Optical techniques for in-core measurements

Background

The in-situ measurement of dimensional changes is a key issue for advanced irradiation programs in Material Test Reactors (MTRs). It is for example crucial to monitor the changes of the dimensions of nuclear fuel assemblies as well as those of mechanically stressed structural material samples during in-pile irradiations. Different techniques already exist to carry out such measurements but they all come with a number of drawbacks. SCK•CEN and CEA have therefore decided to share the development of a measurement system that was never applied before in the core of a nuclear reactor. It relies on optical dimensional measurements and brings along unprecedented non-intrusiveness combined with high resolution. A clear advantage in using compact optical sensors results in a more efficient occupation of the irradiation volume available for target testings as well as a significant reduction of the gamma-heating associated with the in-pile instrumentation.

Objectives

The objectives of these shared studies are to design, develop, test and qualify an in-pile dimensional measurement system based on optical techniques, with the goal to implement this system in future MTR irradiation experiments. In 2006, we focussed our activities on sensor analysis, selection of the sensor prototypes, procurement and first irradiation experiment.

Principal results

Optical displacement or elongation measurements typically rely on the ability to generate interference with light. Such interference phenomena can be exploited in multiple ways depending on the sensor configuration. We restrict the sensor analysis to two sensor types: Fibre Bragg Gratings (FBGs) and Extrinsic Fabry-Pérot interferometer (EFPIs) based fibres. The analysis showed that EFPI cavities are likely to be the best candidate for sensing applications in a MTR. Figure 1 illustrates the simplest configuration of a EFPI sensor with its typical dimensions.

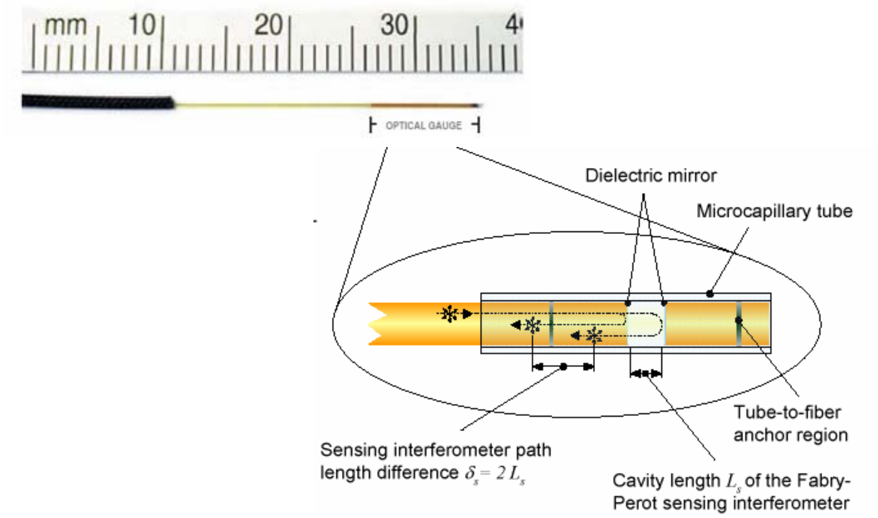

Figure 1: Schematic view of an Extrinsic Fabry-Pérot Interferometer and its working principle. [G. Daplain, technologie interferométrie en lumière blanche, www.opsens.com]

Nevertheless in view of the intense radiation field inside MTR cores the EFPI will also suffer from radiation, mainly through radiation-induced compaction which causes an unwanted drift of the interference signal.
Such a drift has indeed been observed in gamma-irradiated EFPI cavities made from radiation-resistant optical fibres and interrogated by means of a white-light interferometry measurement scheme. Figure 2 depicts the spectral interference pattern (interferogram) recorded by the interrogation unit before irradiation (solid line) and after 5.8 MGy of irradiation (dashed line). As expected, EFPI fabricated with radiation-hard fibres can transmit interference signals at such gamma dose levels with a negligible drop of the optical intensity. The drift of the interferogram to the right however indicates an apparent increase of the Fabry-Pérot cavity length. Figure 3 shows the saturating drift of the central wavelength with respect to the irradiation time.

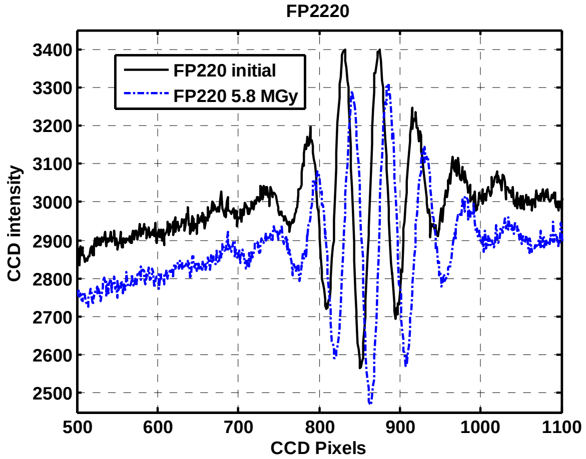

Figure 2: Comparison of the interferogram of a EFPI before (solid line) and after (dashed line) gamma irradiation.

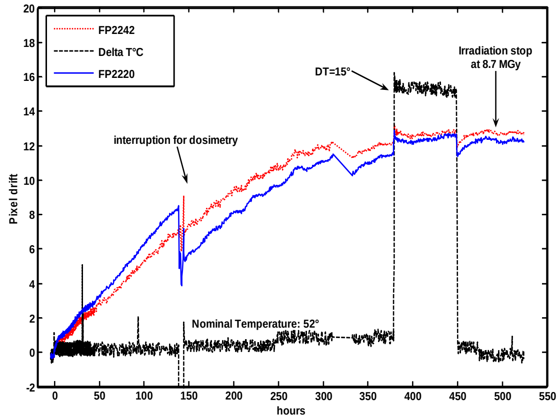

Figure 3: Evolution of the central wavelength drift (expressed in pixels) as a function of the irradiation time (up to 8.7 MGy). 1 pixel corresponds to a 9 nm change in the Fabry-Pérot cavity length.

At the end of 2006 we also carried out a reactor irradiation test of the EFPI in the BR2 reactor up to a moderate fast neutron fluence of 10^{19} n/cm^2. Preliminary results show an identical radiation-induced drift of the sensor signal. A more detail analysis of the experimental data is currently on-going to understand the real nature of this radiation-induced signal drift.

Future developments

In 2007 we will analyze in depth the experimental data of the EFPI irradiated in the BR2 reactor. The objective of the analysis is to identify the origin of the induced shift. Possible reasons are the combination of radiation-induced absorption (modifying the light source spectrum) and the compaction effect (physically changing the dimension of the cavity). Based on this analysis a new sensor design will be proposed for evaluation in the BR2 reactor in 2008.

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Main references

[1] G. Cheymol and B.Brichard, "*Optical in pile dimensional measurement: report on the analysis of measurement systems and reference experiment description*", CEA-report, NT DPC / SCP 06-180-A, July 2006

[2] B. Brichard, "*Optical in-pile dimensional measurements: report on the first irradiation tests of optical fibre Fabry-Perot sensors",* ARI/5613/06-03, December 2006