PROCEEDINGS OF SCIENCE

Production line and quality assurance of mPMT photosensors for WCTE

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The Water Cherenkov Test Experiment (WCTE) at CERN aims to test technologies related to water Cherenkov detectors. The experiment will use 100 multi-PMT photosensors in a 41-ton water tank. These sensors, each comprising nineteen 3" PMTs, are similar to those that will be used in the Hyper-Kamiokande experiment. The production process involves electronics and mechanics assembly, including application of an optical gel. Rigorous quality assurance was implemented to ensure reliability for long-term data collection. WCTE assembly at CERN has already begun, with data collection expected to start in October 2024.

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1. Introduction

The Water Cherenkov Test Experiment (WCTE) is an experiment that will take place at CERN, aiming to test various technologies and techniques related to water Cherenkov detectors. It will feature approximately 100 multi-PMT photosensors positioned within a water tank measuring 3.8 meters in diameter and 3.6 meters in height, with a total water mass of 41 tons (Fig. 1). Each multi-PMT unit comprises nineteen 3" PMTs and associated front-end electronics enclosed in a water-tight pressure-tolerant vessel. Similar modules will also be used in the Intermediate Water Cherenkov Detector (IWCD) and the Far Detector (FD) of the Hyper-Kamiokande experiment in Japan. The multi-PMT module detectors for the IWCD and the FD share many similarities, but there are some distinct differences:

- The FD version has strict power consumption requirements (below 4W) and must withstand at least 7 bar pressure [3].
- The version for WCTE and IWCD has relaxed requirements in terms of pressure rating and power consumption but should allow operation at high pulse rates and, therefore, utilizes Flash-ADC type acquisition.

This paper will focus on the current state of production of WCTE and IWCD multi-PMTs.

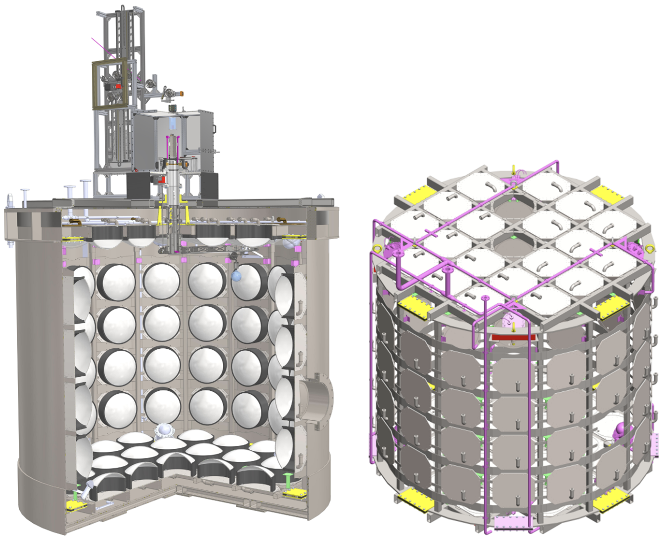

Figure 1: Left: WCTE drawing with tank, mPMTs, support structure and Central Development System (CDS) of calibration sources. Right: Drawing of mPMTs mounted into support structure with water piping [1]

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2. Parts and Gelling process

The main mechanical parts of the multi-PMT pressure vessel include a UV transparent acrylic dome, a PVC cylinder, and a stainless steel backplate with welded feed through pipe (Fig. 2).

Figure 2: Machanical Components of mPMT; Acrylic Dome, PVC cylinder and Back plate

Stainless steel bolts and a clamp ring are used to assemble and secure the acrylic dome to the PVC cylinder. [2]

Multi-PMT modules are equipped with nineteen 3-inch R14374 photomultiplier tubes manufactured by Hamamatsu Photonics, which have a spectral response down to 300 nm, thereby facilitating detection of the Cherenkov radiation. Each tube is equipped with an active high voltage supply board (Fig. 6) that utilizes a Cockcroft-Walton voltage multiplier (HV) and a Front End (FE) board (Fig. 5) that provides control of the voltage multiplier and converts signal from the photomultiplier's anode to a differential signal. FE board is connected to the main board (so-called Big Red Board - BRB - Fig. 3) via a twisted-pair flat cable, terminated with a Micro-Match connector. The analog to digital conversion of signals from all the PMTs occurs on the BRB. Five four-channel, 12-bit, 125 MSPS Analog-to-Digital Converters (ADCs) are used. The control function, as well as digital signal processing, is done using a Xilinx XCZU6EG-1FFVC900I System-on-a-Chip (SoC) mounted on an Enclustra ME-XU1-6EG-1I-D11E System-on-Module (SoM). The power to the mainboard is delivered via Power-over-Ethernet. Each BRB also has a daughter board, the Light Pulser Card (LPC). The LPC provides fast LED-based light sources for timing calibration of the whole detector and slow LED light sources for photogrammetry (Fig. 4). The LEDs are connected to diffusers and collimators mounted into the assembly matrix using optical fibers.

