Development of Reader System for Superheated Emulsion Neutron Detector and its Performance Evaluation

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Abstract—The paper presents development of microcontroller based automatic reader system for neutron measurement using indigenously developed superheated emulsion detector and its performance evaluation. The system is designed for real time counting of bubbles formed in superheated emulsion detector. A piezoelectric transducer is used for sensing bubble acoustic during the nucleation. The front end of system is mainly consisting of specially designed signal conditioning unit, piezoelectric transducer, an amplifier, a high-pass filter, a differentiator, a comparator and mono-stable multivibrator. The system is based on PIC 18F6520 microcontroller having large internal SRAM, 10-bit internal ADC, I²C interface, UART/USART modules. The paper also describes the design of following microcontroller peripheral units viz temperature monitoring, battery monitoring, LCD display, keypad and a serial communication. The reader system measures and displays neutron dose and dose rate, number of bubble and elapsed time. The developed system can be used for detecting very low neutron leakage in the accelerators, nuclear reactors and nuclear submarines. The important features of system are compact, light weight, cost effective and high neutron sensitivity. The prototype was tested and evaluated by exposing to ⁴⁰⁰Am-Be neutron source and all the results are compared with response of the conventional neutron REM counter (Cardinal Health, Australia).

Index terms—Micro-controller, piezoelectric transducer, superheated emulation, neutron detector, signal conditioning and processing; inter system programming (ISP).

I. INTRODUCTION

"Ref. [1]" The superheated emulsion based detector invented by Apfel is based on bubble chamber principle. The drops of low boiling refrigerant are suspended in a host polymer matrix. When neutron interacts with these droplets, the nucleation (bubbles) occurs. The number of nucleation or bubbles can be correlated to neutron equivalent dose. The formation of bubble is accompanied with acoustic. "Ref. [2, 3]" Apfel enterprise & Bubble technology Industries, Canada have also been reported such type of neutron survey meter using acoustic technique.

"Ref. [4, 5, 6, 7, and 8]" Defence Laboratory, Jodhpur (DLJ) is actively engaged in developing superheated Emulsion Technology for neutron and gamma measurements and finally succeeded to establish this technology. Fig. 1 shows the photograph of DLJ developed superheated emulsion based neutron detector before and after the neutron exposure. After establishing the technology of superheated emulsion based gamma and neutron sensor, the laboratory has attempted to develop reader system indigenously using acoustic technique. The developed reader can be used as a neutron survey meter for detection and measurements of the neutron intensity in reactor and accelerator environment, Medical Cyclotron, neutron leakage in nuclear submarines and neutron flux measurements during blast of enhanced radiation weapons like suit case bomb or neutron bomb. The reader system finds extensive applications in research laboratory as a neutron area monitor for occupational workers.

The conventional REM Counter used as a neutron area monitor are bulky, heavy and does not measure cumulative dose. Considering these disadvantages, the efforts have been made to develop a compact and light weight electronic instrument (a reader system) based on superheated emulsion detector. The developed reader system consists of high performance PIC 18F6520 microcontroller which has on chip large internal memory, ADC, serial communication and peripheral modules etc. The C code programme is written using MPLAB software development tool.

The paper discusses about the technical design details of the developed acoustic bubble reader system and its performance evaluation compared to conventional neutron REM counter. The advanced electronic modules designed indigenously, fabricated and got assembled. The developed prototype reader system has also been tested in neutron radiation environment and results are presented.

II. SENSOR DEVICE & DETECTION TECHNIQUE

Unexposed Exposed

Fig. 1 Superheated Emulsion drop detector
Fig. 2 Reader system

Fig. 3 Inner view of the reader system

Fig. 1& fig. 2 show an indigenously developed superheated emulsion drop detector and developed reader system. The detectors consist of polycarbonate tube of 4 cm³ volume filled with sensor material and a pressure screw cap. The sensor material is a transparent polymer medium suspended with liquid drops of refrigerants.

When the pressure on the detector matrix is released by unscrewing the top of the detector, the liquid droplets become superheated. These superheated droplets vaporize into bubble on interaction with neutrons. The number of bubbles is proportional to equivalent dose. The bubbles are fixed in elastic medium and can be subsequently counted visually or with the help of macro lens. “Ref. [9]” The automatic bubble counting is also carried out using imaging software as well as by acoustic technique.

The acoustic technique has an advantage that both dose and dose rate can be measured. The acoustic signal is generated when neutron energy is transferred to superheated droplet uniformly suspended in polymer matrix, forming a bubble. Re-compressing the detector materials transforms the bubble back in to droplet and detector can be reused. Fig.3 shows the inside look of sensor and reader system.

III. SYSTEM DISCRIPTION

The block diagram of reader system is shown in Fig. 4. It consists of PIC18F6520 micro-controller unit with I/O interfaces modules. The system has the following interfacing modules.

(i) Signal conditioning and anti coincidence circuit (ii) Temperature monitoring circuit (iii) Audio-visual signaling unit (iv) Real time clock (v) Display and keyboard interfaces (vi) Battery monitoring unit (vii) RS-232 Interface (viii) Power on reset circuit.

