High-Speed Residual Stress Measurement by X-Ray Diffraction (Coil Spring and Linear Guide) – OneSight Wide-Range High-Speed Detector –

**Residual Stress Measurement of Metals**
Stress measurement by X-ray diffraction can be used to measure the residual stress of mechanical components such as spring materials and piston rings, and is therefore used for strength evaluation and heat treatment management for automobile components and the like which require high durability. Here, we introduce an example of high-speed measurement of the residual stress in a linear guide and a coil spring using the OneSight wide-range, high-speed detector and stress measurement attachment.

**OneSight Wide-Range High-Speed Detector**
The OneSight wide-range high-speed detector consists of a semiconductor array with more than 1000 channels. Compared with the conventional scintillation detector, higher-speed measurement is achieved due to its sensitivity, which is more than twenty times that of the scintillation type.

In residual stress measurement by X-ray diffraction, where one peak of interest is targeted, it is effective to utilize the “One-Shot mode” in which the detector is fixed using a wide acquisition angle that includes the target peak position.

**Measurement Principle of Residual Stress**
Assuming a plane of a sample surface as defined by the $x$ axis, specifically the direction of stress measurement, and the $z$ axis, defined as the sample normal direction, if the strain in the OP direction derived from the slope of the $z$-axis and the angle $\theta$ is $\varepsilon_{\psi_x}$, and $\theta_{\psi_x}$ is the X-ray diffraction angle, the strain in the $x$ direction is given by the following expression.

$$\sigma_x = \frac{E}{1 + v} \times \frac{\partial (\varepsilon_{\psi_x})}{\partial (\sin^2 \psi)} = \frac{E}{2 (1 + v)} \times \frac{\cot \theta_{\psi_x} \times \frac{\partial (\theta_{\psi_x})}{\partial (\sin^2 \psi)}}{\frac{\pi}{180}} \text{[MPa]}$$

Here, $E$ : Longitudinal elastic modulus 
$v$ : Poisson’s ratio 
$\theta_{\psi_x}$ : X-ray diffraction angle specific to a particular crystal lattice plane perpendicular to the OP direction 
$\theta_0$ : Diffraction angle when the material is in a non-strain state

Regarding the $\psi$ point, after $2\theta_{\psi_x}$ is measured, if $2\theta_{\psi_x}$ is plotted with respect to $\sin^2 \psi$, theoretically, a straight line is obtained.

From this slope ($M$), the stress value $\sigma_x$ can be determined using the following expression.

$$\sigma_x = K \cdot M \text{[MPa]}$$

$$K = \frac{E}{2 (1 + v)} \times \tan \theta_0 \times \frac{\pi}{180} \text{[MPa/deg]}$$

$$M = \frac{\partial (\theta_{\psi_x})}{\partial (\sin^2 \psi)} \text{(deg)}$$
Residual Stress Measurement of Linear Guide
We measured the residual stress around the hole of the linear guide using the side-inclination method. The measurement conditions are shown in Table 1. A 20-second integration time was used for each \( \psi \) angle point.

<table>
<thead>
<tr>
<th>Mode</th>
<th>One-Shot mode (Using stress measurement attachment, Side-inclination Method)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>XRD-7000</td>
</tr>
<tr>
<td>X-ray target</td>
<td>Cr</td>
</tr>
<tr>
<td>Tube voltage – tube current</td>
<td>40 kV - 40 mA</td>
</tr>
<tr>
<td>Monochromatic</td>
<td>V filter</td>
</tr>
<tr>
<td>Measurement range</td>
<td>146.9 to 165.3 degrees (Goniometer 2 ( \theta ) fixed angle: 156.1 degrees)</td>
</tr>
<tr>
<td>( \psi ) angle</td>
<td>( \psi = 0, 16.8, 24.1, 30, 35.3, 40.2, 45 ) degrees</td>
</tr>
<tr>
<td>Integration time</td>
<td>20 seconds (for each ( \psi ) angle)</td>
</tr>
<tr>
<td>Detector</td>
<td>OneSight wide-range high-speed detector</td>
</tr>
<tr>
<td>Measurement plane</td>
<td>( \alpha )-Fe 211</td>
</tr>
</tbody>
</table>

Residual Stress Measurement of Coil Spring
We measured the inner side residual stress of a coil spring using the side-inclination method. The measurement conditions were the same as those shown in Table 1. Also, the sample could be fixed using clay, thereby permitting measurement of a specific site only with good S/N by fixing a pinhole slit to the X-ray divergence-side slit.

We measured the residual stress around the hole of the linear guide using the side-inclination method. The measurement conditions are shown in Table 1. A 20-second integration time was used for each \( \psi \) angle point.

Table 1 Analytical Conditions

Fig. 3 Sample (Linear Guide)

Fig. 4 \( 2\theta \psi x - \sin \psi \psi \) Diagram (Linear Guide)

Fig. 5 Sample (Inner Side of Coil Spring)

Fig. 6 \( 2\theta \psi x - \sin \psi \psi \) Diagram (Inner Side of Coil Spring)