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Flow measurement inside a zinc-nickel flow cell battery using FBG based sensor system

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ABSTRACT

A detailed knowledge of the internal flow distribution inside a zinc-nickel flow battery is of critical importance to ensure smooth flow of the electrolyte through the battery cell and better operation of the device. Information of this type can be used as a useful means of early detection of zinc deposition and dendrite formation inside the cell, negative factors which affect the flow and thus which can lead to internal short circuiting, this being a primary failure mode of these types of batteries. This deposition occurs at low pH levels when zinc reacts with the electrolyte to form solid zinc oxide hydroxides. Traditionally, manual inspection is conducted, but this is time consuming and costly, only providing what are often inaccurate results – overall it is an impractical solution especially with the wider use of batteries in the very near future. Fibre Bragg grating (FBG) sensors integrated inside the flow cell offer the advantage of measuring flow changes at multiple locations using a single fibre and that then can be used as an indicator of the correlation between the internal flow distribution and the deposition characteristics. This work presents an initial study, where two networks of FBGs have been installed and used for flow change detection in an active zinc-nickel flow battery. Data have been obtained from the sensor networks and information of battery performance completed and summarized in this paper. The approach shows promising results and thus scope for the future research into the development of this type of sensor system.

Keywords: Fibre Bragg Grating-based sensor system, zinc-nickel flow cell, flow measurement

1. INTRODUCTION

Electrical energy storage solutions are attracting significant attention at the moment across the range of industries and applications[1] in light of initiatives to increase the use of electrical power across a number of transport sectors. The Redox Flow Battery (RFB) distinguishes itself among a number of emerging technologies in this field as an excellent candidate for large capacity stationary storage applications[2]. Zinc-based rechargeable batteries, such as the zinc-nickel design is one of the most attractive electrical storage solutions, with its main advantages being low cost, abundance of raw materials and simplicity of design. In comparison to other more conventional and widely used counterparts, such are nickel metal hydride batteries, they offer higher energy density in terms of both weight (Wh kg^{-1}) and volume (Wh L^{-1}), since the nominal voltage for the zinc-nickel battery (1.6 V) which is higher than that for the nickel metal hydride battery (1.2 V)[3].

One of the main challenges limiting wider use of zinc-nickel rechargeable batteries is a short life-cycle which is mainly caused by dendrite formation occuring upon charging[4]. This non-uniform electrodeposition is a result of the system being strongly non-linear and far from equilibrium[3]. Investigations have been carried out by a number of researchers under various conditions, and various morphologies of zinc electrodeposition have been identified, including flat, mossy (bulbous), and dendritic[4] types. Ito *et al* have concluded that higher charging rates lead to more dendritic zinc deposits on charging and tend to result in degradation of the cell performance. When the electrolyte velocity is higher than 15 cm s^{-1}, the direction of movement of the dendrites was then toward the flow direction and any internal short circuit was suppressed[3].

In light of meeting the above challenges with zinc-nickel batteries and the importance of having such batteries deployed in a number of applications, there is a need to develop a suitable monitoring method which can provide useful information on electrolyte flow changes due to dendrite formation inside the flow cell. To date, a manual approach, using visual inspection has been the only effective technique used to examine the condition of a battery, looking at dendrite formation – however this technique is both costly and not very accurate[5]. In this work, the use of a Fibre Bragg Grating (FBG)-based technique is proposed, creating sensors to detect both internal flow changes and the flow distribution inside the cell, through the variation in strain that accompanies such flow changes. FBG-based optical sensors are becoming increasingly effective as sensing elements for the number of industrial applications and for the measurement of strain, temperature and wide range of other parameters[6]. Their intrinsic immunity to electromagnetic interference, ease of multiplexing, intrinsically insulating nature and small size and light weight often makes them more suitable than electrical sensors particularly in very harsh environments[7], such are experienced here inside the battery.

