A portable test-bench for real-time radiation damage measurements in scintillating and wavelength-shifting fibres

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A portable test-bench for real-time radiation damage measurements in scintillating and wavelength-shifting fibres

Peter R. Hobson, David R. Smith

***Abstract*— A portable test-bench has been developed to enable the real-time measurement of radiation-induced absorption in scintillating and wavelength-shifting fibres. Such fibres are typically used in the readout of fibre calorimeters or scintillating tiles such as those used in some hadron calorimeters. The test-bench has been designed to be used in a range of facilities, such as ^{60}Co irradiators or high-intensity test beam facilities, and can accommodate fibres with length up to 300 mm and diameter greater than 1.0 mm. The test fibres are illuminated using a combined deuterium and halogen light source focussed onto the end of the fibre with a 0.25 NA radiation-tolerant quartz lens. The light transmitted by the fibre is collected by an identical lens and measured as a function of wavelength with a linear charge-coupled device spectrometer covering a wavelength range of 190 to 850 nm. We present the design of the test-bench, and studies of the systematic errors arising from the components. We measured induced absorbance in the fibres tested and determined the major systematic error to be the stability of the light source. Planned enhancements to the test-bench are discussed.**

***Index Terms*— fibre, scintillator, radiation damage.**

I. INTRODUCTION

A test-bench, for measuring radiation induced optical damage to fibres, was designed and constructed at Brunel as part of the AIDA-2020 project [1]. The motivation is the evaluation, in real-time, of changes in the optical properties of scintillating and wavelength-shifting fibres such as might be used in fibre calorimeters.

II. METHODOLOGY

The concept is to provide a small, radiation-tolerant test-bench which can be used in a variety of facilities from a test beam at CERN or DESY to a high-intensity radiation facility using a radioactive source. The challenge is primarily that the spectrometer and light source must be located in a region of low radiation; this is particularly challenging when using facilities such as high activity isotope irradiators.

Fig. 1 shows the test-bench when located in our ^{60}Co irradiation facility. A broadband light source, located remotely and coupled to an optical fibre, is focused onto the test fibre by a quartz singlet lens. The transmitted light from the test fibre is then focused onto a second optical fibre, using a duplicate quartz singlet lens, and transported to a remote spectrometer. The light source is a stabilised combined deuterium and halogen light (StellarNet SL5) and the spectrometer is an F2 flat-field, holographic grating type with a linear charge-coupled device readout, a spectral range of 190 to 850 nm, and a standard fibre-optic input connector (StellarNet Black Comet). Integration times of up to 65 s are possible per scan.

An overview of the dark-current performance of our spectrometer is available here [2]. The major systematic error is the stability of our light source which shows peak variations of up to 1% between successive measurements taken at 120 s intervals, as shown in Fig 2.

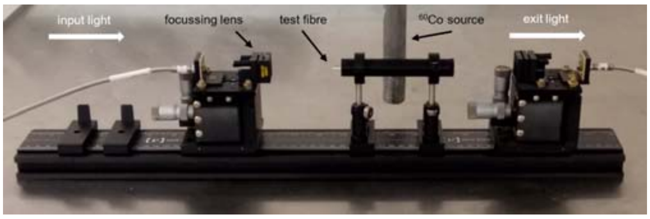

Fig. 1. The test-bench located in our ^{60}Co irradiator. A 20 m long, 200 µm core diameter, quartz fibre provides light from a remote source which is focussed by a quartz lens onto the polished face of the test fibre which is held in a black aluminium cylinder. Light exiting from the other end of the test fibre is focussed back onto a second, 20 m long, quartz fibre which goes to a remote spectrometer. The vertical metal container holds the ^{60}Co source.

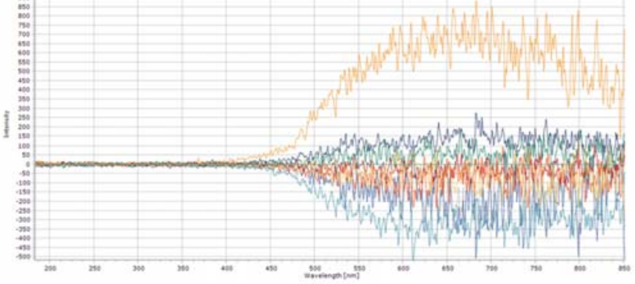

Fig. 2. Variation in intensity as a function of time for the halogen light source. The interval between each scan is 120 s and shown are the differences between individual scans and the average of all scans. The maximum difference (orange curve at 700 nm) is 1% of the average intensity.

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III. RESULTS AND DISCUSSION

Fig. 3 shows the result of a four-day continuous gamma irradiation, to a total dose of approximately 10 kGy, of a 3 mm diameter commercial polymethyl methacrylate (PMMA) rod that was highly absorbing prior to irradiation at wavelengths shorter than 390 nm due to a UV absorbing additive.

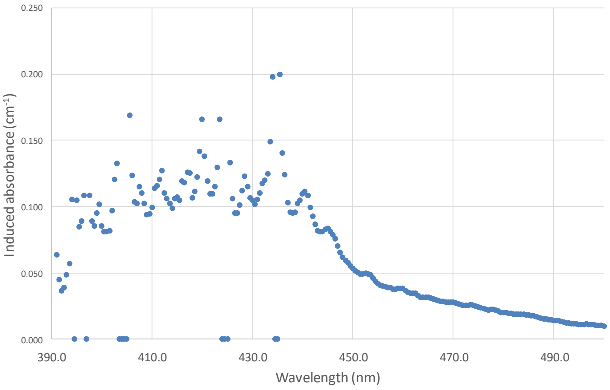

Fig. 3. Radiation induced optical absorbance per cm after 10 kGy irradiation of a commercial PMMA rod. An average of eight, 8 s exposures was used for both signal and dark current.

We have investigated the possibility of using the fibre test-bench to measure dynamically radiation induced effects on the decay time of fast scintillators using single-photon time-correlated spectroscopy. We adapted our laboratory-based system, using a fast pulsed laser diode to excite fluorescence, a fast SiPM based photon detector and a PicoHarp 300 time correlator, to see whether the effect of adding additional time dispersion via the large core diameter multi-mode fibres used in the test-bench would significantly degrade time resolution. We used 0.1 m, 1.0 m and 20.0 m long optical fibres and measured the decay time constant of a 1 cm thick fast plastic scintillator (polystyrene with PPO and PPOP fluors) excited at 377 nm. We used a tail fit starting approximately 1 ns after the peak and fitted a single exponential. Table 1 compares the results.

TABLE I
EFFECT OF FIBRE LENGTH ON FITTED DECAY CONSTANT

Fibre length (m)	Decay time (ns)	Error (ns)	Chi-square / DOF
0.1	1.53	± 0.01	6.0
1.0	1.57	± 0.01	8.8
20.0	1.64	± 0.01	6.3

IV. FURTHER WORK AND CONCLUSIONS

Currently underway is the determination of the optimum operating protocol (including light source stabilisation, sensitivity to temperature, effect of optical fibre movement etc.) for the test-bench and optical simulation, using Zemax OpticStudio [3], of the implications of using the singlet quartz focussing optics with the inevitable longitudinal chromatic aberration. A new conceptual design, which is achromatic using off-axis parabolic mirrors, is currently being studied.

We have designed, built and tested a small, portable system to evaluate the response of both scintillating and wavelength-shifting fibres during irradiation. The system has been tested using a high intensity ^{60}Co source and the major source of systematic error in measuring induced absorption determined.

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