DESIGN AND DEVELOPMENT OF AN OCTOPUS THERMOMETRIC SYSTEM FOR THE 704 MHZ SINGLE-CELL SPL CAVITY AT CERN

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Abstract

The octopus thermometric system is designed for the 704 MHz superconducting proton linac (SPL) cavity to detect hot spots and X-rays caused by normal conducting defects and the impact of emission electrons. This system features an octopus body and tentacle structure for good contact with the cavity and easy assembly, a multiplexing circuit with integrated microprocessor for efficient readout and a high density temperature sensor arrangement in order to complete a high resolution temperature and X-ray map. The first prototype is being manufactured and investigations are undergoing for further development.

INTRODUCTION

Thermometric systems have been developed over the past few decades to locate heating or quench spots in superconducting cavities during RF operation. The use of carbon resistors as temperature sensors has become popular in such systems ever since mapping the temperature distribution on the cavity surface was first applied at CERN [1]. The most widely used thermometric systems nowadays are the rigid board based design developed by the Cornell University in 1994 [2]. There have been also R&Ds on different geometrical designs for dedicated cavities [3-4]. At CERN, a newly designed flexible octopus thermometric system for the 704 MHz single-cell SPL cavity is now under development and will be described in this paper.

The paper is split into four parts. First, the design concept is revealed. Second, hardware development and fabrication realisation are presented which is followed by the software development as the third part. Finally, the paper is completed with a summary and future work.

DESIGN CONCEPT & FEATURES

The design takes special account of factors such as thermometer sensitivity, contact with the cavity surface, resolution, reusability, flexibility, and ease of assembly to complete the skeleton of the system. In the end few pieces of software altogether bring the system to life. An octopus-inspired piece proposed here gives an image of flexible tentacles wrapping around an object and attaching it tightly with its suction cups (Fig. 1).

Sensors as the Suction Cups

Allen-Bradley (AB) carbon composition resistors (1/8 W, 100 Ω) have been experimentally proven reliable and with unbeatable sensitivity regardless of thermal cycle issues. The 100 Ω, 5% AB resistors in stock at CERN are also found to be 4 times more sensitive at 1.5 K/2.1 K compared with 1k Ω surface mount thick film resistors [5-6]. Therefore, these AB resistors (100 Ω, 1/8 W, 5%) will be used throughout this one-cell system. However due to cessation of production, the resistors have become scarce. Search for alternative sensors would be crucial and determinant in the near future.

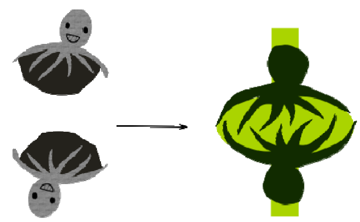

Figure 1: An octopus wraps around an object inspired this thermometric system with two octopuses sitting on opposite half cells.

The Octopus Structure

A complete system requires two octopuses to cover the top and the bottom half cell. One octopus is composed of three parts – the neck part for the iris region, body area for the nearly flat half cell plane, and the tentacles cover the equator region (Fig. 2(a)). Six neck strips each with 3 diodes are responsible for X-ray detection at the welding area. The resolution is at 15 mm (Fig. 2(b)). The 138 resistances on the main cavity area are aligned with 4 circumferences of a common centre point and with 18.4 ~ 19.2 mm spacing on the circle. The interval between each circle radius is 34 mm. There are 15 tentacles on a complete octopus and each has 10 thermometer sensors with 18.3 ~ 20 mm horizontal spacing and 20 ~ 23 mm vertically. The gap between two tentacles is designed to allow one tentacle from the bottom to lay in thus the resolution stays the same on each circumference. A complete system would require 576 resistors and 18 diodes.

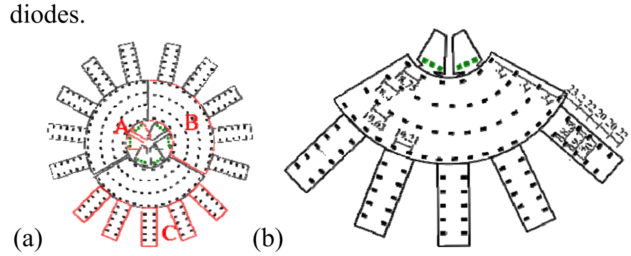

Figure 2: (a) An octopus includes A. a neck part B. main body area and C. the tentacle part. (b) One third octopus with sensor resolution.

