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In-core high temperature measurement using fiber-Bragg gratings for nuclear reactors

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The Pebble Bed Modular Reactor Pty. Ltd. (PBMR) has called for research into the possibility of distributed in-core temperature measurement. In this paper, several methods for distributed temperature measurement in high-pressure, -radiation and -temperature environments have been investigated by means of a literature study. The literature study revealed fiber-Bragg grating (FBG) temperature sensors to be the most feasible solution to the temperature measurement challenge.

Various parameters affecting the propagation of light in optical fibers and consequently the FBG reflection profile was investigated. The differential equations describing FBG structures were solved and implemented in Matlab in order to simulate wavelength division multiplexing (WDM) of a distributed FBG sensing system. Distributed sensing with apodized FBGs written into the sapphire optical fibers is considered.

Temperature measurement using wavelength division multiplexing of apodized FBGs written into silica optical fibers were also demonstrated in a test platform. The measured results corresponded with the theory. It was found that when there is a strong temperature gradient across the FBG, spectral widening of the reflection profile occurs. This fact should be taken into account when allocating bandwidth to a certain FBG and choosing a demodulation algorithm. Sapphire FBGs were also acquired and the optical properties investigated. Furthermore, high temperature stable FBGs written with femtosecond laser radiation in silica Sumitomo Z-Fiber have been evaluated and shown to be a good option for temperature measurement below 1000 °C.

Finally, the implementation of FBGs in a high temperature nuclear reactor is discussed and recommendations are made for future work.

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1. Introduction

A Pebble Bed Modular Reactor (PBMR) project was initiated to answer the global need for cleaner and more effective power generation when the company was founded in 1999. The PBMR would have a first-of-a-kind 400 MWt (165 MWe) inherently safe, helium-cooled, graphite moderated nuclear reactor. A temperature profile of the nuclear core during operation would assist in the improvement of current plant models and the control of the plant itself. A temperature profile of the PBMR core would also be of great interest to the nuclear industry because of its unique design.

In order to address the need for a temperature profile of the PBMR core, it has been suggested that multiple temperature sensors be inserted along the central and side reflectors of the nuclear core. This would provide the operators and control systems with real-time temperature measurements that can be used to monitor and optimize plant control. Integrating a thermodynamic and heat transfer model with several temperature measurements along the reflector wall will allow the temperature distribution along the wall to be determined. Temperatures close to wall-pebble contact points will be higher than in between the contact points, where the coolant can freely circulate. By monitoring the change in temperature of the hotter regions with position and time and idea of the pebbles closest to the wall could be obtained. Hotspots inside the reactor may result in possible temporal deformation of the pressure vessel which can then be closely monitored if temperature measurements are available. The information that a Distributed Temperature Sensor (DTS) in the core can provide is therefore invaluable for safe and stable reactor operation.

Extreme environmental conditions within the PBMR core present the most significant obstacle. The combination of high

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