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TITLE

RESIDUAL STRESS DETERMINATION BY NON-DESTRUCTIVE METHODS SENSORS: NUMERICAL MODELING AND CONSTRUCTION

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Residual Stress Determination by Non-Destructive Methods
Sensors: Numerical Modeling and Construction

by

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ABSTRACT

Three methods of nondestructive residual stress determination, X-ray Diffraction (XrD), Magnetic Barkhausen Noise (MBN), and Electromagnetic Acoustic Transduction (EMAT) were used to determine known applied (through four-point jigs) stress states or residual stress states in steel and aluminum specimens and parts of steel engineering components. The results were compared with the stress states determined by two destructive methods, Hole Drilling Method (HDM), and Cut-and-Section Method (CSM).

There was a two-part objective of this study: 1) to assess the accuracy of the methods on known stress states, and 2) apply the methods to unknown stress states. The known stress states were applied to steel and aluminum specimens with simple geometries, such as slender bars and/or plates, instrumented with strain gauges, subjected to four-point bending, so that the surface stress components were calculated directly from strain readings and the unknown stress states were determined in such parts of engineering components as angled strips that are used to make high voltage transmission towers in Canada, and rolled steel that is used to make thin-wall pipes.

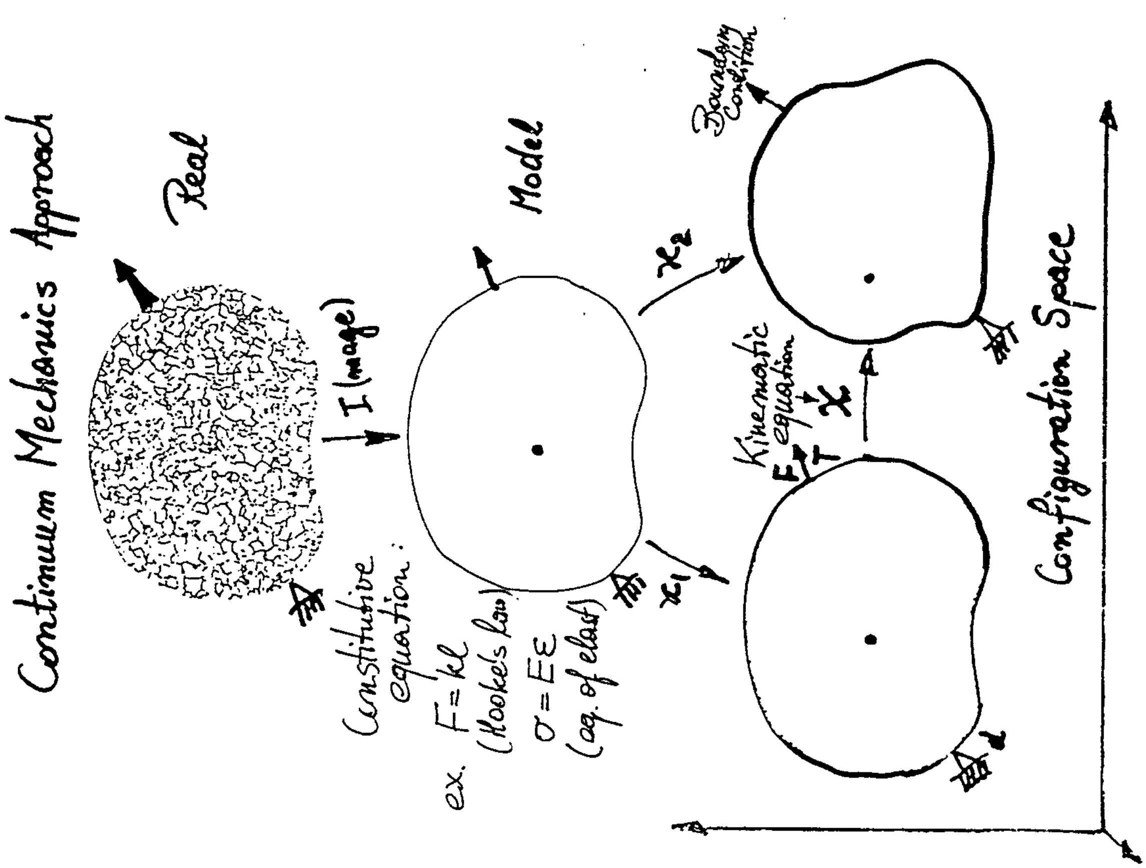
The known stress states in the instrumented steel plates were determined by MBN and XrD, and in the aluminum bars by EMAT and XrD, whereas the unknown stress states were determined in the rolled steel by XrD and HDM, and in the angled strips by XrD, MBN, HDM, and CSM. The results indicate an adequate correlation between the determined stress states within acceptable engineering error bounds of 5-10%.

