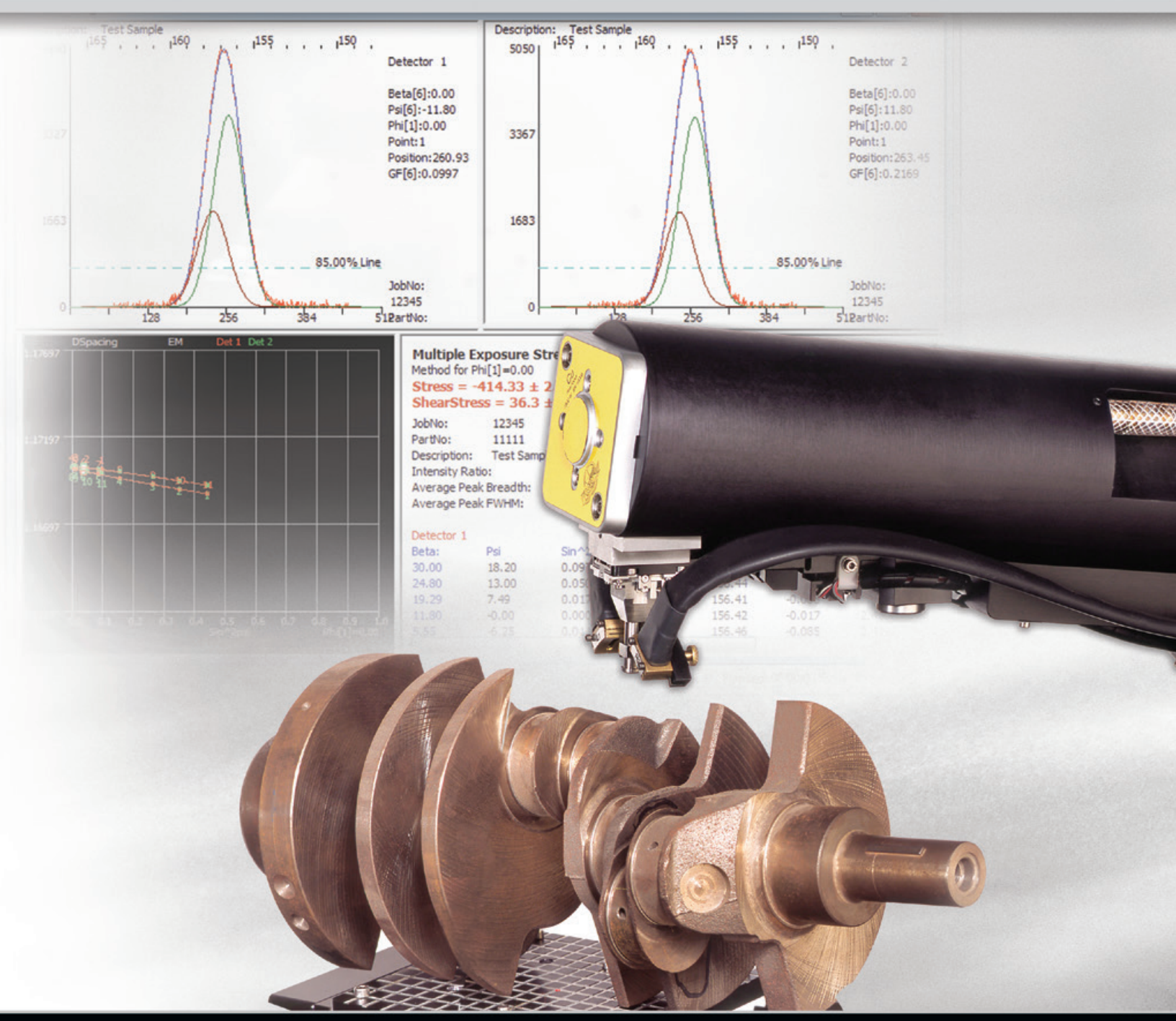
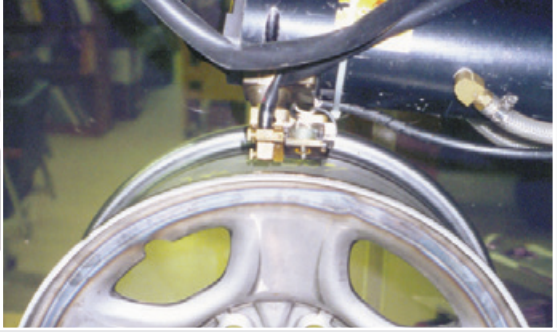
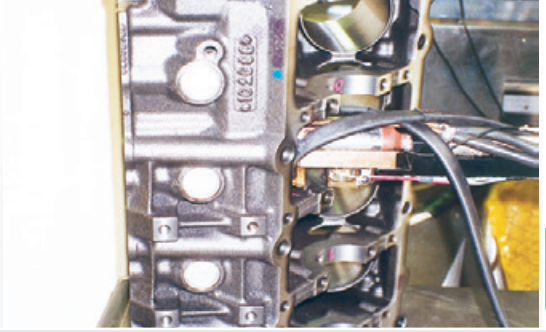
PROTO MANUFACTURING