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System Assembly

In order to reduce fabrication difficulty, the octopus is divided into three sections and small assembly holes are left for binding later during assembly. The mounting process is composed of three steps – (1) align the neck region with the gap between the strip and body part and fix with a clamp. (2) align the middle AB sensors on each tentacle to the equator (dotted lines in Fig. 2). (3) fix all parts on pre-drilled holes with re-closable fasteners while doing step (2) for the bottom octopus.

Measurement Procedure

Due to the thermal cycle behaviour of the AB sensor, each measurement is preceded by a calibration process done at 2 K and 4 K on all sensors when no temperature gradient presents around the cavity. When the calibration curve is stored for every sensor, the temperature conversion process then starts. The result is visualised in a three dimensional map on a LABVIEW interface, indicating possible heating areas. The overall system is shown in Fig. 3.

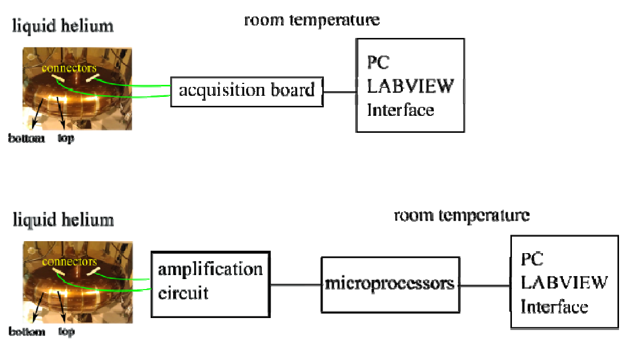


Figure 3: A complete acquisition process block diagram. The bottom process will be chosen finally once the amplification circuit is subject to liquid helium and X-ray exposure test.

HARDWARE DEVELOPMENT & FABRICATION

The first prototype includes 1/3 octopus and two types of acquisition boards for test purposes. Due to the successful result using multiplexers in superfluid by the Kyoto University in 2010 [4], multiplexers are arranged to remain in liquid helium along with CERN made AB sensors and connectors to link to the acquisition boards.

1/3 Octopus & Sensor Fabrication

Kapton is used for making flexible printed circuit of the octopus. The total thickness of the board is 0.1 mm including one Kapton film, two copper layers and a top and bottom cover layers. Each sensor is connected with 2 multiplexers – one provides the reference current input (MUX_I); the other (MUX_V) reads the voltage (Fig. 4). 24 multiplexers and two 50-pin connectors lie on the same side while the other side is mounted with AB sensors. Spare material not occupied by the circuit routing is cut out to improve second sound transmission (Fig. 5). The cover layer of the first prototype (without AB sensors) was damaged when the final fabrication stage – soldering flux removing was done in a professional cleaning machine. The cause requires further investigation to be done in the second assembly.

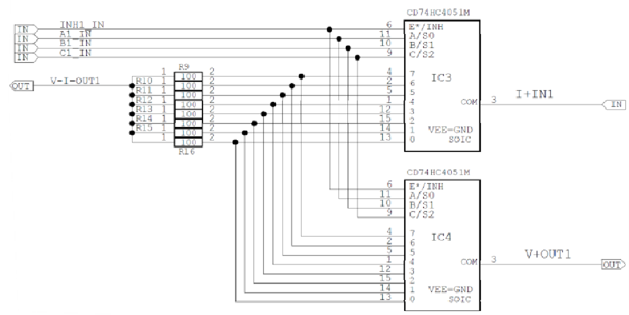


Figure 4: The multiplexer circuit on the octopus for current delivery and voltage measurement.

The method for making the AB sensor package is based on a modified version of the Cornell design. There are two versions to be investigated on a cavity surface – with and without spring support (Fig. 6(a) and 6(b) respectively). These will be mounted on the damaged prototype shown in Fig. 5 for contact test.

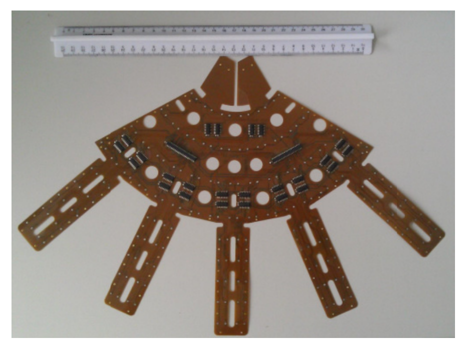


Figure 5: A 1/3 octopus prototype. AB sensors will be mounted when sensor packages are finished. The hollow circle and rectangular space are cut out for second sound transmission. Some areas on the cover layer are peeled away due to the flux cleaning process.