To be able to tune EMAT sensors to work in steels, numerical modeling was applied to understand better their (EMAT's) impulse generation in magnetostrictive materials and acoustic wave propagation caused by the impulse.

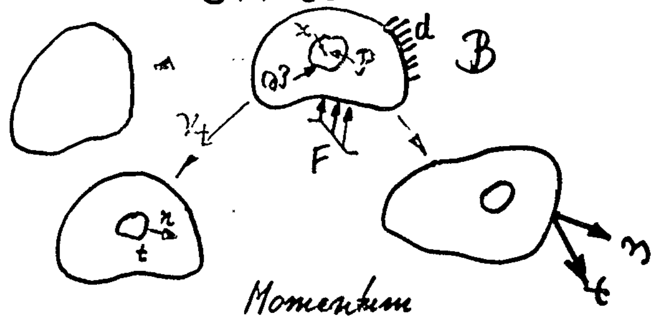
Nondestructive Methods:

1) X-ray Diffraction;
2) Magnetic Barkhausen Noise;
3) Acoustoelastic - Electromagnetic Acoustic Transducers

Destructive Methods:
1) Hole Drilling; and
2) Cutting



Stress State



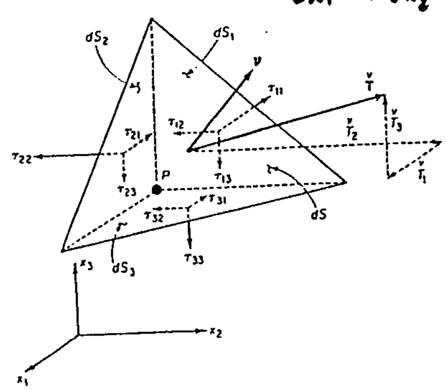
Momentum

$$\forall_t \forall_{P \subset B} \frac{d}{dt}\int_{\chi_t(P)} \rho v \, dV = \int_{\chi_t(P)} \rho b \, dV + \int_{\chi_t(\partial P)} t \, dS$$

Traction vector $\rightarrow t = \tau \cdot n \leftarrow$ normal to surface vector
(τ: Stress tensor)

$$\forall_t \forall_{x \in B} \left(\frac{\partial v}{\partial t} + (\nabla v)v\right) = \rho \dot{v} = \rho b + \operatorname{div} \tau$$

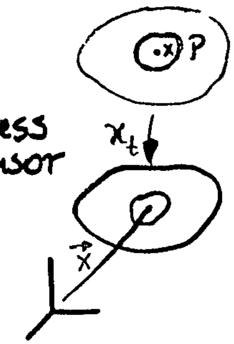
$$\operatorname{div}\tau = \frac{\partial \tau_{11}}{\partial x_1} + \frac{\partial \tau_{21}}{\partial x_2} + \frac{\partial \tau_{31}}{\partial x_3}$$