AUTOMOTIVE

X-ray Diffraction Residual Stress Measurement

WHAT IS RESIDUAL STRESS?

Residual stress is the Internal stress distribution locked into a material. These stresses are present even after all external loading forces have been removed. They are a result of the material obtaining equilibrium after it has undergone plastic deformation.

HOW DOES RESIDUAL STRESS COMPARE TO APPLIED STRESS?

Applied stress is generated inside a material due to an external load (often measured with a strain gauge). Residual stress is present inside the material regardless of loading. The total stress experienced by the material at a given location within a component is equal to the residual stress plus the applied stress.

TOTAL STRESS = RESIDUAL STRESS + APPLIED STRESS

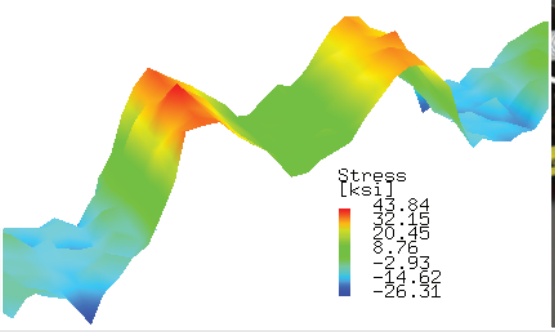
If a material with a residual stress of a -400 MPa is subjected to an applied load of +500 MPa. The total stress experienced by the material is the summation of the two stresses (+100 MPa). Therefore, knowledge of the residual stress state is important to determine the actual loads experienced by a component. In general, compressive residual stress in the surface of a component is beneficial. It tends to increase fatigue strength and fatigue life, slow crack propagation, and increase resistance to environmentally assisted cracking such as stress corrosion cracking and hydrogen induced cracking. Tensile residual stress in the surface of the component is generally undesirable as it has the opposite effect.

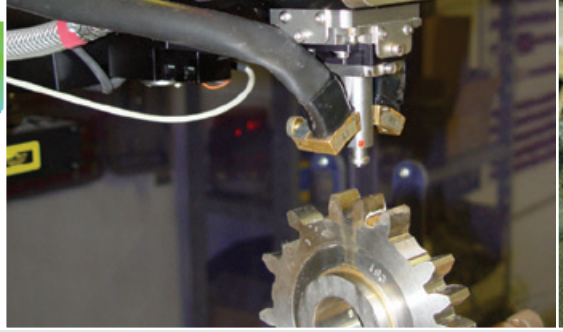
Compressive (-) residual stress acts by pushing the material together, while tensile (+) residual stress pulls the material apart, enabling small cracks to grow at a faster rate. Stresses are characterized as either a normal stress that acts perpendicular to the face of a material or a shear stress that acts parallel to the face of a material. There are a total of 6 independent stresses (3 normal and 3 shear) at any point inside a material.