2. EXPERIMENTAL SETUP

A FBG-based sensor system was designed specifically for this preliminary study and flow change measurements. To do so, inside a single cell 6 FBG-based sensors, written into two optical fibres were used, where one set of sensors is installed in the horizontal orientation (FBG1H, FBG2H and FBG3H) and the other set in the vertical orientation (FBG1V, FBG2V and FBG3V), as it is shown in Figure 1. The FBG-based sensors in the horizontal orientation were fixed to the top surface of the flow cell, while the vertically oriented sensors were mounted on its bottom side. The main purpose of this arrangement was to investigate the response (and thus the sensitivity) of both sets of sensors to the flow detection changes, in order to understand better the key parameters in this measurement.

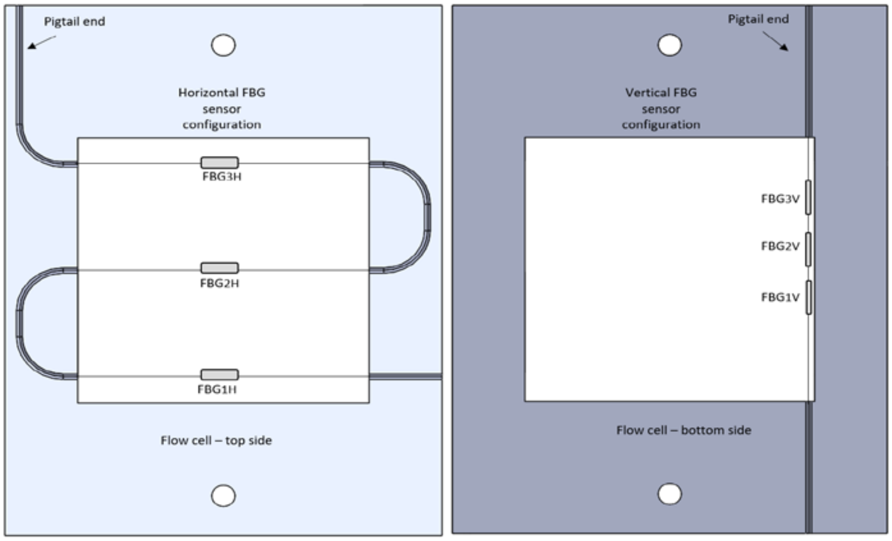

Figure 1. FBG-based sensor system layout on the single flow cell used for the study undertaken

Both optical fibres carrying the FBG-based sensors were integrated inside a previously machined groove on the surface of the flow cell, secured using Duralco 4525IP epoxy (they were pre-strained at different levels, as reported in Table 1). The flow cell in this case is made of Acrylate material, with the following dimensions: 200 x 150 x 6 mm (L x W x H). The instrumented flow cell thus created was placed between two larger pieces of Acrylate in order to ensure appropriate sealing and not to allow liquid to flow out of the cell. Figure 2 shows the experimental setup used.

Table 1. FBG sensor characteristics: baseline characteristic wavelengths and for each the value of pre-strain applied during the installation into the instrumentation in the battery

FBG name	Baseline [nm]	After pre-strain [nm]	Wavelength shift due to application of pre-strain [pm]	Baseline after one test [nm]
FBG1H	1521.62	1521.93	0.32 x 10^3	1521.63
FBG2H	1529.76	1530.12	0.37 x 10^3	1529.79

FBG3H	1539.83	1540.09	0.25 x 10^3	1539.84
FBG1V	1521.59	1521.68	0.90 x 10^2	1521.62
FBG2V	1529.69	1529.78	0.93 x 10^2	1529.71
FBG3V	1539.79	1539.89	0.99 x 10^2	1539.90

The sealed instrumented cell at one end is connected to the shut off valve and the pump (used to allow water is allow water to enter the cell) and the other is connected to the water tank, shown in Figure 2. The optical fibre sensors used are interrogated using a Hyperion 'single board' interrogator (supplied by Micron Optics), providing measurement over the range from 1510 nm to 1590 nm, at a sampling frequency of 1 kHz. The pump laser used for all the tests reported (in the next section of this paper) had power of 19 W and a water flow rate of 800 L/h was used.

