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How Precise Can Be the Residual Stress Determined by X-ray Diffraction?

A summary of the Possibilities and Limits

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Abstract
Many springs are shot peened and the quality of shot peening is essential for the fatigue life. Today the determination is often done via x-ray diffraction. The lattice distance is measured and out of this information the residual stress is determined (and not directly measured). For this kind of measurement an absolute measurement is not available. The only way is to calibrate it in some way. It is shown how precise measurements today are in relation to different x-ray diffractometers and a specimen must be designed to get something like a usable calibration sample. The difference between statistical and systematic errors is shown and the consequences of these errors are discussed.

Introduction
Today the determination of residual stresses for many products is a common procedure, e.g., to prove the efficiency of the shot peening process or other hardening processes. Mostly it is done with the help of the x-ray diffraction method, because it is fast and not so expensive. The demands of the automotive industry concerning the accuracy and the number of measurements are still increasing. The question is whether precise measurements can be even performed. Here, round robin tests are reported designed to calibrate such a x-ray-diffractometer.

Basics of stress determination by x-rays
One popular method to determine the residual stresses in springs is the x-ray method. The idea is the measurement of the lattice distance within a solid or spring steel. The basic method is called Bragg reflection. A detailed description of the method will be found in the literature: [1;2]. A very brief summary is given here. X-rays with the wavelength λ are sent under certain angles Ψ to the surface normal and the diffraction angle 2θ with the maximum intensity is determined. The following equation can then be used:

$$\varepsilon = (1 + \nu) / E * \sigma \sin^2 \psi - \nu / E * (\sigma_{11} + \sigma_{22}) \quad (1)$$

From the measured reflection angle a lattice spacing $D = \lambda / (2 * \sin \theta)$ is determined and is compared with the lattice spacing D_0 without any stress ($\varepsilon = (D - D_0)/D$). (E is the Young's modulus, ν is the Poisson's ration, $\sigma_{11} + \sigma_{22}$ are stresses in the main direction on the surface)

The main aspect is that the stress is not measured directly. The lattice parameter is measured at different angles Ψ and a slope m is calculated that depends on material constants and the stress thus:

$$\sigma (m = (1 + \nu) / E * \sigma) \quad (2)$$

Out of this equation the stress σ can be calculated or determined. These considerations show that it is better to speak about determination of residual stress instead of measurement.

Conclusions
When comparing residual stresses from different labs, one must keep in mind that there may be great differences measuring the same objects (e.g., springs). To minimize the variation a calibration sample that has been used in round robin tests is useful. Laboratories have to make their own samples to monitor the long- term stability. Today an absolute calibration of an x-ray diffractometer is not possible and the measurements have a systematic uncertainty of at least 5%.

In many (delivery) specifications very small errors are claimed, which are in no relation to the systematic uncertainty of 50 MPa respectively 5% . One way to solve the problem is to organize round robin tests with a huge number of participants.