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SALSA—A new instrument for strain imaging in engineering materials and components

Thilo Pirling [a,*], Giovanni Bruno [a,b], Philip J. Withers [b]

[a] *Institut Max von Laue-Paul Langevin, 6 rue Jules Horowitz, BP156, F-38042 Grenoble, France*
[b] *Materials Science Centre, University of Manchester, Grosvenor St., Manchester M1 7HS, UK*

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Abstract

Residual stresses are very hard to predict and if undetected can lead to premature failure or unexpected behaviour of engineering materials or components. This paper describes the operation of a new residual strain-mapping instrument, Strain Analyser for Large and Small scale engineering Applications (SALSA), recently commissioned at the public user facility, the Institut Laue-Langevin in Grenoble, France. A unique feature of this neutron diffraction instrument is the sample manipulator, which is the first of its kind, allowing precise scanning of large and heavy (<500 kg) samples along any trajectory involving translations, tilts and rotations. Other notable features of the instrument are also described.

Keywords: Strain scanning diffractometer; Double-focusing monochromator; Stewart platform; Radial collimators; Residual stress

1. Introduction

If they are not anticipated, residual stresses (RS) can add to service loads to give unexpected failures in a wide range of engineering components. Diffraction is one of the most effective ways of determining residual stress fields non-destructively. Each of the different diffraction methods, laboratory X-ray, high energy (synchrotron) X-ray and neutron diffraction, has its advantages. A feature of neutron diffraction is the high penetration depth in all common crystalline engineering materials. This is especially useful for alloys of high average atomic number because the penetration of X-rays falls off rapidly in this regime. In contrast to penetrating high energy (short wavelength) X-rays, the wavelength of thermal neutrons (∼1–3 Å) enables a scattering geometry of around 90°. This means that even for large and bulky components deep regions are often accessible at a number of tilt angles, allowing complete determination of the stress tensor.

Since the first dedicated facility (ENGIN) was built in the UK at ISIS [1], many neutron sources all around the world have built or are building diffractometers dedicated to the determination of residual stress. Although some of the first strain-mapping experiments were performed at the European Institut Laue Langevin (ILL) facility on the instrument D1A in the 1980s [2], a dedicated instrument has not been available. Within the framework of ILL's Millennium Instrument Development Programme, started in 2000, ILL in collaboration with a team of UK universities led by the University of Manchester and funded by the UK Engineering & Physical Sciences Research Council set about building an instrument dedicated to measuring engineering strain. Named SALSA, which stands for "Strain Analyser for Large and Small scale engineering Applications", it has been commissioned for use by the user community in 2005.

The high neutron flux of the ILL reactor gives the opportunity to design an instrument for measurements in very large samples and to optimise the conditions for high spatial and strain resolution. Therefore, SALSA is designed as a very flexible instrument suited to a broad range of materials science and engineering applications. The instrument features the first six-axis sample manipulator based upon hexapod technology. It enables the precise manipulation of large samples of up to 1.5 m length and over 500 kg weight. The robot is able to perform scans along any trajectory in space including translations, rotations and tilts. Thanks to the VAMAS-standard compatible sample mounting plate, pre-alignment of samples is straightforward. A laser combined with a 3D closed TV-circuit system with on screen measurement features aid the final alignment of the sample on the instrument.

* Corresponding author. Tel.: +33 476 20 7007; fax: +33 476 20 7648.
E-mail address: pirling@ill.fr (T. Pirling).

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2. The general concept of SALSA

SALSA (Fig. 1) is a monochromatic strain diffractometer (strain imager) stationed on a continuous flux neutron beam. It is positioned at a super-mirror neutron guide with a relative critical angle of reflection of $m = 2$. Its location on a guide-tube provides low background, which improves the sensitivity and depth capability of the instrument [3] while the super-mirror coating delivers a high neutron flux to the station ($\sim 5 \times 10^7$ n s^{-1} cm^{-2}). The gain in flux, compared to conventional Ni-coated guides, is mainly due to an increase of the angle of the neutrons that are reflected by the guide-walls, which increases the transmitted beam divergence. It is thus important to match all the subsequent optical components with the beam properties in order to maximise the flux at the sample position while at the same time achieving the required lateral and angular resolution. This aim is achieved by using a double-focusing monochromator having a column of bent perfect crystals in combination with radial focusing collimators. The curvature of the monochromator focuses the divergent beam onto the sample position and by adjusting the bending radius of the crystals the angular resolution is optimised. Radial focusing collimators transmit the whole divergence of the beam whilst defining a precise gauge volume. Furthermore, they reduce the extent of anomalous shifts in diffraction peak position as the sampling gauge enters or leaves the engineering component. This allows precise measurements near surfaces and interfaces [4,5]. Flexibility in the choice of gauge dimensions is available through the provision of an automated slit system.