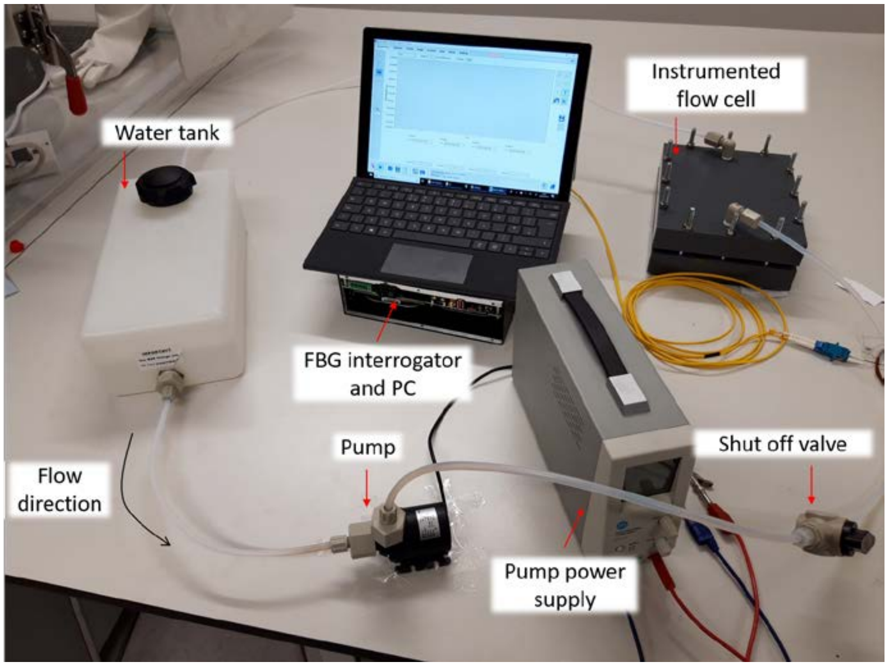

Figure 2. Experimental setup for preliminary study of the flow changes inside flow cell

3. EXPERIMENTAL RESULTS

Before any flow measurement was conducted, using the experimental setup reported in Figure 2, both types of FBG sensor system integrated inside the flow cell were calibrated with respect to any changes in temperature changes by placing the system in an environmental chamber and changing the temperature from 25 °C to 45 ºC, in steps of 5 ºC. A linear response is obtained with a temperature sensitivity of 99 pm / ºC (vertical FBG sensors) and 94 pm / ºC (horizontal FBG sensors).

Figure 3 shows the results of the study of the flow measurement, using both types of sensors, in two different tests (these were repeated multiple times in order to ensure the consistency of results obtained). Figure 3a and 3b show data collected from the first test and it can be seen clearly that the horizontal sensors show a higher sensitivity to flow than do the vertically placed FBGs. It is also very noticeable that the highest flow is detected in the middle of the cell (and by FBG2H), which would be expected for this experimental setup. However, the vertically installed FBGs have not demonstrated as good a capability for useful flow measurement and quite inconsistent data are obtained in both the first and subsequent tests that were conducted. Figure 3c shows data collected by the horizontal sensors during the second tes – this is consistent with all other tests conducted using single cell. Before this measurement was taken, the baseline wavelength of the FBG sensors used was checked and the inspection showed that the previously applied pre-strain had disappeared (which is demonstrated by the result reported in Figure 3). This implies that under these conditions, this particular epoxy does not provide the quality of bonding needed of the fibre to the surface, in the wet environment experienced and a different and better suited epoxy should be used in subsequent tests.

