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Technical notes

Online fault diagnostics and testing of area gamma radiation monitor using wireless network

Padi Srinivas Reddy[a,*], R. Amudhu Ramesh Kumar[a], M. Geo Mathews[a], G. Amarendra[b]

[a] Reprocessing Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, TN 603102, India
[b] Material Science Group, Indira Gandhi Centre for Atomic Research, Kalpakkam TN 603102, India

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ABSTRACT

Periodical surveillance, checking, testing, and calibration of the installed Area Gamma Radiation Monitors (AGRM) in the nuclear plants are mandatory. The functionality of AGRM counting electronics and Geiger-Muller (GM) tube is to be monitored periodically. The present paper describes the development of online electronic calibration and testing of the GM tube from the control room. Two electronic circuits were developed, one for AGRM electronic test and another for AGRM detector test. A dedicated radiation data acquisition system was developed using an open platform communication server and data acquisition software. The Modbus RTU protocol on ZigBee based wireless communication was used for online monitoring and testing. The AGRM electronic test helps to carry out the three-point electronic calibration and verification of accuracy. The AGRM detector test is used to verify the GM threshold voltage and the plateau slope of the GM tube in-situ. The real-time trend graphs generated during these tests clearly identified the state of health of AGRM electronics and GM tube on go/no-go basis. This method reduces the radiation exposures received by the maintenance crew and facilitates quick testing with minimum downtime of the instrument.

1. Introduction

The AGRMs are GM tube based instruments for continuous monitoring of gamma radiation in and around the nuclear plants. After the invention of GM tube in 1928, the electronic technology of radiation monitors evolved from vacuum tube based electronics to the transistor, microprocessor, microcontroller and field programmable gate array based electronics. Similarly, data communication technologies from field radiation monitor to the control room has been advanced from 4 to 20 mA current loop, RS-232, RS-485, Ethernet and wireless networks. In nuclear facilities, the wireless networks are a novel technology with the potential to perform distributed sensor tasks [1], especially online monitoring and control. The wireless network provides easy installation, substantial cost reduction, redundancy path for real-time nuclear systems and where processing time is one primary requirement of I & C system design. The ZigBee based wireless communication is preferred in this work over the other technologies [2] Wi-Fi, Bluetooth, Wibree, and Ultra wideband, etc. It is mainly because of its low power consumption, considerable long range and low cost. The commercial ZigBee transceivers are provided with an integrated antenna, media access control, and physical layer inside the module.

The AGRM provides the Dose Rate (DR) measurement range from 0.1 to 1000µSv/h with an accuracy of ±10%. The AGRM is a microcontroller based counting electronics, interfaced with LCD, alarm set keypad, visual & audio alarm, detector probe, and an RS-485 communication port. The detector probe contains a GM tube, High Voltage (HV) circuit, and pulse processing electronics enclosed in a thin SS enclosure. It displays the radiation DR locally and enables the visual & audio alarm if the DR level crosses the alarm-preset level.

The conventional method of manual surveillance of these device suffers from high man-Rem expenditure, contamination, more time consumption, high cost, lack of precision and downtime of the instrument [3,4]. The emerging technologies can be used for the complete fault diagnostics, online testing, and calibration [5,6]. Two electronic circuits were developed, one for AGRM electronic test and another for AGRM detector test. These circuits were installed in prototype AGRM. The online AGRM electronic test detects the faults associated with the pulse processing and counting electronics of the AGRM. It includes the functionality of passive components, amplifier, sensitivity [7], pulse shaping, and digital circuits. The three point electronic calibration provides checking of the accuracy of the AGRM. The percentage of relative intrinsic error [8] is calculated at these points to verify the accuracy. The online AGRM detector test is designed based on count-rate versus applied HV characteristics of

* Correspondence to: Reprocessing Group, IGCAR, Kalpakkam, Tamilnadu 603102, India.
E-mail address: padi@igcar.gov.in (P.S. Reddy).

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the GM tube. The HV characteristics of GM tube gives the information [9] about i) GM threshold voltage, ii) Minimum operating voltage, iii) Maximum operating voltage and iv) Recommended operating voltage. The life of GM tube depends [10] on a) GM threshold voltage, b) Plateau length, c) Plateau slope (% of count rate/100 V) and d) Background count rate. The state of the GM tube in the installed AGRM cannot be judged easily based on the background, due to the continuous background variations in nuclear plants. The values of GM threshold voltage, Plateau length, and Plateau slope are considered as per the technical specification [11]. The GM threshold voltage and plateau slope play a crucial role to decide the life of the GM tube. These parameters are expected to change due to vibration, high temperature, age, the chemical reaction of the primary gas, and loss of quenching mechanism [12,13] inside the GM tube. The online testing of GM tube is nothing but verification of the GM threshold voltage and plateau slope [14] in the limits. A dedicated Radiation Data Acquisition [15] System (RADAS) was developed using an Open Platform Communications (OPC) server and Supervisory Control And Data Acquisition (SCADA) software in Server PC. The Modbus RTU protocol [16] is used on ZigBee based wireless communication to exchange data between Server PC and field device. The Modbus protocol address tags were configured for real-time data monitoring, testing and recording in a structured query language database for every 100 ms interval. The database is used to generate reports, history trend graphs for post analysis of radiation data and checking healthiness of AGRM.