In static equilibrium $\dot{v} = 0$.
If there are no body forces, $b = 0$, then

$$\forall_t \forall_{P \subset B} \int_{\chi_t(\partial P)} t \, dS = 0$$

$t \rightarrow n\sigma \leftarrow$ stress tensor



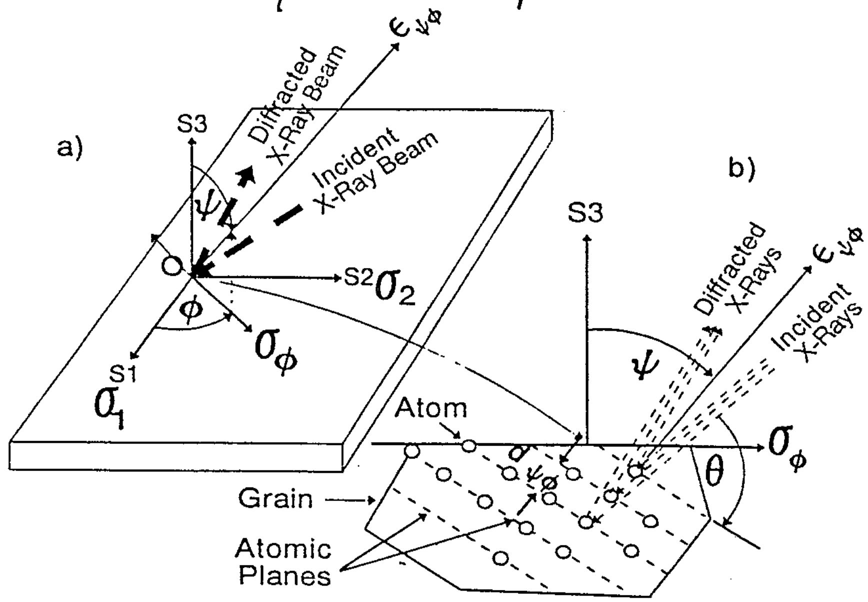
Moment of Momentum

$$\forall_t \forall_{P \subset B} \int_{\chi_t(\partial P)} \vec{x} \wedge t \, dS = 0$$

Exterior multiplication: $\vec{x} \otimes t - t \otimes \vec{x}$

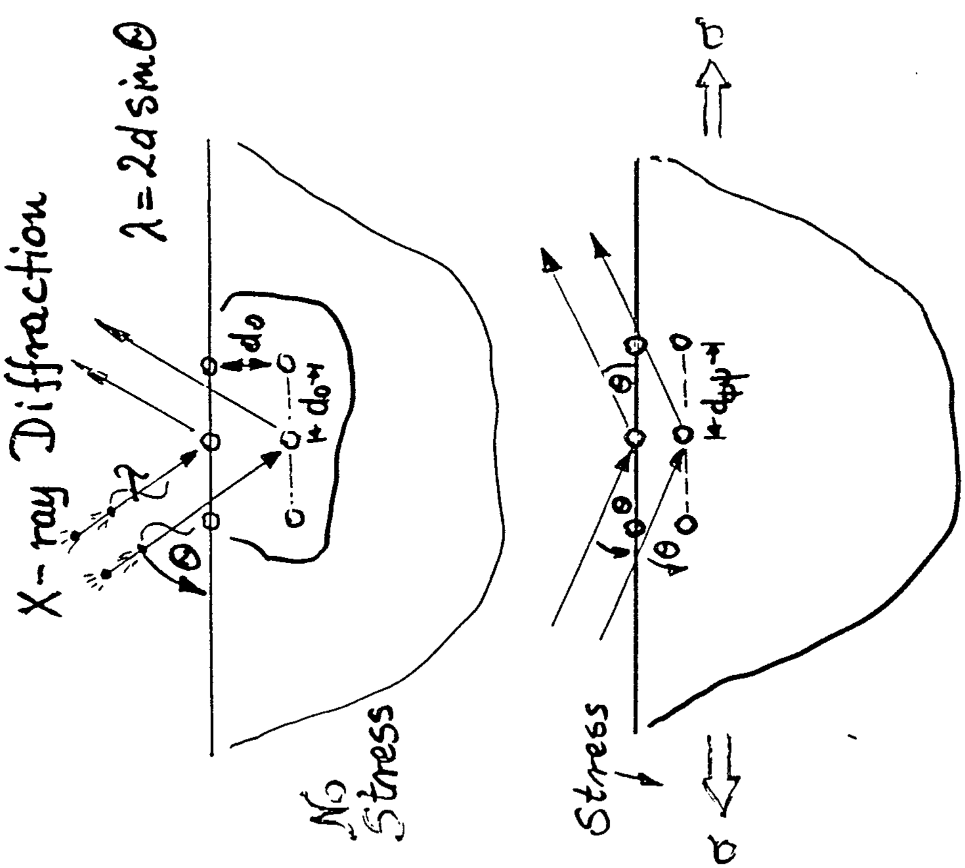
Residual Stress – Stress State that results in the body if all external effects are removed