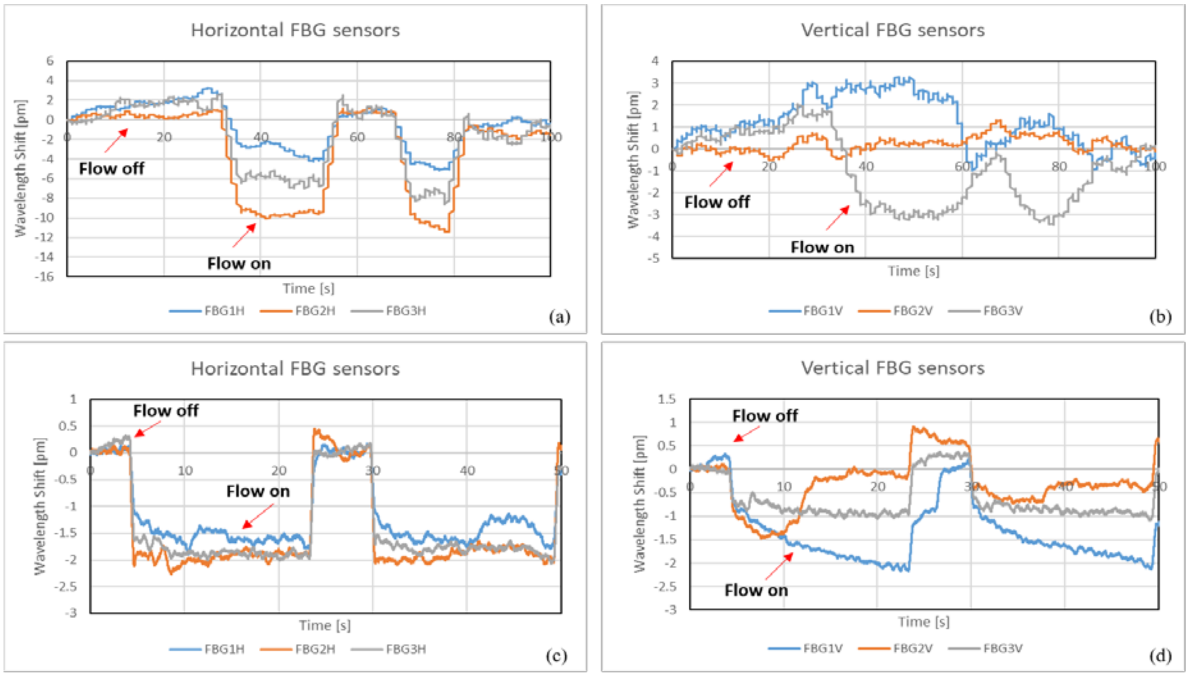

Figure 3. Flow measurement data using horizontal and vertical FBG-based sensors; first test (Figs. 3a and 3b) and second test (Fig. 3c and 3d)

4. CONCLUSIONS AND FUTURE WORK

The outcome of this initial study allows several conclusions to be drawn and thus future actions planned, in order to deliver a better sensing solution for zinc-nickel flow battery monitoring to overcome current challenges. The work done has shown that the horizontal sensors demonstrated are more sensitive to flow changes and that this configuration has the greatest promise for future research. The level of pre-strain used in the sensor is also important, and the results obtained clearly show that once that pre-tensioning of the sensors is lost, their utility and sensitivity to flow changes is significantly reduced. Considering that changes in temperature can occur within the battery in use, there is also a need to provide the familiar additional accurate temperature compensation mechanism by instrumenting the cell with a dedicated FBGs ensuring it is free of strain effects but sensitive to any temperature change. Further, to ensure that the pre-starin that has been identified as necessary is achieved after several tests, an appropriate epoxy has been identified and verified in a similar environment. This will be used in the on-going work which will take the form of a next round of tests where, in addition, a larger number of FBG sensors will be used inside the cell in order to provide a more accurate flow distribution mapping. The results of this investigation will be reported in the near future.

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