Optical fibres for ionising radiation measurements

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Abstract—The work focuses on studying methods of measuring ionizing radiation using optical fibres. More attention is paid to their use, together with scintillation materials. The proposed method allows the connection of an electronic detector with a scintillation sensor by optical means. The interconnection provides the possibility of shielding the detector from the effects of high ionizing radiation activities. The shielded detector will thus not be subject to the adverse effects of this radiation and can be used even for long-term measurements of high activities. First experimental measurements of reference sources verify the principle of the proposed method.

Keywords—Ionizing radiation, scintillation detectors, ionizing radiation measurement, optical fibres.

I. INTRODUCTION

Ionizing radiation has been utilized widely for a very long time in many different fields. A significant increase in detection possibilities has resulted from its widespread use, which is crucial for the preservation of human life. Geiger-Müller counters and photosensitive materials were used in the beginning. Further options, including the utilization of semiconductor structures or the scintillation of specific materials, were gradually introduced. All these techniques can be used to measure ionizing radiation activity. However, exposure to high activities usually damages the detection electronics and shortens the detector’s lifetime.

To get around this issue, optical fibres are used. This prevents ionizing radiation from harming the typically expensive detector electronics. Yet, the use of optical fibre as a radiation sensor also has drawbacks due to its limited range, low sensitivity, and typical requirement for material implementation.

The technique we suggest combines the utilization of optical fibres with a scintillation crystal-based luminous sensor. This will eliminate the requirement for optical fibres that require special modifications and open the way for optical fibres that are highly resilient to radiation damage and commercially available. Moreover, using a scintillation crystal enhances the measurement range and adds the required sensitivity. The overall design will provide a way to position the electronics away from radiation damage. As a result, we can measure high gamma radiation doses over long periods of time [1][2].

II. METHOD DESCRIPTION

There are three major elements to the entire measurement. They are the detector, communication path, and sensor. The detector is positioned outside of radiation range. For our measurement, we are using primarily photomultiplier tubes (PMTs). Another detector, such as a silicon photomultiplier or single photon counter, might be used as an alternative. The communication path consists of optical fibre with high radiation resistance. Optical fibre servers purely as transport for photons between sensor and detecting PMT. The final part is scintillation material, which is exposed to radiation. We are using inorganic materials, also called scintillation crystals.

A. Principle

Radiation interacts with scintillation crystal. Thanks to material properties, specifically fluorescence, material is able to convert high-energy photons into ones with lower energy. Newly formed photons have wavelengths that fall inside the visible-light spectrum. One photon of gamma radiation creates several visible photons, resulting in the creation of a light pulse. Thus, light pulses hold information about activity and energy. A schematic connection is displayed in Fig.1.

Light pulses are routed to optical fibre. Pulses are able to travel long distances due to low attenuation of optical fibres. By doing so, we can easily lead the light signal from the measured location and protect the detector from radiation exposure. The light pulse is then caught by detector and converted to an electrical pulse for later calculations. Detection

Fig. 1. Scheme of the proposed method
depends on device used. PMT maintain information about energy in form of amplitude and activity in form of pulse count. After signal processing, there are many things we can learn about the initial radiation, including, for example, which particle caused the pulse. For the purpose of this work, the activity of gamma radiation is measured. Then, one of the previously mentioned detectors can be used. Especially single photon counter which only provides information in the form of pulse count [2].

B. Scintillation crystal

We are using scintillation materials for the conversion of high-energy particles (in our case, high-energy photons of gamma radiation) to visible light. This process is possible with some materials thanks to fluorescence. Fluorescence is a very quick reaction and creates light photons almost immediately after radiation passes through material. Creating a thin light pulse to observe. There are other processes that are competing with fluorescence and decreasing the effectiveness of the scintillator. Especially phosphorescence and slow fluorescence which create after-glow effect. Last mentioned is loss due to heat transfer in material [1].

There are two types of scintillation materials: inorganic and organic scintillators. Each material has a different mechanism for luminescence therefore each has unique advantages. It is high light-yield for inorganic materials and a quick response for organic ones. We choose to use cerium doped lutetium-based scintillation crystal (LYSO). It is inorganic material and has one of the highest densities among scintillators. Materials with higher densities are better at absorbing radiation. Also, LYSO is one of the materials with a higher light yield. These are reasons for choosing this type of scintillators [3] [4].

The scintillation crystal is stored in a steel case that prevents random light interference. When radiation passes through crystal, it creates photons with random directions. Random direction creates a great loss in signal strength because optical fibre is attached only to one side. To reduce this loss and increase signal output, we cover the crystal with Teflon tape. Teflon works perfectly as a mirror for light waves generated by LYSO crystal. This way, we can link more photons to fibre and reduce light loss [2]. The LYSO crystal is shown in Fig. 2.

C. Optical fibre

We use multimode optical fibres with higher radiation resistance covered with steel protection tube to extend the life of optical fibres and avoid mechanical damage. We achieve resistance to radiation by choosing a pure silica core of optical fibre. A larger core diameter and a high numerical aperture (NA) are also essential properties. By doing so, we may extend the distance between the sensor and the detector, the life of the fibre, and the quality of light signal extraction on the sensor side [5] [6].