The acoustic generated in bubble formation is sensed by piezoelectric transducer (AP 48) and converted into electric signal. A signal conditioning circuit is developed to provide noise elimination, amplification and conversion of signal into TTL pulse. The signal conditioning circuit comprises Instrumentation amplifier, band pass filter, comparator and non-retrigable mono-stable multivibrator as shown in the figure 5. The band pass filter is designed to pass frequency band of 200 Hz to 120 KHz which further reduces the noise.

The output of the band pass filter is connected to comparator which eliminates noise below a set threshold 100mV. The output of the comparator is fed to mono shot whose time constant is set to 300µS such that ringing pulses are eliminated. Fig.6 shows the output signal of the piezo-electric signal transducer which is generated during the one bubble event. The signal comprises of main pulse along with small pulses due to ringing effect. The signal has 30µs rise time and complete event takes 250µs time. The outputs of mono-stable multivibrators are TTL pulses.
applied to the microcontroller unit through anti coincidence circuit.

The anticoincidence is designed to avoid the false bubble counting due to external noise (shock and vibrations). The anti coincidence circuit comprises of two piezoelectric transducers mounted on same plate, one in contact with superheated emulsion detector and other in contact with environment. The output of piezoelectric transducer is passed through signal conditioning units, and fed to XOR gate for coincidence removal of environmental noise. Finally the filtered signal will be fed to the PIC microcontroller for computing neutron dose and dose rate.

A temperature monitoring of the neutron sensor, is realized using temperature sensor (Pt100) which is in contact with bubble detector. The output of the temperature sensor is processed and fed to ADC of microcontroller for necessary corrections. The audio-visual alarm indication can be set at three different radiation levels. PWM of microcontroller generates different frequencies whenever neutron exposure exceeds the set dose level. Real Time Clock (RTC) DS 1307 is used to keep record of time and date while storing the readings of the reader systems. 2x4 key pad is used to interact with the system and connected to the interrupt pin of microcontroller. Liquid Crystal Display (LCD) is used to display information of the neutron dosimeter like bubble count, neutron dose, neutron dose-rate, temperature, elapsed time etc. The readily available 16×4 alphanumeric LCD Display Module from Oriole having built-in controller & driver was interfaced directly to the microcontroller.

IV. IMPLEMENTATION

A. Hardware

The simulation of different circuits and their PCB designs were carried out using Virtual System modeling software along with PCB design from M/s Proteus, UK. The entire component has been mounted and soldered on the PCB. Functionality of the electronic modules have been tested and interfaced with the micro-controller unit.

B. Software

The microcontroller firmware software was written in plain C code using development tool (MPLAB) that is provided by Microchip. The MPLAB package includes an assembler, a C compiler, a linker and series of debugging tools that allows easy development of applications. "Ref. [10]" provision in the software is made for user to initially select a type of detector and type of the detector sensitivity depends on the quantity of refrigerants used. To cover entire dose rate range from 0.01µSv/hr- 0.01Sv/hr., a provision is made in software to select from three types of detectors i.e. high sensitivity moderate sensitivity and Low sensitivity. The non linearity in the sensitivity is corrected using interpolation technique.

V. PERFORMANCE EVALUATION

Experiments were conducted for neutron response of superheated emulsion detector and the comparison of performance study of neutron reader system with REM Counter (Cardinal Health, Australia). The superheated emulsion detector device was acoustically coupled with piezo electric transducer of the reader system. The output of the transducers is connected through coaxial cable to the signal conditioning circuit of reader system. During the experiment the superheated emulsion detector device was irradiated using calibrated 1Ci Am-Be neutron source. The Radiation source was procured from Amersham, U. K. in 1984 and has a half life time of 470 years. The output of the source is calibrated against pre calibrated Rem counter. The distance between the source and superheated emulsion detector device is varied for testing at different dose rates. To carry out neutron response study of superheated emulsion detector device were exposed to 1Ci Am-Be neutron source at a dose rate 115µSv/h. The height of the neutron sensor and the neutron source is kept 1.5 meter above the surface to minimize the interference of surface scattering on the neutron response of the superheated emulsion detector.

VI. RESULTS AND DISCUSSIONS

The performance study of microcontroller based reader system was carried out by exposing superheated emulsion detector to 1 Ci Am-Be neutron source. Fig. 8 shows comparison of acoustic and visual bubble counts. The straight line curve shows a linear relationship between the bubbles formed in superheated emulsion detector device and bubble displayed by reader system. Fig.9 shows the comparison of neutron dose response studies of superheated emulsion detector using developed reader system and REM counter have been carried out and results shows linear relationship from 10µSv - 120µSv for detector having sensitivity of 1bub/µSv. Fig. 10 shows neutron dose rate response. The curve shows flat response from 17µSv/h to 115µSv/h. It is comparable with the standard REM Counter. Fig. 11 shows relation between expected dose rate and observed dose rate. The curve shows linearity and comparability with the existing instrument (REM Counter).
CONCLUSION

The developed neutron reader system is a light in weight (1 kg) and has high sensitivity as compared to conventional neutron survey meters. The system was tested with $^{241}$Am-Be source and results confirms the suitability of developed electronic instrument for measurement of neutron dose, dose rate. The relationship between visual counting and acoustic counting of bubbles formed due to neutron exposure is within the permissible limits. The work is in progress to collect some more data using low and moderate sensitivity detectors. Further experiments will be conducted using other threshold energy neutron detectors. The development of neutron zone monitor with provision for automatic compression /decompression is in progress for continuous neutron monitoring in the restricted zone.

REFERENCES