Each PMT is coupled to the acrylic dome by optical gel SILRES® 604 (silica resin), which provides good optical contact. In addition, aluminum reflectors have been used to improve light collection efficiency, as well as to optimize the field of view of each PMT. When it comes to the assembly process of the multi-PMT modules, two gelling strategies were tested:

- The 'Ex-situ' strategy: All PMTs are gelled separately, coupled to 3D printed cups from PLA material. In order to provide the proper shape of the gel, a dedicated mold consisting of two 3D-printed parts and a polished stainless steel bottom plate is used. In order to optimize production time, the gelling was done in batches of 40 units, which provided PMT assemblies for two multi-PMT modules. Then, the PMT assemblies were placed in a 3D-printed matrix attached to the backplate with a pre-assembled mainboard (the BRB). Subsequently, the cylinder with the attached acrylic dome was lowered onto the whole assembly, thus closing the multi-PMT module. This assembly technique requires a large amount of labor, but the main advantage is that it allows for an easy replacement of a single PMT after the assembly of the whole multi-PMT (Fig. 7). The achieved production capacity was four multi-PMTs per week.

- The 'In-situ' strategy: PMTs and reflectors are attached to a CNC-machined foam matrix

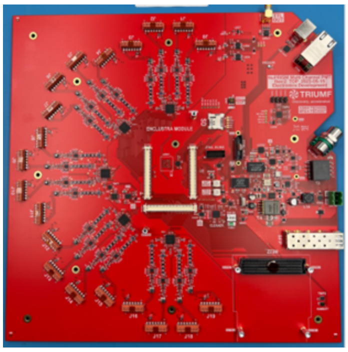

Figure 3: Big Red Board

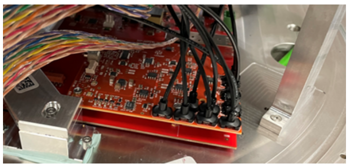

Figure 4: Light Pulser Card with connected fibers.

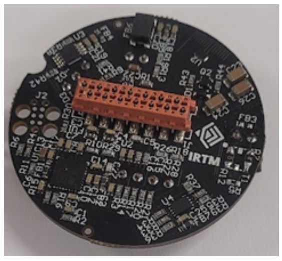

Figure 5: Front End board

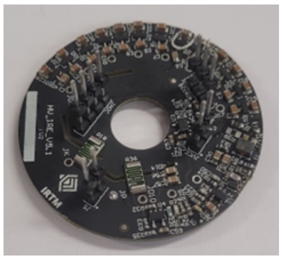

Figure 6: High Voltage board

Electronic Components of mPMT

using a silicon-based glue. Then, the matrix is mounted on stands that connect it to the back plate with the already assembled mainboard (the BRB). Afterward, the gel is poured into the cylinder with an attached acrylic dome, and then the whole PMT and backplate assembly is lowered into the gel. Next, screws are used to secure the backplate to the cylinder, and everything is moved for curing for 48 hours. This technique is less labor-intensive and yields an output of 8 mPMTs per week. (Fig. 8).

Figure 7: Ex-situ mPMT during assembly, with mounted gelled PMTs

Figure 8: In-situ mPMT with PMTs and reflectors, ready to be gelled

3. Quality assurance

The Hyper-Kamiokande experiment is designed for continuous data collection over 20 years. Consequently, all components must be highly reliable, with a large Mean Time Between Failures

(MTBF). Therefore, several quality assurance (QA) procedures were developed and tested during the production of multi-PMTs for the WCTE experiment to ensure the high quality of the modules.

