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Design and Implementation of the Instrumentation and Sensor System for testing of a sub modelled 10 MW offshore superconducting wind turbine.

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Abstract. The large head mass of an offshore wind turbine can be reduced by using superconducting technology. As a proof of concept, a superconducting 10 MW wind turbine for offshore application is investigated under the SUPRAPOWER project funded by EU-FP7. SC coils were developed using MgB2 tapes and cooled to 20 K by a two stage Gifford McMahon cryocooler in a modular rotating cryostat. To study the coil performance and to measure and control the sub model, a LABVIEW based instrumentation system is developed. To measure the temperature distribution in a rotating cryostat, an optical based sensing system is designed and introduced. The effect of rotation on an optical based sensing system is studied. In this paper, the instrumentation along with the thermal characteristics and validation of the optical sensing system for rotating machines and its installation techniques will be reported.

1. Introduction

The SUPRAPOWER (SUPerconducting, Reliable, lightweight, And more POWERful offshore wind turbine) project aims at developing and testing a small sized economic 10 MW wind turbine characterised increased efficiency and maximized power conversion. The Institute of Technical Physics (ITEP) at Karlsruhe Institute of Technology (KIT) is involved in developing the modular cryostat and cryogen free two stage GM cooling system to cool the superconducting (SC) MgB2 rotor coil [1-4]. A thermal load distribution is estimated to understand and validate the design of the modular cryostat shown in Fig. 1 (see reference [4] for construction details) and to determine the cooling efficiency of the cooling system. To measure the thermal distribution along the rotor coil, an optical based Fiber Bragg Grating (FBG) sensors is proposed. A FBG sensor has many advantages and can perform strain and temperature measurements under harsh environment conditions, where conventional sensors cannot operate[5-8].

This paper reports on the sensor and instrumentation design, the initital experiments which demonstrate the effects of rotation on FBG sensors and the thermal characteristics of organically modified ceramic coated and copper coated FBG sensors will be reported. Also a scheme to install the fabricated FBG sensors in a submodelled SUPRAPOWER wind turbine is discussed.

2. SUPRAPOWER Sensor system: Fiber Bragg Gratings

The working principle of a FBG sensor is well documented [9-10]. It's basic working principle is the wavelength reflection due to a change in the grating length, see Fig. 2. Gratings with different

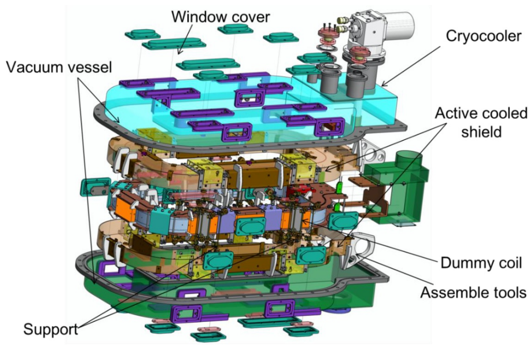

Figure 1. Prototype of SUPRAPOWER modular cryostat arrangement with GM cryocooler connections

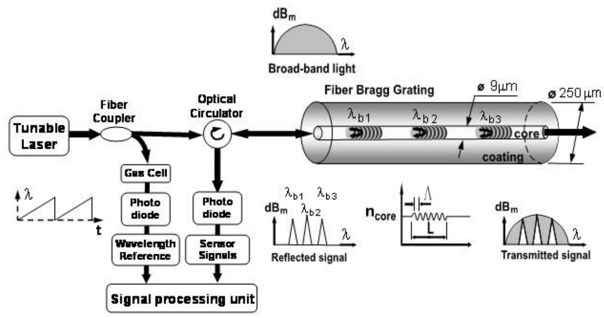

Figure 2. FBG Principle and General Measurement Scheme

spatial period are arranged at various positions along a single mode fiber in the rotor coil of the SUPRAPOWER wind generator. Rotor temperature will vary the grating period, which can be read out with a tunable laser in a wavelength division multiplexing (WDM) scheme. The spectral position of the reflections may be correlated with the spatial position of the gratings, and the shift of the gratings maximum reflection indicates the change of the gratings period is proportional to the temperature change.

2.1. Thermal characteristics

The Bragg-wavelength shift of an uncoated bare FBG sensor does not depend on the temperature change below 120 K. To overcome this problem, the FBG sensors can be attached or coated with material which has a higher thermal expansion coefficient at low temperatures. Proper selection of coating materials and the coating techniques determine the performance and characteristic of a coated optical cryo sensors [10].