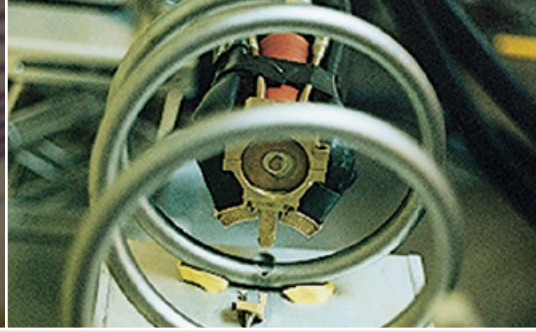
WHAT CAUSES RESIDUAL STRESS?

Residual stresses are generated, upon equilibrium of material, as a result of plastic deformation caused by applied mechanical loads, thermal loads or phase changes. Mechanical and thermal processes applied to a component during service can also alter its residual stresses.

MECHANICAL	Plastification of a material during machining.
THERMAL	Difference in solidification of the material. (i.e. in a cooling casting)
PHASE CHANGE	Precipitation / Phase transformation resulting in a volume change (i.e. Austenite to Martensite)







RESIDUAL STRESS MANAGEMENT

Harmful residual stress can lead to stress corrosion cracking, distortion, fatigue cracking, premature failures in components, and instances of over design. Techniques, such as heat treating, controlled cooling and localized heating are applied to help manage potentially harmful residual stresses created during manufacturing. Other techniques, such as shot peening, are used to introduce beneficial residual stress into a component to help increase fatigue life. Knowledge of the residual stresses is required to ensure that these processes have been correctly applied. Small changes in the residual stress can often have a significant effect on the life of a component.

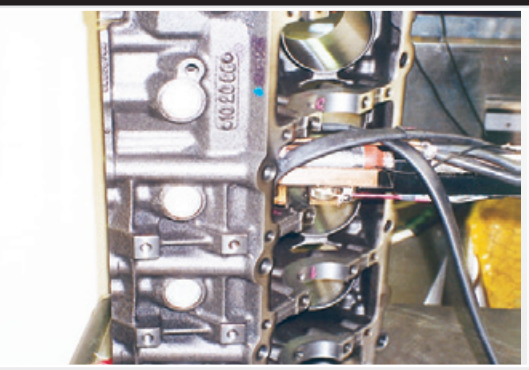
IMPORTANCE OF RESIDUAL STRESS

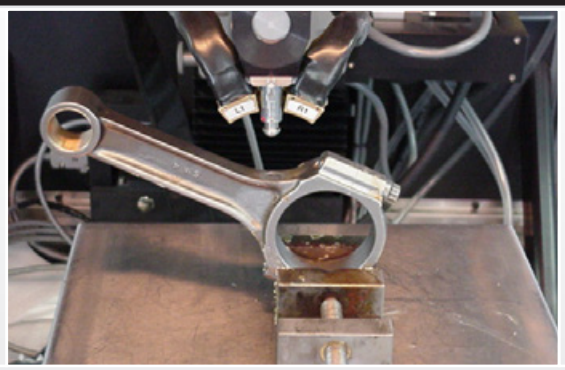
Residual stress affects:

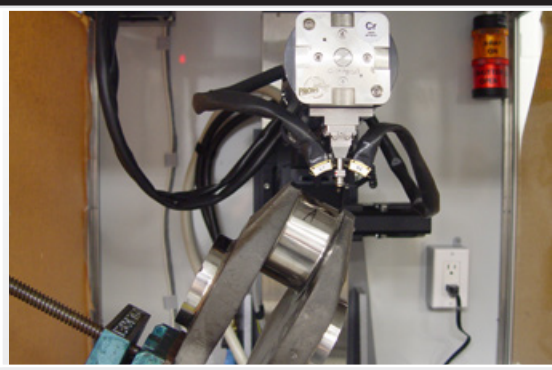
- Low cycle and high cycle fatigue performance
- Distortion during machining and after applying a process
- Peen forming (controlled distortion)
- Fretting
- Stress corrosion cracking (SCC) and hydrogen initiated cracking (HIC)
- Crack initiation and propagation