$\sin^2\psi$ - technique

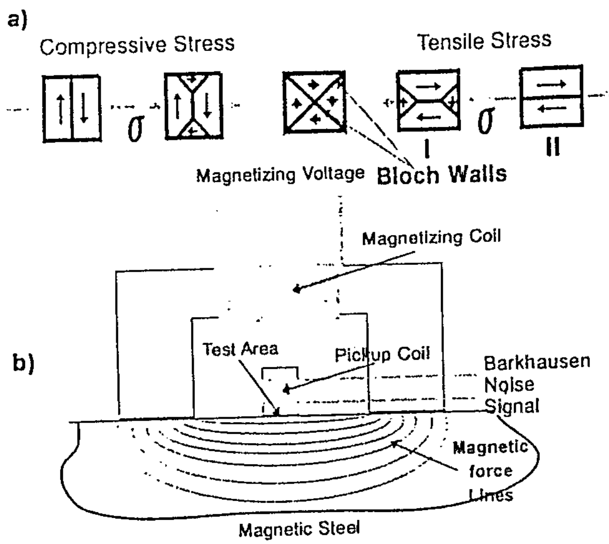


a) Diffraction of X-rays, b) Angular relations between measured strain, stress state, and X-rays in a grain.

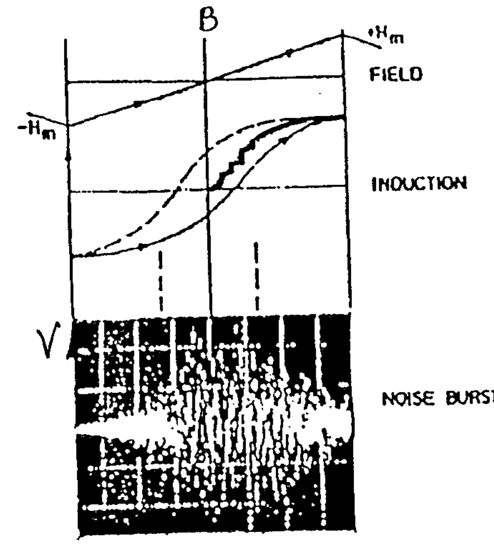
$$\varepsilon_{\psi\phi} = \frac{d_{\psi\phi} - d_o}{d_o} = \frac{1+\nu}{E}\,\sigma_\phi \sin^2\psi - \frac{\nu}{E}\left(\sigma_1 + \sigma_2\right)$$

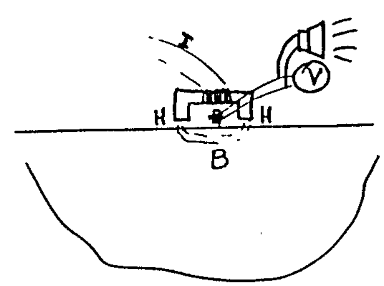


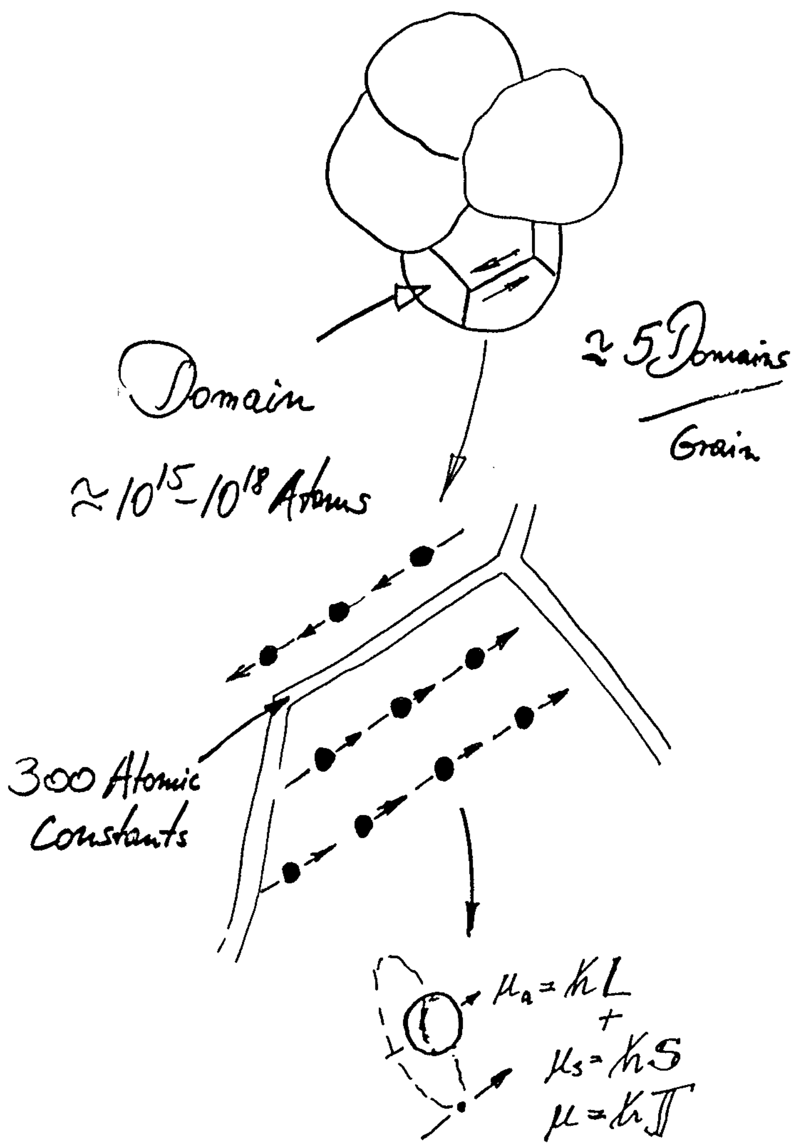
Magnetic Barkhausen Noise (MBN)