The first step involves checking the High Voltage (HV) and Front End (FE) boards using a dedicated, fully automated tester. Tests include calibrating high voltage, measuring power consumption, checking voltage and current monitoring, and verifying communication and programming procedures (Fig. 9). After positive test results, the boards are soldered to PMTs and covered with an acrylic coating.

Next, we test the PMTs with soldered HV and FE boards in a dark box (Fig. 10). We are using a Light Pulser Card (LPC) mounted on the BRB, and we split the light from the LEDs on the LPC using a commercial optical splitter to illuminate twenty Photomultipliers in the tester. The test takes around one hour and includes a gain scan, a dark rate check, and a threshold scan (i.e., dark rate vs threshold, with LEDs turned off). Also, in this process, the tester is used to check the correctness of the voltage reported by the manufacturer (Hamamatsu) for the expected PMT gain of 5×10^6.

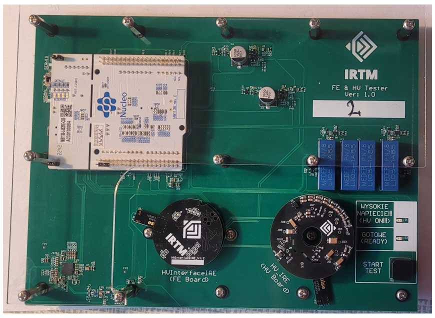

Figure 9: Tester of HV and FE boards

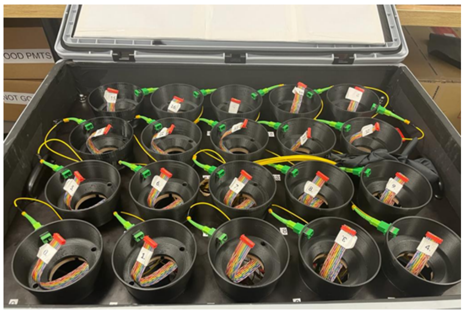

Figure 10: Tester of PMTs with fibers

Then, fully assembled multi-PMT modules are checked in another dark box, with the inside painted with reflective white paint (Fig. 13). The test's purpose is to obtain final confirmation that all the sub-systems in the multi-PMT work correctly. The test process utilizes fast LEDs that are now part of the multi-PMT, eliminating the need for additional testing equipment.

Selected modules were also measured using an XYZ Robot (Fig. 11), which provided a detailed performance scan of the module. In this case, the light source was a picosecond laser with a wavelength of 405 nm. The robot scans the whole surface area of the multi-PMT. In addition to 3-axial movement, the robot can also change the fiber collimator's angle, which, on the one hand, allows to ensure perpendicularity of the incident light to the surface of the acrylic dome, and on the other to also check performance with various angles of incidence of the incoming light. Fig. 12 presents scan results for a case when a thousand waveforms were recorded and analyzed for each robot position.

4. Summary

The WCTE represents the first opportunity to test Hyper-K type multi-PMTs in a working experiment. The production process has been finished and approx. 100 modules were manufactured at two production sites (in Poland and in Canada). Two assembly strategies were tested and the 'in-situ' strategy was chosen for the assembly of remaining modules that will be prepared for the

Figure 11: Tester of mPMT with XYZ robot inside

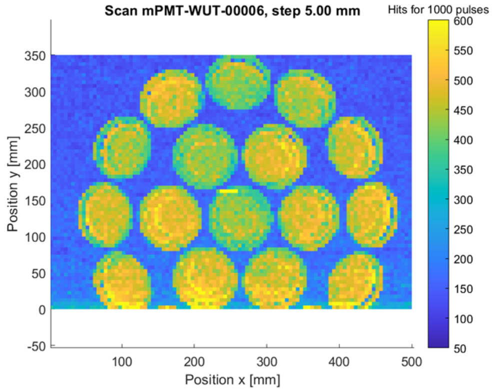

Figure 12: Scan of mPMT in tester with fast laser with 5mm step

IWCD detector in Hyper-Kamiokande. The assembly of the modules in the WCTE detector frame in CERN is ongoing (Fig. 14), with expected completion in September 2024. Data taking will start in October 2024.

Figure 13: mPMT black box tester with matte white paint inside

Figure 14: mPMTs delivered to CERN, ready for assembly in the frame of the wCTE detector

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[2] Mechanical design of multi-PMTs for IWCD, 10.1088/1742-6596/2374/1/012134

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