THE BENEFITS OF MEASURING AND MONITORING RESIDUAL STRESSES

- Optimize manufacturing processes
- Provide a quantitative metric to enable specifications and Go/No-Go decisions
- Improve product quality, substantiate supplier quality, engineering source approval (ESA)
- Improve safety and reduce catastrophic failures
- Extend component life by ensuring sufficient compressive residual stress is present
- Validate repair area has been "restored" to original specifications.
- Residual stress inf ormation can improve the probability of detection of other nondestructive techniques.
- Validate residual stress distribution from FE models or fracture mechanics







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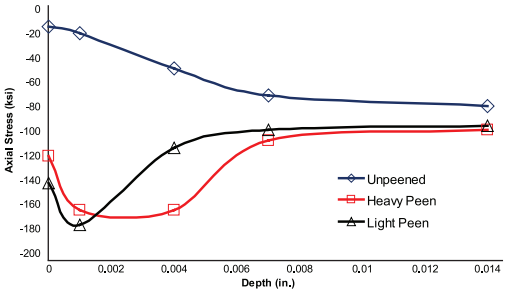
MEASURING RESIDUAL STRESS IN AUTOMOTIVE COMPONENTS

X-ray diffraction has become the industrial standard for residual stress characterization of automotive components. It is an essential tool for process optimization, design improvements and failure analysis.

VERIFY SURFACE ENHANCEMENTS

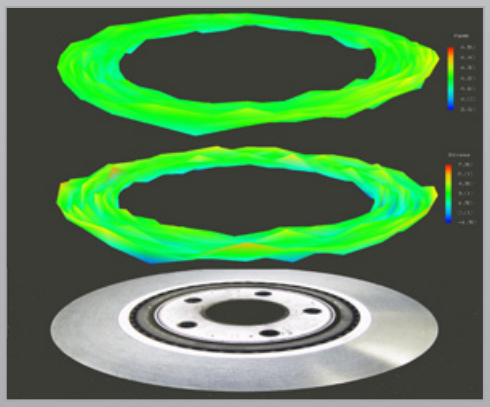
The fatigue life of a component is often enhanced by cold-working processes such as shot peening. XRD residual stress measurement can be used to verify that these locations have been enhanced to the specified residual stress level. A residual stress value, once established, can be specified on the engineering and processing documents.



Residual Stress vs. Depth on Shot Peened Samples.

MACHINING

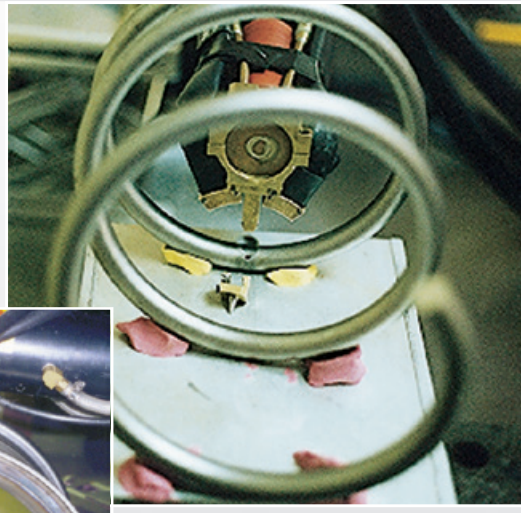
Aggressive or abusive machining can create regions of tensile stress that can make this area of a component susceptible to crack initiation, and increase the rate of crack propagation.



Residual Stress Map of Brake Rotor

VALIDATION OF FINITE ELEMENT MODELS

Residual stress measurement can be used to verify that finite element models are predicting the correct residual stress in a component. When deficient, the known residual stress can be used to improve the FEA models.



FATIGUE LIFE AND STRESS CONCENTRATIONS

The residual stress state in automotive components is critical when stress concentration geometries exist that can magnify the effects of applied loads. When issues of fatigue cracking are considered, potentially harmful tensile residual stresses alone or in combination with stress concentrations can lead to fatigue crack initiation and propagation.