The fabricated sensors were placed inside cylindrical holes of a copper calibration block along with a Class B calibrated thin film PT-1000 as reference sensor. The entire setup was then inserted in a cryostat and the communication devices were connected via the optical and electrical feedthroughs. The complete experimental setup is shown in Fig. 3. Liquid Nitrogen is used to cool the system to 77 K and liquid Helium is then used to cool the system further down to 10 K. The response of the FBG sensor array and the PT 1000 sensor is recorded during the cool-down. The system was allowed to warm up to ambient conditions by natural convection. A total of six thermal cycles were done between 4.2 and 10K to anneal the FBG sensor behaviour in this thermal region, to remove internal stresses existing in the coating materials and to study the thermal characteristics in this temperature range. The sensor behaviour was found to be drifting during initial three cycles, but in the last three cycles the thermal behaviour of the sensor become stable and repeatable for all sensors.

Fig. 4 shows the temperature response of the organically modified ceramic coated and copper coated FBG sensors. The plot shows the average values of the last three cycles. It is evident from Fig. 4 that the FBG sensor coated with copper show a higher sensitivity compared to the organically modified ceramic coated FBG sensors. From the experimentation results, it is also found that the copper coated FBG sensors show good repeatability, reproducibility and precision in the temperature range of 300 K- 30 K when compared to the organically modified ceramic coated sensors in which the sensitivity is found to be poor below 50 K. From the measurement, it can be seen that the sensitivity of the organically modified ceramics FBG sensor and the copper coated FBG sensor is 8pm/K and and 24 pm/K respectively.The detection unit having

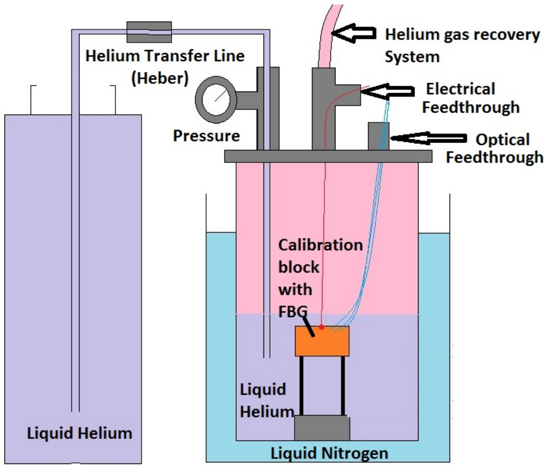

Figure 3. Experimental setup to study thermal dependence of FBG sensors

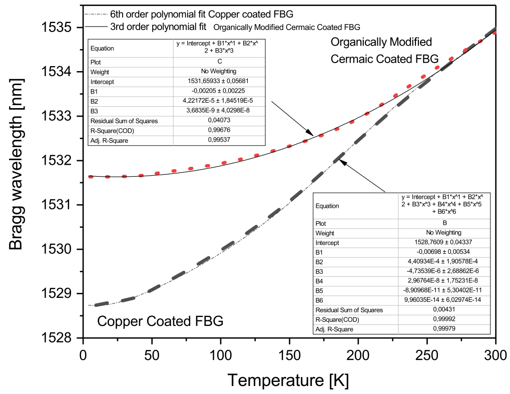

Figure 4. Thermal characteristics of organically modified ceramic coated and copper coated FBG sensors

a resolution of 0.5 pm and the absolute accuracy of ±2.0pm.

2.2. Rotational effects

In order to use the FBG sensors in a SUPRAPOWER wind turbine, it is important to check the survival of FBG sensors in rotating devices and to estimate the associated measurement error induced due to the rotational speed. The vacuum tight rotatory optical feed through (VROF) has to be validated for its signal transmission capability without signal distortion and for the capacity of handling the required rotational speed. To investigate the rotational effects, a simple experimental setup was developed as shown in Fig. 5. One end of the stainless steel tube (SST) was connected to the rotating motor and other end is connected to VROF and then to a detection unit. Initial test were conducted by installing both FBG sensors one after the other in the middle of the tube. The sensor was fixed along a G-10 fiber rod with adhesive tape to avoid any bending of the fiber and to provide mechanical support during SST rotation.