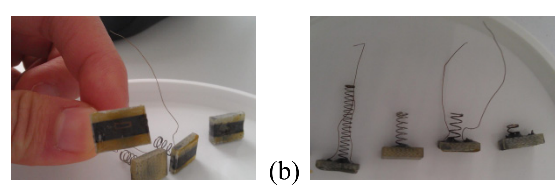
(a)  (b)

Figure 6: CERN made sensor with AB resistors lying in a glass fibre board casing and epoxy. (a) Sensor with two manganin leads will be directly mounted on the octopus PCBs (b) sensors with spring support (diameter ranges from 3 ~ 4.5 mm).

Electronics for Acquisition

A microprocessor (ADuC 831) used in the prototype board is equipped with an 11 MHz quartz which leads to a maximum rate of ~ 4 µs per instruction. 5 µA current

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generated from four current sources (LM334) feeds through four multiplexers (74HC4051M) on the octopus assembly. The voltage amplification part is modified from a PT100/Allen-Bradley circuit designed for the LHC operating in the range 4K to 26K. On the 1/3 octopus prototype, three microprocessors are used and synchronised by an I^2C (Inter-Integrated Circuit) component (P82B96PN). Two prototype boards are ready to be tested. One to be tested in room temperature (Fig. 7(a)) has a full acquisition circuit and equipped with 0 Ω resistors to bypass a voltage amplification circuit. The board containing only the voltage amplification part (Fig. 7(b)) will be placed in helium along with the octopus assembly and connected with the full board (at room temperature). The goal is to verify the IC durability in liquid helium; this enhances circuit performance by avoiding signal loss through long cables.

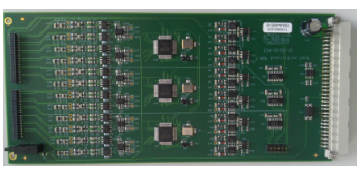
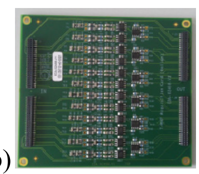
(a)  (b) 

Figure 7: The data acquisition is done by either connecting the acquisition board outside the cryostat (a) or placing (b) the amplifier board in helium with the octopus and connecting to the microprocessors at room temperature.

SOFTWARE DEVELOPMENT

There will be two pieces of programmes used in total – a C programme for the microprocessors and an automatic LABVIEW controlled programme for 3D visualisation on a computer (Fig. 8). The microprocessor program first selects a MUX_I channel (0 to 7) and switches on current sources (all 4 sources) to allow only one reading of voltage on each MUX_V. The programme averages 20 sets of I and V measurements and send result to the computer.

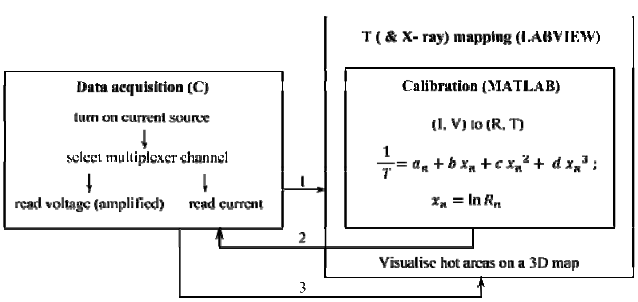


Figure 8: Programmes used during measurement.

A calibration MATLAB code already completed uses (I, V) data that was sent to the computer for obtaining the unique characteristic (R, T) curve of each AB sensor. This will be integrated into a LABVIEW programme which reads temperature sensor value near the cavity and converts (I, V) readings into temperature. On the screen panel, a 3D cavity view with local AB sensor temperature and helium bath temperature will be shown. An optimal mode will integrate this octopus LABVIEW code with second sound quench localisation result from a MATLAB programme [7] and a data from an optical inspection system and its programme [8].

SUMMARY AND FUTURE WORK

The new octopus thermometric system for the SPL cavities is now under development with the parts of a prototype 1/3 octopus system already manufactured. The system features fast measurement time, high resolution maps, good contact with the cavity and reusability.

Sensor fabrication and mounting on octopus flexible board are to be completed and tested on the SPL single cell cavity, along with two acquisition boards and two software programmes. The diode features will then be added to complete the system. A search for Allen-Bradley 100 ohm 5%, 1/8W resistor replacements as acceptable sensors are to be done by testing presently available resistors.

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