ABOVE: Measuring Residual Stress on a Spring

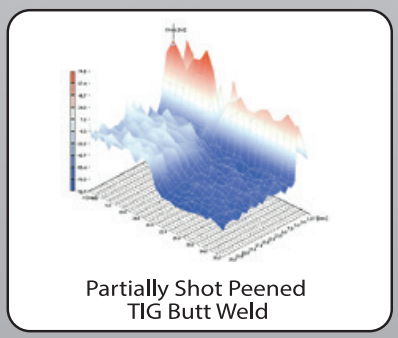
LEFT: Measuring Residual Stress on a Wheel

HEAT TREATMENT PROCESSES

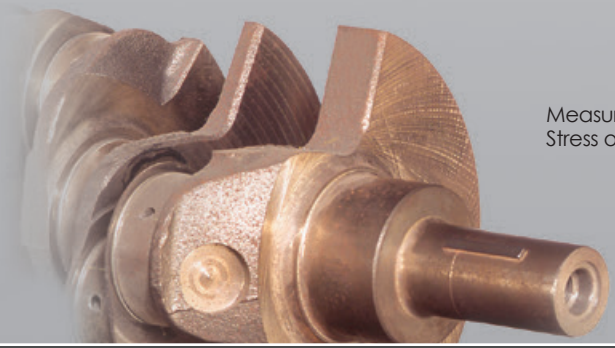
Heat treatment processes are commonly applied to automotive components to lower or reduce the residual stresses present. Residual stress measurement can be used to ensure that such processes have been correctly applied and that any harmful residual stresses have been reduced to an acceptable level.

RESIDUAL STRESS IN WELDS

Tensile residual stresses created during the welding process can lead to cracking. Components can be measured before welding, after welding, and after post-welding processes, to ensure stresses are properly managed.

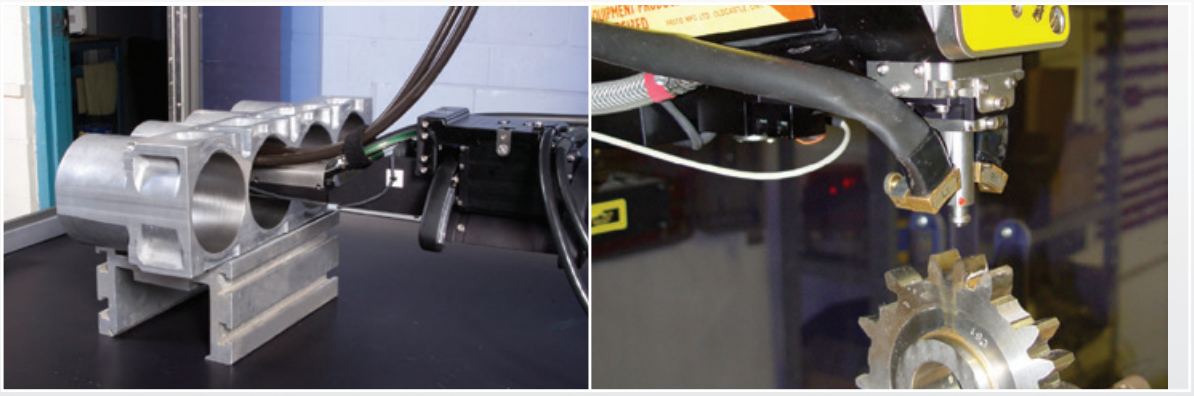


Example of a residual stress map on a partially peened weld.



Measuring Residual Stress on a Crank Shaft

AUTOMOTIVE



DESIGN TO RS - PRODUCE TO RS - MANAGE TO RS

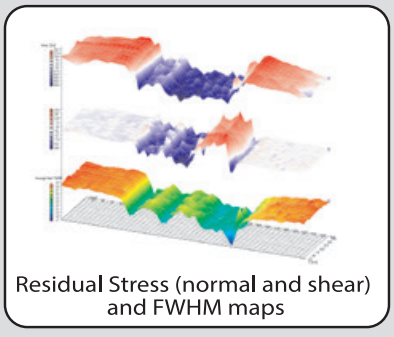
Utilizing a design to RS, produce to RS and a manage to RS philosophy provides the Engineer with a powerful, modern approach to design. Careful control of the residual stress inside a manufactured component is possible and easily achieved in today's manufacturing environment.

