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Analysis of Energy Spectrum of a Small X-ray Tube Operating at Pulsed Mode

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1. Introduction

Recently, the importance of X-ray fields has emerged in various fields such as medical imaging and industrial non-destructive testing [1]. In these fields, high-energy X-ray involves radiation exposure. Therefore, utilization of low-energy is essential, and an analysis of their characteristic should be conducted.

In this study, the X-ray energy spectrum of a small X-ray tube with carbon nanotube (CNT) cathode was analyzed for various operating voltages. In addition, an X-ray pulse generator was developed that can apply a high voltage to perform experiments.

2. Experimental Setup

2.1 Development of X-ray Pulse Generator

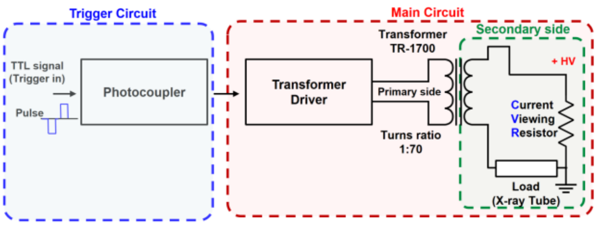

Fig. 1. Schematic diagram of X-ray pulse generator

Figure 1 shows a circuit diagram of a X-ray pulse generator used to apply high pulsed voltage to a load (X-ray tube). It consists of a trigger circuit and a main circuit. The trigger circuit drives a photocoupler and the main circuit operates from the transformer driver to the output. A transformer with 1:70 ratio is used to generate high voltage pulses stably. In general, the voltage, frequency, and duty of the TTL signal is set to 5 V, 0.1 kHz, 0.1% respectively. The amplified output voltage was measured through current viewing resistor (CVR).

2.2 Detection of X-Ray Tube

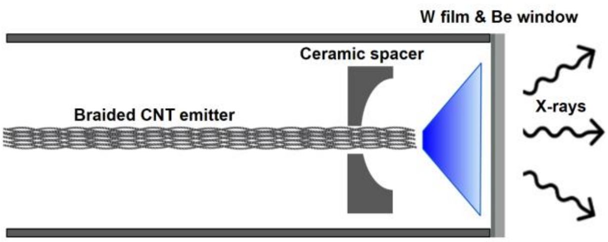

Fig. 2. Cross-sectional diagram of a small X-ray tube using CNT cathode

Figure 2 shows a small X-ray tube composed of CNT cathode and tungsten anode. In the experiments high-voltage pulses with ~10 kV are applied to the X-ray tube, inducing electron beam emission through a field emission at the cathode. The emitted electrons interact with the tungsten target, producing bremsstrahlung or characteristic X-rays, which are released through a beryllium window. The X-ray energy spectrum was measured using the XR-100SDD, a fast silicon drift detector (SDD). The measurement distance from the X-ray tube is set to 0.8 m to minimize the pile-up phenomenon in the detector and optimize the count rate. It is noted that the Fast SDD was calibrated using Fe-55 sources, which are commonly used for low-energy calibration [2].

3. Results & Discussion

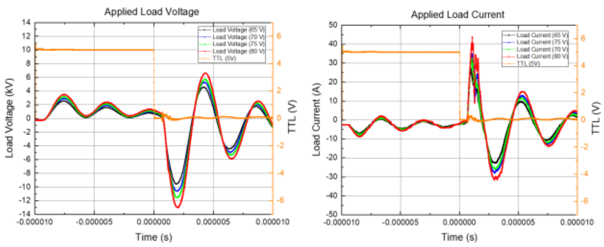

Fig. 3. Applied Voltage and Current at Load

Figure 3 shows the voltage and current applied to the CNT tube by adjusting first side of pulse-generating switch from 65 to 80 V. Before TTL signal is applied, voltage oscillation phenomenon is considered to occur during transformer charging. The rise time is about 800 ns, and maximum voltage applied to the CNT tube was about 9.5, 10.5, 11.5, 14 kV respectively. The maximum current for each case was 27, 32, 35, 43 A respectively. After about 1.2 μs, the current shows a tendency to oscillate. it is judged that result of the virtual cathode effect occurs when voltage reaches around 5 kV which discharge begins.

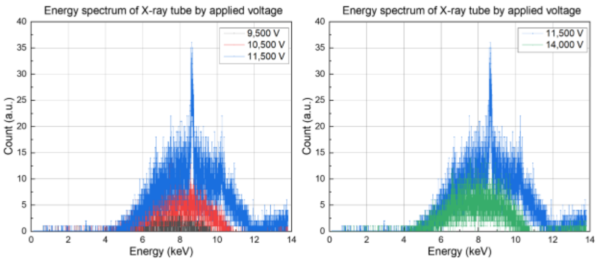

Fig. 4. Energy spectrum of X-ray tube by applied voltage (9.5, 10.5, 11.5, 14 kV)

Figure 4 shows the X-ray spectrum broadened as the applied voltage increased from 9.5 to 11.5 kV range. It indicates greater emission in the high-energy region. This trend aligns with the general bremsstrahlung phenomenon, where higher voltages in the X-ray tube produce stronger X-ray emissions [3]. However, when 14 kV was applied, the total coefficient of the energy spectrum tended to decrease. This is likely due to pile-up effect in the measuring instrument, causing the energy to be recorded as higher than the actual energy.

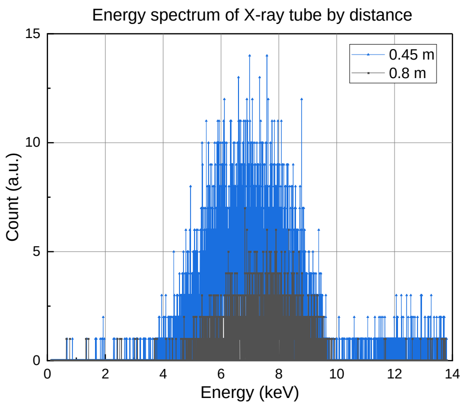

Fig. 5. Energy spectrum of X-ray tube by distance at 10.5 kV

Figure 5 presents the X-ray spectrum results based on distance, measured at 0.8 m and 0.45 m, respectively. Theoretically, the intensity of the incident X-rays differs by a factor of about 3.16, as it is inversely proportional to the square of the distance. Similarly, experimental results confirmed that the closer the distance, the greater the emission of incident X-rays, approximately three times. Although the maximum peak energy remained similar, the collected X-ray counts in the lower energy range increased as the measurement distance decreased. The count in the energy spectrum does not appear as a whole number; for example, coefficient values between 1 and 2 are estimated from the results of statistical processing within detector.

4. Conclusions

A High voltage X-ray pulse generator has been developed. The X-ray spectrum was measured at a distance of 0.8 m from the CNT tube to minimize the pile-up phenomenon and considering the count rate in the measuring detector. When output voltages of 9.5, 10.5, and 11.5 kV were applied to the CNT tube, the amount of X-ray emission increased. This analysis of energy spectrum of small X-ray tube is useful to medical imaging application.

Acknowledgements

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