:

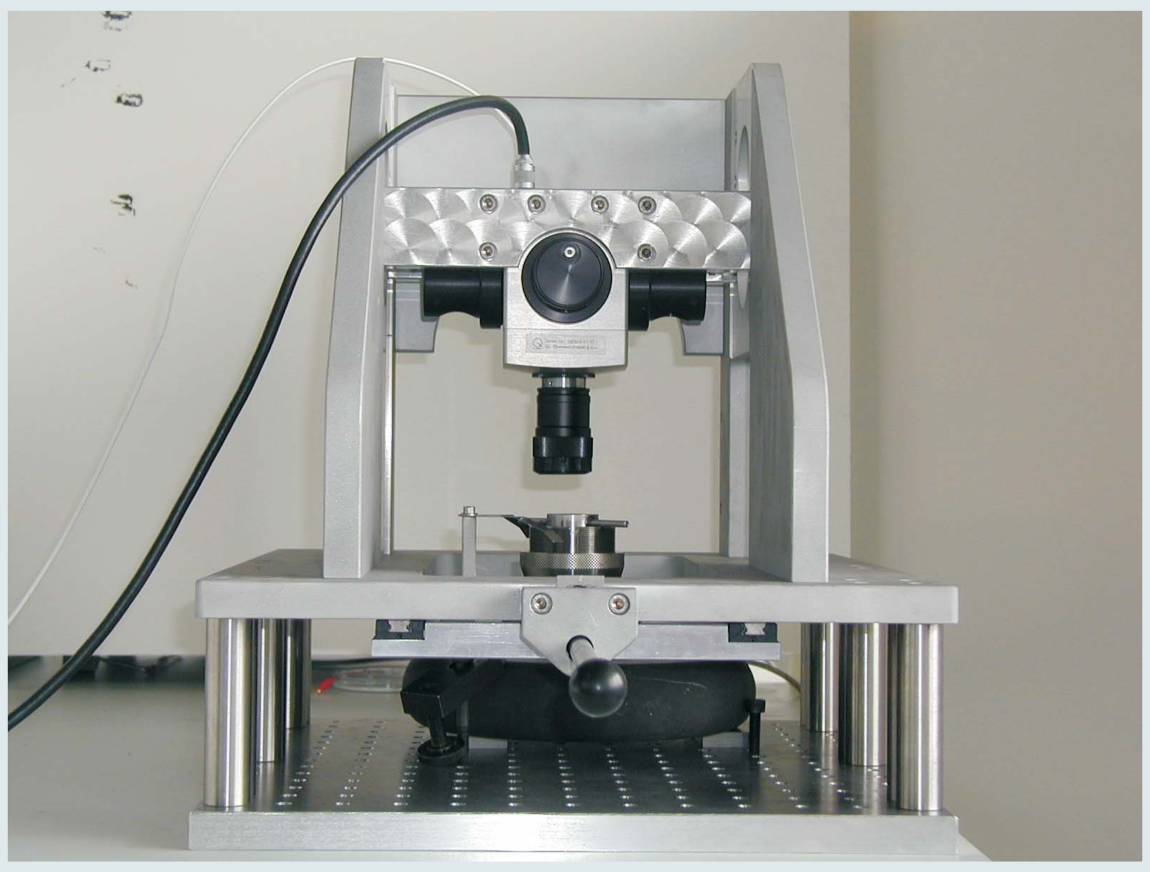
- No surface preparation
- No application of strain gage
- No wiring
- No alignement of the drilling axis
- Non-contact optical measurement
- Increased number of data
  → noise reduction, enhanced calculation accuracy

