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SMARTS – a spectrometer for strain measurement in engineering materials

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Abstract. A new spectrometer called SMARTS (Spectrometer for Materials Research at Temperature and Stress) has been commissioned at the Los Alamos neutron science center and entered the user program in August of 2002. Its design maximizes capability and throughput for measurements of (a) residual macrostrain in engineering components and (b) *in situ* loading. This paper describes some aspects of the instrument.

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Measurements of strain in engineering materials place demands on neutron diffraction spectrometers that differ from instruments designed for conventional crystallography. Notably the range in shape and size of engineering specimens requires more spacious access to the sample position than is typically found on conventional diffractometers. Moreover efficient and accurate measurements require precise optical alignment (of samples with irregular shapes) with respect to the beam - which imposes limitations on shielding and line-of-sight access to the sample. Over the last few years these limitations have led to adaptation of existing instruments and new instruments being designed for engineering strain measurements [1, 2]. SMARTS is the first instrument at a pulsed source to be designed from a "green field" site for engineering strain measurements. A similar instrument called ENGIN-X is under construction at the ISIS facility at the Rutherford Appleton Laboratory in the UK.

1 Incident beam transport

The incident beam transport comprises; a water moderator, a series of scrapers (in the bulk shield), a straight super mirror guide (with Ni58 and 2θ vertical and horizontal surfaces respectively), and a T-zero chopper. The source to sample flight path is 30.75 m, neutrons pass from the moderator through the scrapers to the entrance of the neutron guide approximately 5 m from the moderator. A T-zero chopper is located at a break in the guide 10 m from the moderator where there is also space for a frame-definition chopper (not currently used). Beyond the T-zero chopper the neutron guide extends to the entrance of the cave terminating approximately 3 m from the sample. Two aperture sets (located between the exit of the guide and the sample) permit the beam cross section to be defined continuously in shape and area between 1 and 100 mm^2 (Fig. 1). The guide was purchased from and installed by CILAS (see Fig. 2) and is noteworthy because a 10 m section had to be installed through a pipe approximately 1 m in diameter. The transition through the pipe was effected by pre-aligning guide sections on an I-beam which was subsequently inserted in the pipe on rollers and aligned as a complete section.

Fig. 1. Incident collimation (prior to installation)

2 Detectors and data acquisition

Two detectors comprising a total of 384 single ended ^{3}He tubes are mounted on either side of the incident beam with a secondary flight path of 1.5 m to the center tube(s) at ±90°. The

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Fig. 2. Neutron guide prior to shielding installation

detectors are connected to TOF (time of flight) modules that reside in VXI crates, each of which holds a VME processor into which instrument specific software can be downloaded. The majority of instrument parameters including tube high voltage settings and discriminator values are defined in a Microsoft Access database. A data acquisition server contains all of the information needed to configure the instrument including time compression and how channels are related to physical parameters. The data files are written using the NeXus file format [3].

3 Cave, translator, and radial collimators

A cutaway of the experimental cave is shown in Fig. 3. For spatially resolved measurements definition of the gauge volume (typically between 1 and 30 mm^3) is performed by combining an adjustable incident aperture with a radial collimator supported between the incident beam and the detector (Fig. 4). By varying the specification of the radial collimator the spatial resolution along the beam can be varied. For SMARTS the detector solid angle is six times that of the instrument (NPD) which was previously used for these measurements [4] thus the size and extent of the radial collimators is commensurately larger. A suite of 5 pairs of radial collimators have been purchased from JJ X-ray, providing spatial resolution of 0.5, 1, 2, 3, 4 mm along the incident beam. Each radial collimator subtends 20° in the horizontal plane and comprises 100 mylar blades coated with gadolinium oxide. The angular separation between adjacent blades is 0.2°. For ease of installation, the positioning and support of the radial collimators are mechanically decoupled.

Motion of engineering samples or ancillary equipment with respect to the neutron beam is achieved using a translator

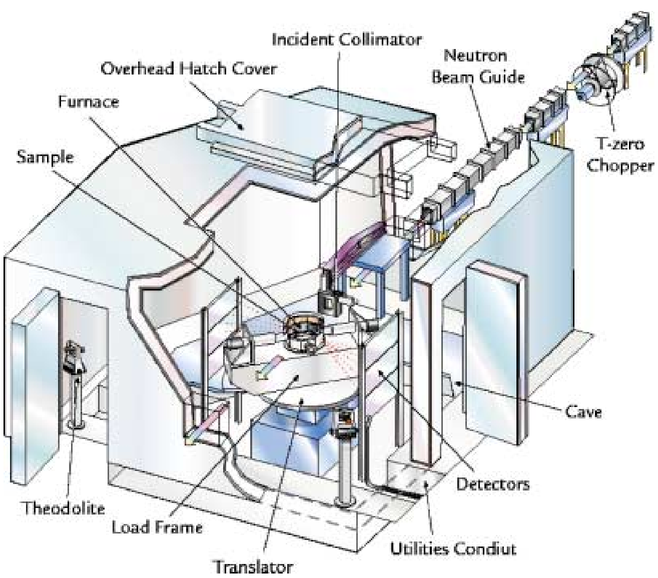

Fig. 3. Cutaway Schematic of cave

Fig. 4. Radial collimator supported in front of detector

Fig. 5. Translator (prior to installation)

fabricated by ADC (who also fabricated the incident collimation equipment) with a capacity of 1500 Kg and positioning accuracy of better than 0.1 mm (Fig. 5). Sample, aperture and collimator alignment is achieved using two Leica theodolites, mounted in corners of the experimental cave, and interfaced to a workstation. By triangulation the theodolites can locate points to an accuracy of 10 μm.