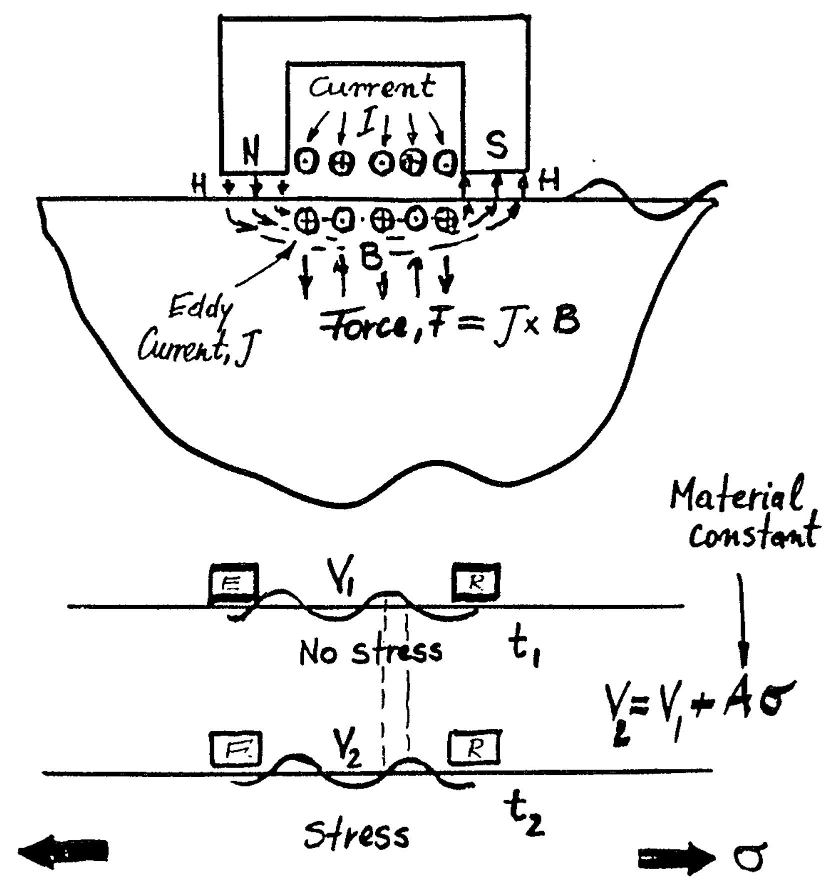
a) Effect of stress on displacement of magnetic domains along Bloch Walls, b) Setup to measure Magnetic Barkhausen Noise