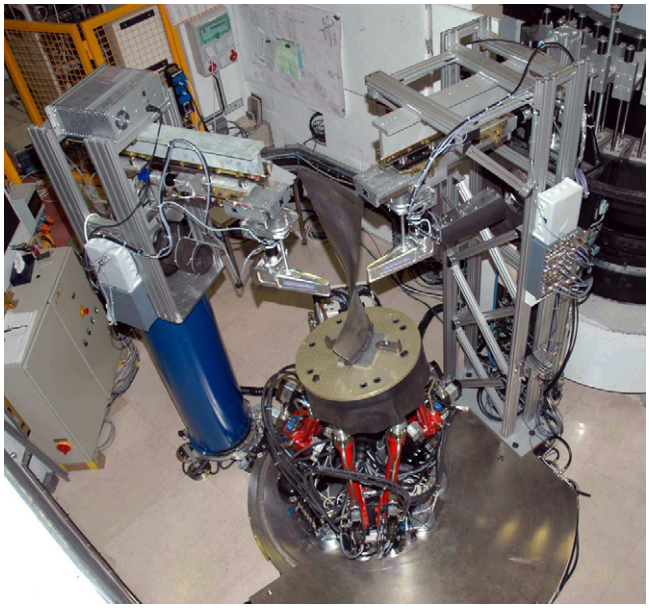

Fig. 1. Photograph of SALSA with an aero-engine fan blade on the sample table.

It can be used either in place of, or in addition to, the radial collimators.

Flexibility and adaptability in terms of samples and scan modes is a central design concept of SALSA. In fact, the sample stage can deal with samples from centimetres to meters in size and weights up to several hundred kilograms. Furthermore,

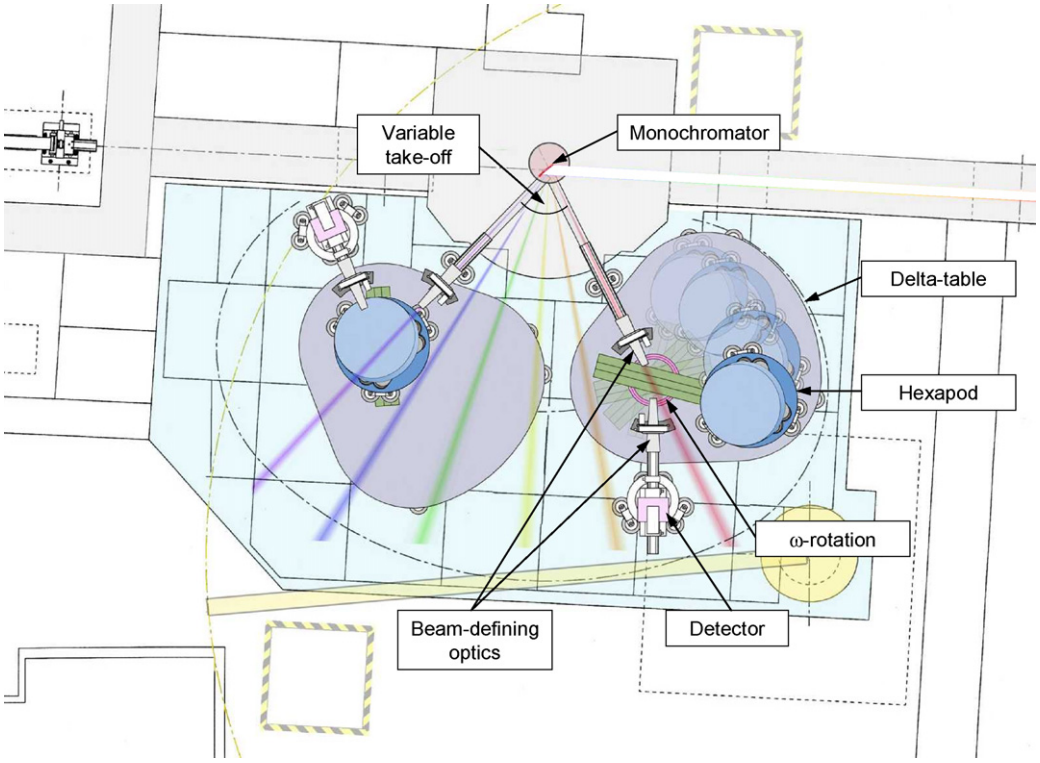

Fig. 2. Principle operation of SALSA, showing the instrument at different positions. On the left hand side the delta-table is positioned at the lowest take-off angle of 55°. The centre of the hexapod base is co-axial with the omega rotation axis around which 360° rotation is possible. On the right hand side the delta-table is shown at the highest take-off angle of 125° with the hexapod in the extended position and at different omega angles as for large samples.