4 Load frame furnace

To satisfy the need to monitor mechanical properties at a microstructural level under a range of conditions a customized load frame and furnace suite has been constructed by Instron and MRF respectively (Fig. 6). Its capabilities include: (i) *in situ* uniaxial loading up to 250 KN, ii) fatigue rating to 100 KN and iii) a simultaneous temperature capability up to 1500 °C. The loading axis is in the horizontal plane with a maximum adjustable distance between the actuator and load cell of 1.2 m. This distance both accommodates the vacuum furnace and provides flexibility for a range of sample geometries and gripping requirements. The vacuum furnace has a maximum "stand-alone" operating temperature of 1800 °C and operating pressures between 5×10^{-6} torr and 2 PSIG. It can operate using inert atmospheres or under vacuum or when used with a retort, oxidizing, corrosive or reducing atmospheres are also accessible. It comprises a water-cooled, double wall chamber with aluminum neutron windows. Bellows (over the pullrods) seal the hotzone when it is used in conjunction with the load frame. A high temperature extensometer can be mounted above the hotzone. When the furnace is used in conjunction with the radial collimators spatial resolution can be achieved within a hot loaded sample.

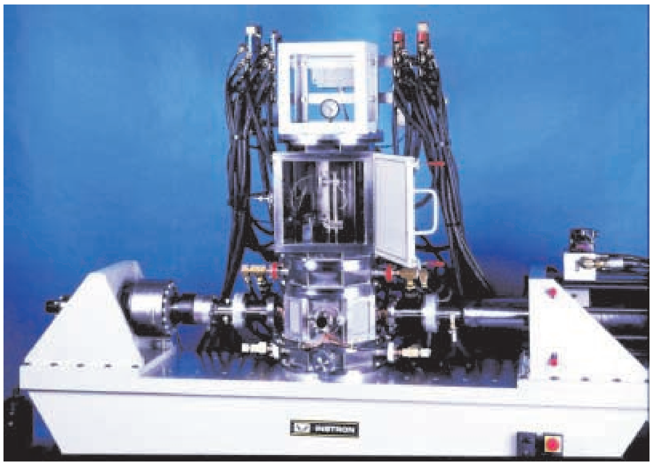

Fig. 6. Load frame with furnace mounted

5 Conclusions

SMARTS began commissioning in the summer of 2001 and entered the BES sponsored user program in 2002. Its principle areas of research include; residual stress in fabricated components, in situ loading in new materials and process monitoring. Design parameters are listed in Table 1.

Table 1. SMARTS Specifications

Performance	
◇ Moderator	Chilled H_2O,
◇ Resolution at 90° (wavelength dependent)	∼ 0.4%
◇ *d*-spacing range	∼ 0.5–4 Å
◇ Nominal time for 1 cm^3 Fe under load at temperature	∼ 10 minutes
◇ Nominal time for 1 mm^3 in 10-mm-thick Fe plate	∼ 60 minutes
Primary Flight Path	
◇ Moderator to sample	∼ 30.75 m
◇ Incident collimation (at sample)	1–100 mm^2
Secondary Flight Path	
◇ Sample to 90°	∼ 1.5 m
◇ 2θ subtended (each 90° bank)	∼ 30°
Load Frame-Furnace	
◇ Maximum uniaxial force (compression or tension)	250 KN
◇ Actuator motion	0.15 m
◇ Furnace maximum temperature	1800 °C
◇ Furnace maximum temperature - under load	1500 °C
◇ Furnace atmosphere	Vacuum or inert atmosphere
◇ Specimen geometries (alternates on request)	Tension (threaded/flat) Compression (flat/cylinder)
Translator	
◇ Capacity	1500 kg
◇ Range of travel	$X = 0.3$ m $Y = 0.3$ m $Z = 0.6$ m $R = 370°$
Radial Collimators	
◇ 2θ angle subtended	20°
◇ Spatial resolution parallel to beam	1, 2, 3, 4, 5 mm

6 Manufacturers

Furnace Materials Research Furnaces Inc., Suncook Business Park, Suite#2 Rt.28 Suncook NH 03275
Load frame Instron Corporation, 100 Royall St. Canton, MA02021-1089
Radial collimators JJ-Xray, Liselundsalle 10, DK-3360, Liseleje, Denmark
Translator and incident collimation Advanced Design Consulting, 126 Ridge Rd, P.O. Box 187, Lansing, NY 14882
Theodolites Leica Geosystems, 3155 Medlock Bridge Rd, Norcross, GA 30071

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