Machining processes can be monitored to ensure that detrimental RS has not developed as a result of machining. This information can be used to ensure damaged parts are removed prior to service, and as a feedback mechanism to optimize machining to reduce scrap rates. Stress reduction steps, such as heat treatment, can be measured before and after to quantify the stress reduction process. Inefficient or incomplete heat treatments can be adjusted; thus improving time and reducing costs. Introduction of beneficial RS through improvement processes such as shot peening must be quantified with RS measurement ensuring that the correct level of beneficial stress has been introduced into the part.

Ultimately, a RS specification can be added to a blueprint. Insisting that suppliers conform to this specification ensures that a consistent part will be produced, regardless of the supplier.

RESIDUAL STRESS MAPPING

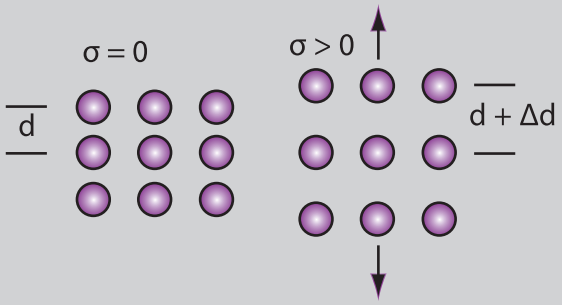
PROTO's patented Automated Residual Stress Mapping technology can generate a comprehensive picture of the residual stress state of any sample. Even curved surfaces such as welds can be automatically mapped allowing designers and engineers to visualize and manage problem areas.

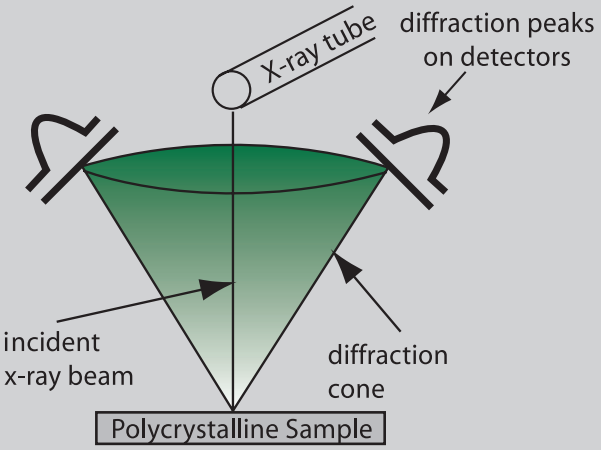


Example of a multi-map with residual stress, shear stress and FWHM maps superimposed or "stacked".

X-RAY DIFFRACTION RESIDUAL STRESS MEASUREMENT

Stress causes change in atomic lattice spacing "d" and an angular shift of the diffraction peak.





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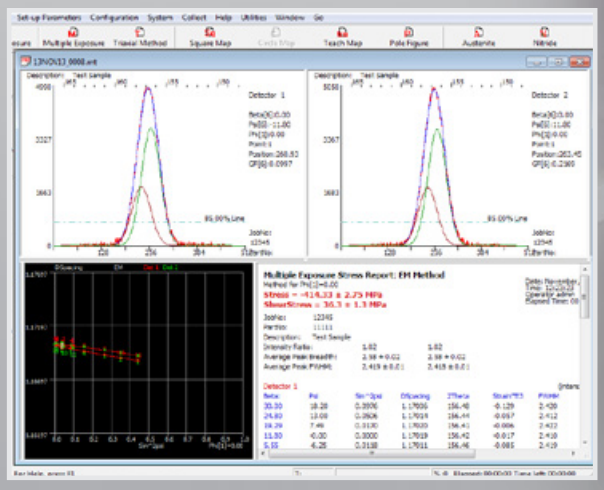