2. Experimental

2.1. Materials and methods

2.1.1. AGRM Electronic test circuit

The AGRM electronic test circuit was designed and developed using discrete electronic components is shown in Fig. 1. The circuit contains two relays, the timer, decade counter, and an oscillator to generate test frequency. The frequency accuracy of the circuit was ±0.2% of full scale from 100 Hz to 2000 Hz at room temperature. The circuit was fine-tuned for required Transistor-Transistor Logic (TTL) output, frequency, pulse width, and timing. The test frequency was applied at the input stage of AGRM counting electronics. The frequency was selected based on the sensitivity (180CPS/μSv/h) of the GM tube. Three DR points were selected at 100 μSv/h, 500 μSv/h, and 900 μSv/h. The equivalent test frequencies at these points were 180 Hz, 900 Hz and 1620 Hz. The time interval is approximately 30 s at each step for stable DR reading on AGRM display. During the online calibration, two relays will energize simultaneously, a two-pole relay (RL1) to latch the test frequency oscillator. Another single pole relay (RL2) was to disconnect the GM tube temporarily from the counting electronics. It is to avoid the background DR during the calibration for better accuracy. At the end of calibration test, the circuit will automatically connect the GM tube for normal operation. In Fig. 2, the profile of TTL test frequency applied to counting electronics of AGRM is shown.

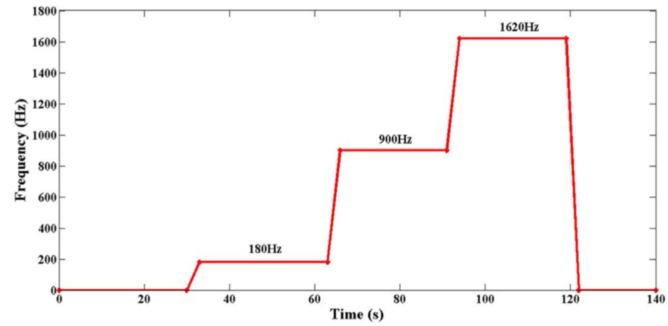

Fig. 2. The test frequency profile applied to the AGRM counting electronics during the AGRM electronic test.

2.1.2. AGRM detector (GM tube) test circuit

The state of health of GM tube in the AGRM was tested using HV characteristics. The conventional HV circuit is a DC – DC converter and provides a constant 500VDC to the GM tube for normal operation. The HV circuit was modified so that it generates three different HV outputs as per the electrical specifications of GM tube during the test. An AGRM detector test circuit was designed and developed using discrete electronic components as shown in Fig. 3. The circuit consists of a two-pole relay, timer, and decade counter. The output of this circuit was connected to error amplifier to control the output HV.

During the online AGRM detector test, a relay (RL1) is latched to activate the timer. The output of error amplifier was connected to the input of the pulse transformer through the push-pull amplifier. It is to obtain the output HVs of 320 V, 450 V, and 650 V for the time interval of 30–80 s at each step. The accuracy of HV output is ±0.5% of full scale from 320 V to 650 V at room temperature. The HV at 320 V is just below the GM threshold voltage (325 V), where ideally no counts are expected for a working GM tube. The HV at 450 V is the minimum operating voltage, and 650 V is the maximum operating voltage. At the end of the test, the circuit will automatically connect 500 V, which is the standard operating voltage of the GM tube. The mean DR values of the AGRM at each step were used to calculate the percentage of plateau slope. In Fig. 4, the HV test profile applied to GM tube is shown.

2.1.3. Configuration of RADAS

A dedicated RADAS was developed using OPC server and SCADA [17] software in Server PC. The prototype AGRM with test circuits was linked to the OPC server using Modbus RTU on RS-485. The required serial communication parameters like device ID, port address, baud rate, data bits, parity, stop bits were configured in OPC Server for communication with the field device. A Modbus protocol supported digital output module was used to activate both AGRM electronic test and AGRM detector test circuits from RADAS. This module can be waived if the AGRM is provided with two Modbus digital outputs.

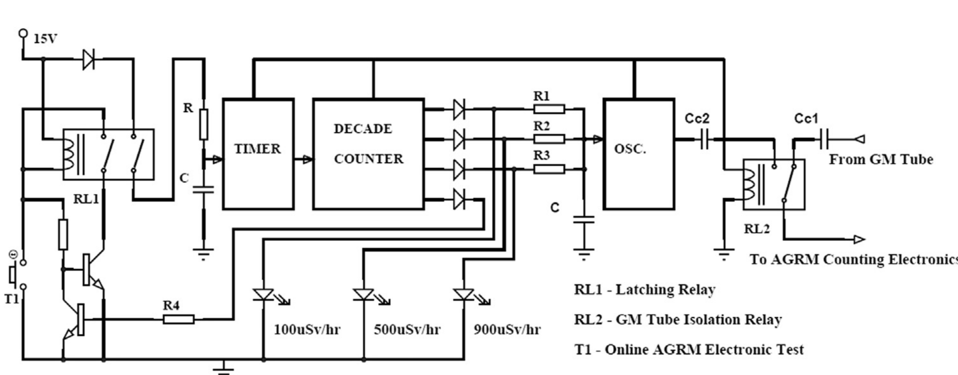

Fig. 1. TTL test frequency generating circuit for AGRM electronic test.