The final test was conducted by installing the sensors between the central tube and an extended arm to study the effects due to centrifugal force by the high speed rotation. For the initial test, the experiment was conducted in four sequences. In sequence 1 and 2, the rotation was increased from 0 to 3600 rpm and then decreased back to 0 rpm. In sequence 3, the sensor was subjected to constant rotation for 10 minutes at 3600 rpm. The sensor then was subjected to pulse ramp up and ramp down in sequence 4. In Fig. 6, it can be seen that for various operating sequences the Bragg wavelength shift is found to be ±6 pm. The corresponding temperature error due to the rotation for a organic modified ceramic coated and copper coated FBG sensor has been estimated to be ±1 K and ±250mK. Also, the Bragg wavelength shift for all sequences of operation lies within ±6 pm and hence it could be corrected for the signal processing. Apart from that, the VROF was able to transmit the signal without any distortion and signal loss.

3. SUPRAPOWER FBG installation plan

Two arrays of copper coated FBG sensors were installed to measure the temperature at 24 locations all along the rotor SUPRAPOWER coil. Each sensor array has 12 sensors which are inscribed using wavelength division multiplexing scheme. The 12 sensors have been equally spaced in a 1.5 m long standard SMF 28 fiber cable. The FBG sensors are also sensitive to mechanical strain and hence the sensors to measure the temperature distribution have been

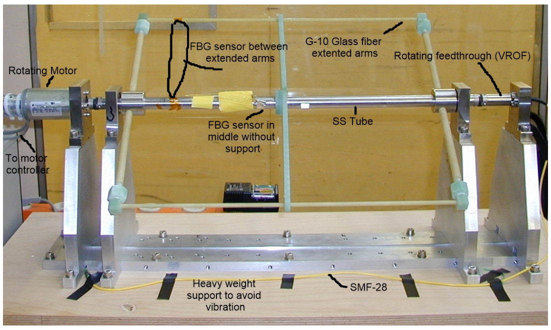

Figure 5. Experimental setup to study rotational effects

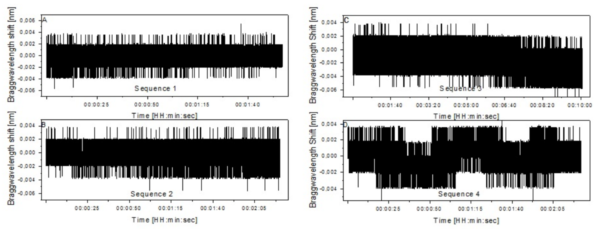

Figure 6. Braggwavelength shift due to rotational effects: A) Ramp Up B) Ramp down C) At constant rotation speed D) Pulsed ramp up and down

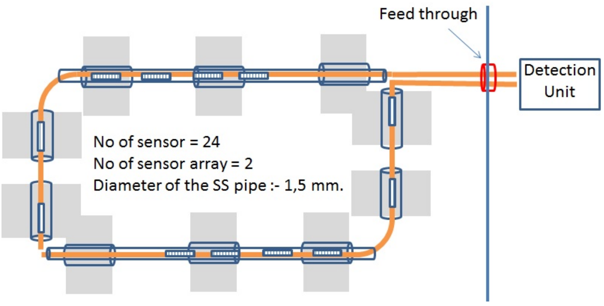

Figure 7. FBG Installation in a SUPARPOWER Model Coil and TVO sensors as secondary measurement

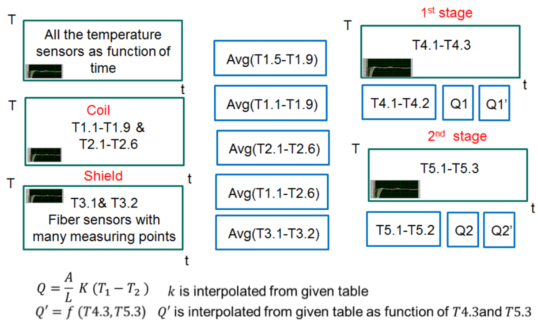

Figure 8. LABVIEW front panel information and control

installed inside a small capillary with diameter of 1.5 mm as shown in Fig. 7. The capillary tube is open at the loaction of sensors to avoid the thermal inertia and to ensure a good temperature measurement. The capillary tube is attached tp the coil using spot welds at defined locations. In the locations of FBG sensors, Apiezon thermal grease has been applied to ensure good thermal contact and efficient heat transport.