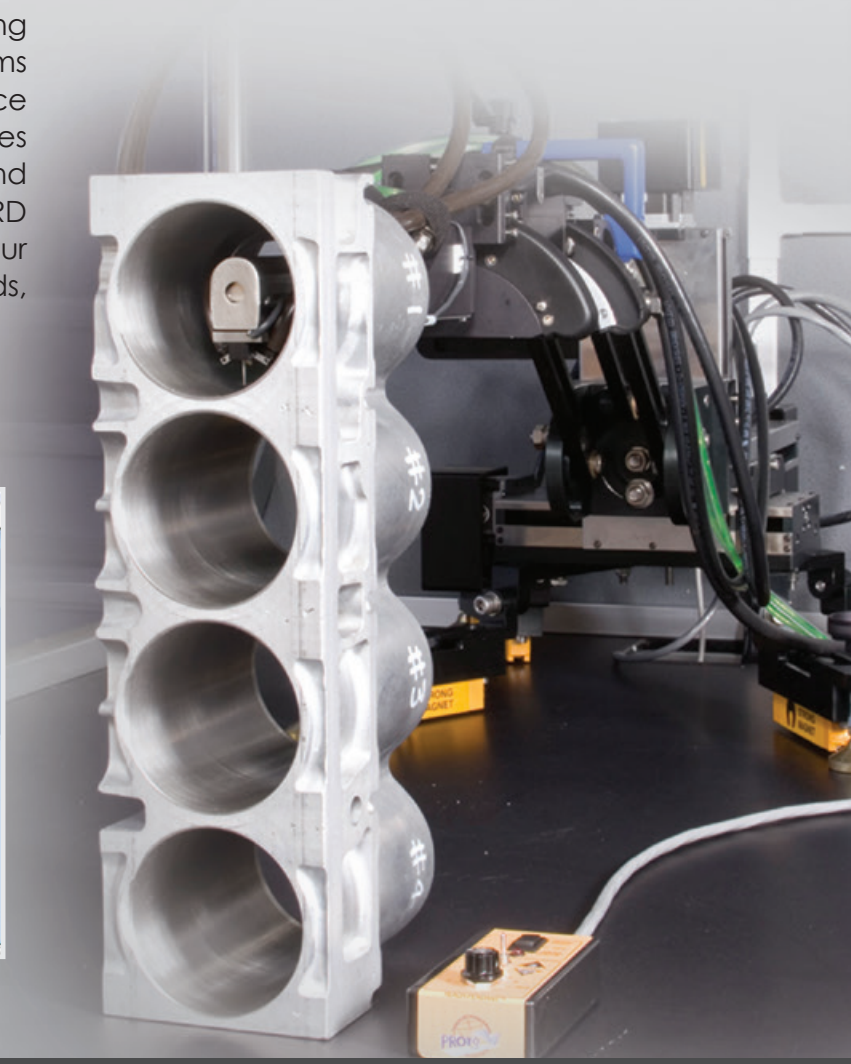

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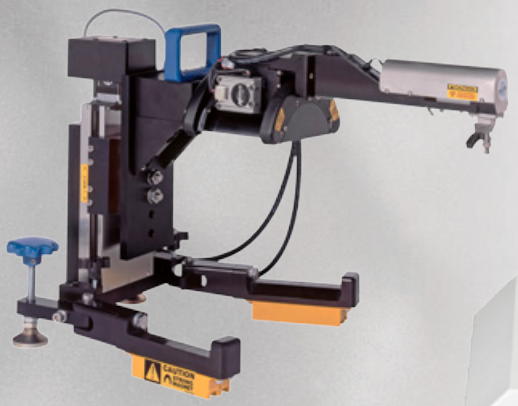

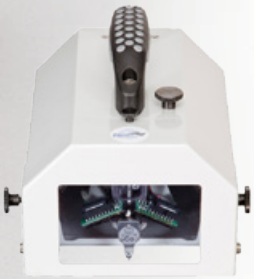

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