Requirements

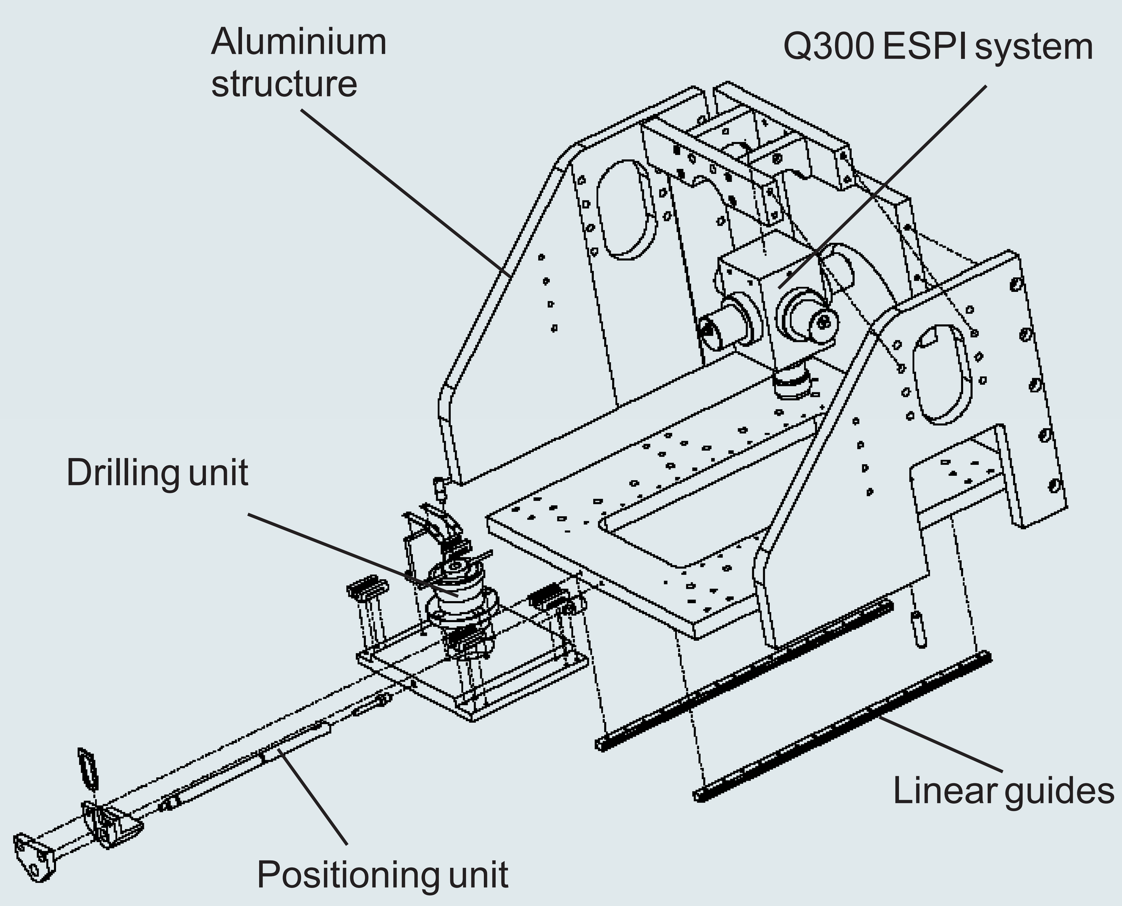
Requirements to the ESPI system:

- highest sensivity
- measurement field: approx. 20 x 20 mm^2

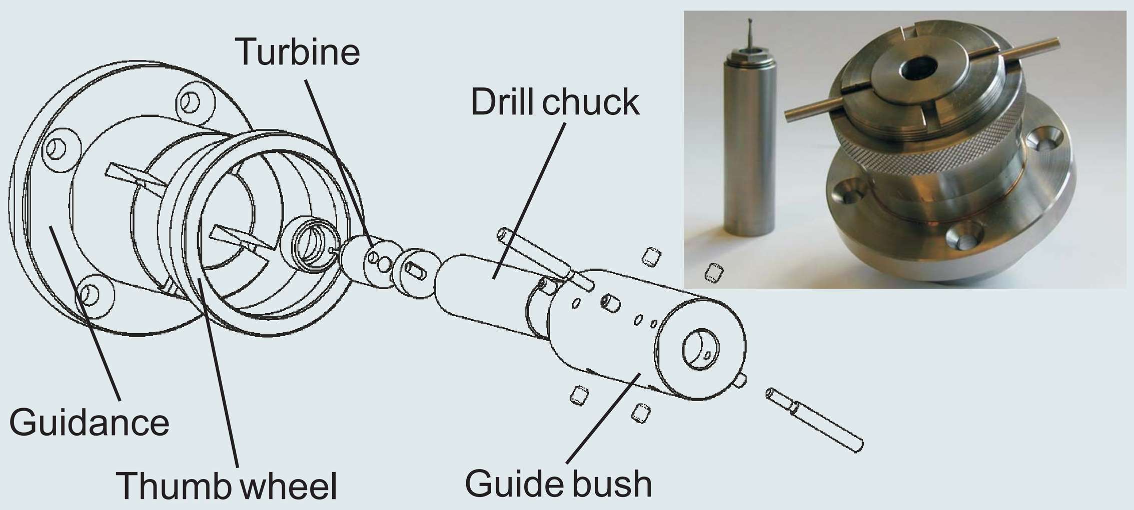
Experimental Setup



Structure and mechanical devices:



Drilling unit:



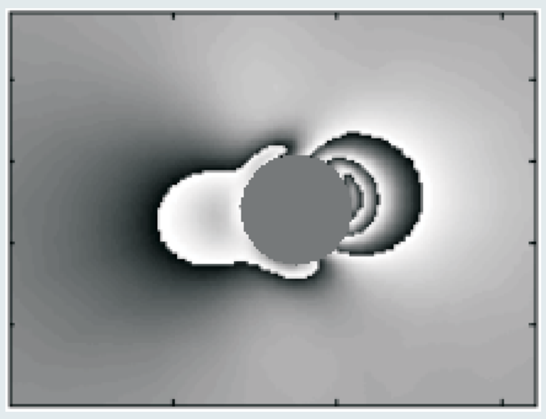
Characteristics:

- High positioning accuracy of the drilling unit
- High stiffness of the overall structure
- Vertical and horizontal usage possible
- Flexible mounting of the specimen
- Low maintenance
- No electronical devices
- Transportable

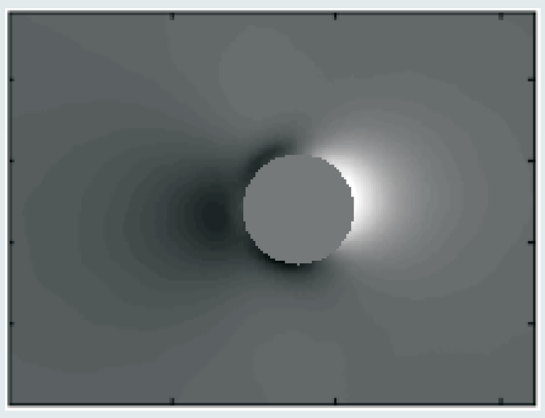
Evaluation of the relaxation data - Solving an inverse problem

Measurement of the relaxation data

The relaxed inplane deformation around the blind hole is recorded after each drilling step.