4. SUPRAPOWER- Instrumentation

The SUPRAPOWER software runs on a standard desktop or laptop PC and is connected to the measurement devices via standard 100Mbits/s Ethernet NIC. A Labview based program is developed to monitor and control the SUPRAPOWER test setup. The front panel information is as shown in Fig. 8. The schematic system design and hardware components along with its communication architecture is depicted in Fig. 9 and Fig. 10. The connection to the hardwares were established using Ethernet and the VISA protocol. The commands used are described by SCPI. Data acquisition is performed at a maximum sampling rate of 1 Hz. The sensor configuration is performed by means of a configuration file in readable format. The temperature value is calculated from the measured DMM voltage value and the known supply (SUP) current value for the TVO sensors. The necessary characteristic curve for the TVO sensors is given by a sensor specific file. This file will be processed using the KALDAT library. The sensor specific file is selected by the sensors label. Each fiber sensor yields a wavelength value from which a temperature value can be calculated via the characteristic curve given by a sensor specific file. The calculated heat flow for two cold heads, the average temperature of T1.5-1.9, maximum ΔT of shield and coil, cool down curve are measured and stored. The data can be visualized and

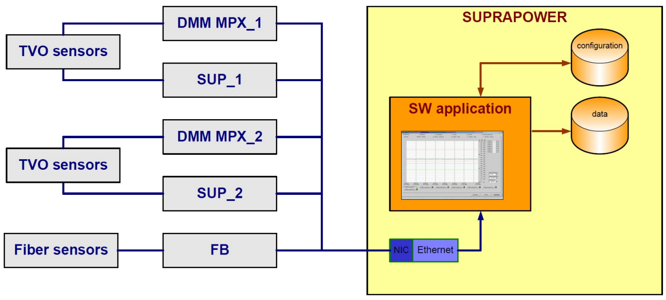

Figure 9. Instrumentation Architecture

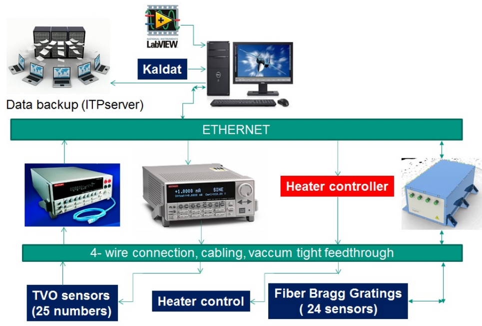

Figure 10. Instruments, communication and cabinet plan

the data storages can be controlled on the GUI of the application.

5. Conclusion

In this work, a FBG sensor coated with organically modified ceramics and copper has been proposed for the use in SUPRAPOWER project. To validate the sensor for its temperature sensitivity and to estimate the errors due to rotation, the thermal characteristics and rotational effects due to centrifugal force on the fabricated sensor have been investigated. From the study, it has been found that the copper coated FBG shows higher sensitivity of 24 pm/K compared to organically modified ceramic coated FBG whose sensitivity is only 8 pm/K. The sensor show a measurement error of ±6 pm which corresponds to ±750 mK and ±250 mK deviation for the organically modified ceramic and the copper coated FBG sensor respectively. The functionality of VROF was found to be satisfactory. A LABVIEW based instrumentation and control architecture have been developed and implemented to study and monitor the submodelled SUPRAPOWER wind turbine performance.

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References

[1] Marloes C, Mark H, Hans-Joerg A, Annette K and Stefanie H 2012 Environ. Sci. Technol 46 4725
[2] Abrahamsen A B, Mijatovic N, Seiler E, Zirngibl T, Trholt C, Nrgrd P B, Pedersen N F, Andersen N H and stergard J 2010 Supercond. Sci. Technol 23 3.
[3] Jiuce S, Santiago S and Holger N, Proc. DKV 2015
[4] Sun J, R. Ramalingam, Sanz S and Neumann H, IOP Conference Series: Materials Science and Engineering, Volume 171, (2017) 012121.
[5] Ramalingam R, Nast R, Neumann H., Sensors Journal, IEEE , vol.15, no.4, pp.2023,2030, April 2015.
[6] Thekkethil, S.R.; Venkatesan, V.N.; Neumann, H.; Ramalingam, R., SENSORS, 2015 IEEE , vol., no., pp.1-4, 1-4 Nov. 2015
[7] R Freitas, F Araujo, J Araujo, R Ramalingam- IOP Conf. Series: Materials Science and Engineering, 101,(2015) 012154
[8] F. Brighenti, R. Ramalingam, H Neumann- IOP Conf. Series: Materials Science and Engineering, 101, (2015) 012087
[9] Hill Kenneth O and Meltz Gerald, Lightwave J, Technol. L715, 1263. 1997
[10] Rajinikumar R, Suesser M, Narayankhedkar K G, Krieg G, Atrey M D. Cryogenics (2009), Cryogenics 49 (2009) 202209