Multimode optical fibres are obtained from Thorlabs with the marking FP1000URT and FP1500URT. The number marks the core diameter in micrometres. Refractive index of fibres is 1.458434 and NA is 0.50. Higher hydroxyl content of these fibres decreases attenuation in the UV parts of the transmitted spectra [7].This is necessary because scintillator we are using has a light emission peak around 415 nm [3]. This modification decreases signal loss but also decreases radiation resistance. Optical fibres need to be adjusted, properly shortened, and shielded with protection to make measurements repeatable. This process is described in Chapter 3.

D. Detection

The second end of the optical fibre is attached to the detector. Light pulses have a very low level of amplitude. To be properly read, we are using a photomultiplier tube. The photomultiplier tube converts light pulses into an electrical signal. Every incident photon reacts with the electrode by emitting an electron. The electron then travels via tube and hits a system of dynodes. Every electron that hits a dynode emits extra electrons as a result of secondary emission. This way, we can get an electric pulse of higher amplitude, which can be much easier to process. Mechanism of signal conversion enables to keep information about amplitude of former light pulse. Amplitude provides details about radiation energy. As mentioned, we are focusing on radiation activity. The activity of the source can be calculated from the number of detected pulses. Pulses can also be detected by the single-photon counter (SPC). The SPC principle is similar to that of an avalanche diode. An incident photon launches an electron avalanche that creates an electrical pulse. The SPC has the advantage of not requiring a high voltage source [1] [8].

III. OPTICAL FIBRES PREPARATION

One of the main procedures during the preparation for the measurement of gamma radiation with the proposed method is the preparation of optical fibres. Measuring needs to be repeatable, adjustable for fibres of various lengths, and resistant to noise from ambient light. To secure the same distance between the sensor and optical fibre, we are using SMA905 connectors. Optical fibre is cut and cleaved for the required length. During this process, parts of the plastic coating near the ends of fibres are removed. The removal of the coating allows the adhesion of connectors. Before adding connectors, the fibre is first shielded with a black shrink film that protects it from ambient light. The next protection layer is stainless steel tube, which gives fibre better mechanical properties. Fibre with a protection is ready for connector gluing. After the adhesive has dried, the procedure continues with the grinding and polishing of the fibre ends. The ends of the optical fibres are aligned with the connectors by grinding. Grindng and polishing also remove grooves from fibre surfaces. This way, we decrease signal loss on both ends due to random light refraction. The result of polishing is shown in Fig. 3. Fibres are polished with diamond lapping sheets. Sheets have diamond grit sizes of 30, 6, 3, and 1 μm. Diamond grit with a size of 0.02 m is used.
for the final (optional) polishing. The whole polishing process requires cleaning with isopropyl alcohol and compressed air. Because the core diameter is larger than usual, periodic cleaning and inspection under an optical microscope are needed. Small, uncleared particles can scratch the fibre surface, and the whole polishing process must be repeated. Fibre is now ready for the measurement. Several fibres are prepared by this procedure [2].

IV. ACTIVITY MEASUREMENT

We are using reference sources for measuring the impact of changes in the length and diameter of optical fibres. These are isotopes cobalt 60 and caesium 137 with different levels of activity. Activity is measured in Becquerels (Bq), where 1 Bq equals 1 disintegration per second. We compare the number of measured pulses (counts) to the value of the reference source. It is essential to keep in mind that while cobalt and caesium have similar activities, cobalt produces more gamma rays than caesium due to distinct decay schemes. Beta rays are also produced during the decay process but are shielded by the casing of the source and scintillator. Thus, creating two types of gamma-radiant etalon with three different activities for each type [1].

A. Measurement

Prepared optical fibres are connected via connectors to PMT and scintillation crystal. A black box is then used to store the measurement setup, and black tape is used to seal the holes for the connectors. This will lessen ambient light noise. Then, measurements are made by laying a reference source close to the scintillator. Pulses from PMT are counted every second for ten minutes. After measuring ends, an optical fibre is replaced by another, and the process repeats. Results from measurement are shown in Fig. 4 for both reference sources.

B. Results

Four optical fibres were measured. Two optical fibres with different diameters and two optical fibres with different lengths. Graphs in Fig. 4 show that for fibres with 1 mm diameter, there is a very small change in counts between different lengths. The larger difference is between optical fibres with different diameters. Greater surface area allows more photons to enter the optical fibre. Every fibre has also almost linear progression. This is an actual advantage compared to other measuring methods. Some methods require another material implementation to secure their linearity. This often decreases their resistance to radiation damage [1] [5]. The difference between FP1000URT – 1 m and FP1000URT – 5 m is almost none. In Fig.4 is shown that longer optical fibre has lower signal loss. This is due to the low attenuation of silica fibre, and the difference could be caused by the polishing process. This is necessary for polishing optical fibre. Even small portions of scratches can cause differences in the final number of counts.

V. CONCLUSION

We have presented a new method for long-term measurements of gamma radiation. The method is based on optical fibres and the use of a scintillation crystal as a sensor. Thanks to this setup, we are able to measure continuously. Furthermore, as demonstrated by the results, a greater distance from the sensor can be achieved. Allowing us to place electronic
devices at further distances and reducing the need for human actions in measured areas. Results have also shown good linearity thanks to the scintillation crystal. Thus, enabling easier activity determination.

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REFERENCES