Fringe pattern



Radial displacement

The radial displacement component u_r at a chosen radius r_m leads to the transformed deformation variables

$$u_p(h) = \frac{1}{2\pi}\int_0^{2\pi} u_r(r_m)\,d\varphi$$

$$u_q(h) = \frac{1}{2\pi}\int_0^{2\pi} u_r(r_m)\,\cos(2\varphi)\,d\varphi$$

$$u_t(h) = \frac{1}{2\pi}\int_0^{2\pi} u_r(r_m)\,\sin(2\varphi)\,d\varphi$$

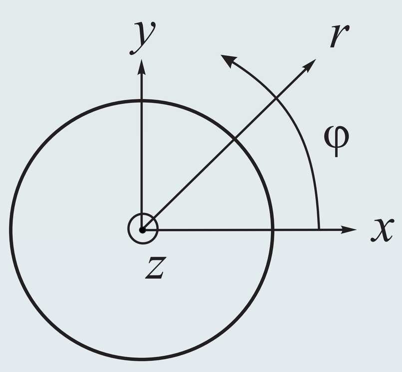
Estimation of the residual stresses

The stress state is specified by the transformed stress variables:

$$P = \frac{\sigma_x + \sigma_y}{2}$$

$$Q = \frac{\sigma_x - \sigma_y}{2}$$

$$T = \sigma_{xy}$$



Considering a linear elastic contitutive law, the transformed stress variables are associated with the deformation variables by the following integral

$$u_p(h) = \frac{1+\nu}{E}\int_0^h \bar{A}(H,h)\,P(H)\,dH$$

$$u_q(h) = \frac{1}{E}\int_0^h \bar{B}(H,h)\,Q(H)\,dH$$

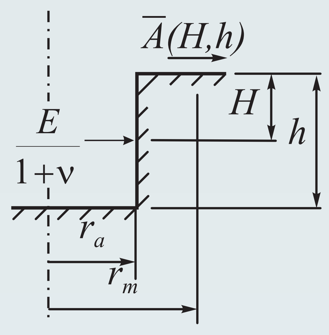
$$u_t(h) = \frac{1}{E}\int_0^h \bar{B}(H,h)\,T(H)\,dH$$

Following the concept of the integral method, the discretization of these relationships into finite depth increments leads to a linear system of equations. The displacement relaxation functions $\bar{A}$ and $\bar{B}$ can be obtained numerically by FEM analysis.

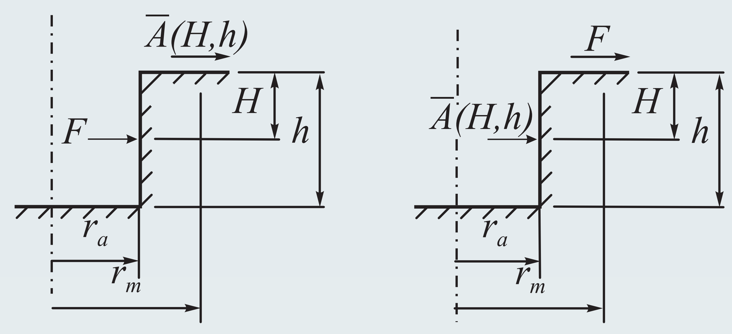
Calculation of the calibration data

$\bar{A}(H,h)$ can be interpreted as displacement caused by a loading

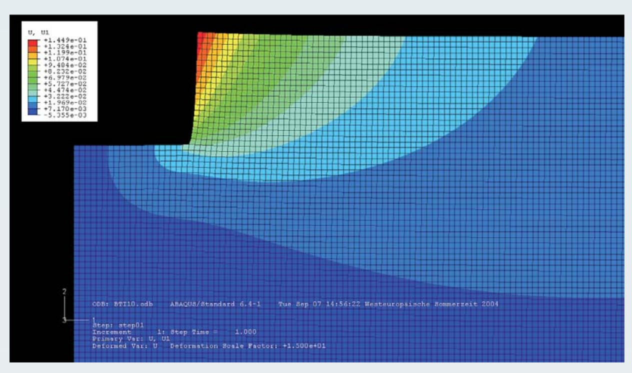
$$p(H) = \frac{E}{1+\nu}\delta(H)$$



Using Maxwells reciprocity theorem the displacement relaxation function for the drilling depth h can be estimated with a single FEM-analysis.



Application of Maxwells reciprocity theorem



Finite Element Model [radial displacements]