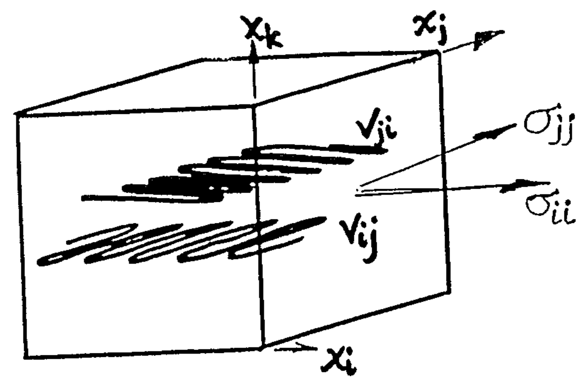






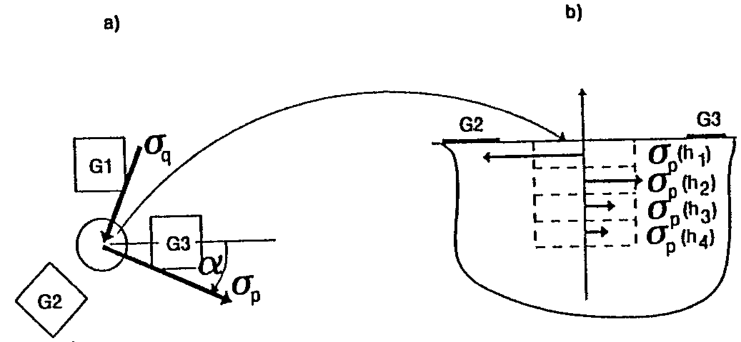
EMAT Stress Determination– Surface Waves





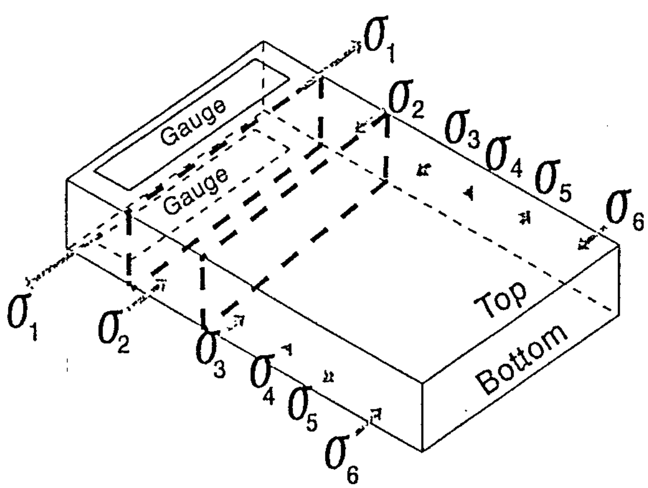
$$\sigma_{ii} - \sigma_{jj} = 2\, C_{ij} C_{ij} \left(\frac{V_{ij} - V_{ji}}{V_{ij}^{o}} \right)$$

Hole Drilling Method

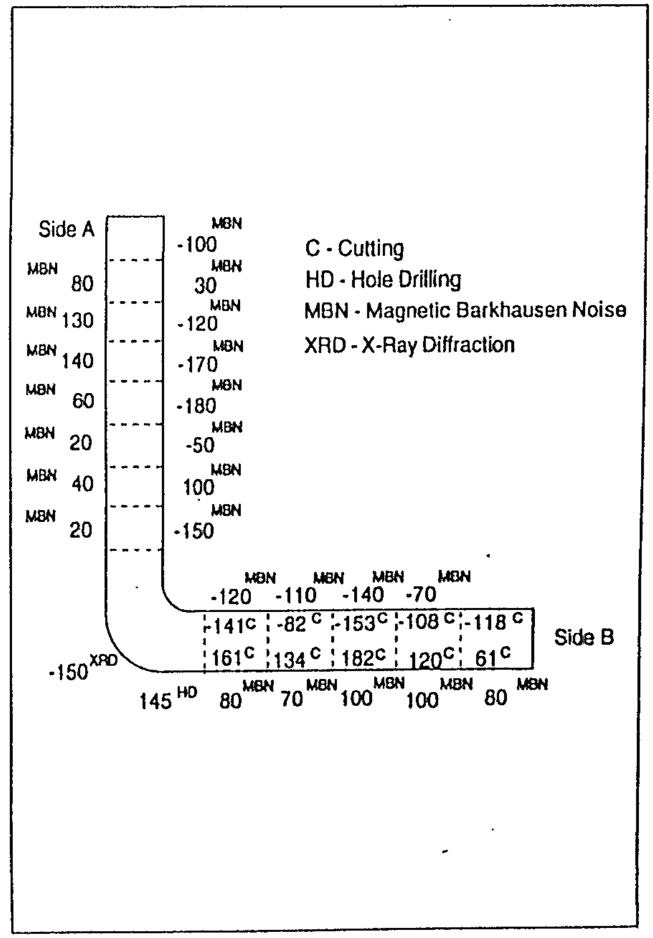


a) Orientation of principal stresses with respect to rosette gauges, b) Residual stress distribution at four depths below the surface

Cutting and Sectioning



Layout of two blocks to be cut from the specimen with residual stresses. The top and bottom gauges are mounted on one block.



Magnitude of the longitudinal components of surface residual stresses along the transverse direction in the specimen BA-109-21; all measurements in MPa.