Simple Flash X-ray Tube Having a New Type of Cathode Driven by a Blumlein Pulser

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(Received June 3, 1989, in final form July 20, 1989)

A simple flash x-ray tube with a new type of cathode and fundamental studies for generating a high-voltage pulse by using a Blumlein circuit are described. This radiation tube had the following major parts: a rod-shaped anode tip made of tungsten, a plane cathode made of aluminum which gave two parts of a x-ray window and a metal filter, a vacuum vessel made of glass, and others. The output voltage of this Blumlein pulser ranged from 70 to 160kV, but the tube voltages were determined by the anode-cathode (A-C) space since a pulse-forming device was not employed. The x-ray pulse widths primarily increased according to increases in the A-C space, and their values ranged from 20 to 50ns. The x-ray intensity was less than 1.0μC/kg at 0.3m per pulse when the discharge capacity of about 430pF was employed. The effective focal spot size was determined by the diameter of anode tip and its value ranged from 0.5 to 3.0mm in diameter.

1. Introduction

Recently, theoretical and experimental investigations for producing x-rays by using a vacuum discharge have been performed 1-4). In particular, since the soft x-rays with photon energies of less than 200 keV are useful for medical diagnosis, various methods for producing soft x-rays by using the vacuum arc discharge have been investigated by the authors 5-10).

For the x-ray tube having a cold cathode, the glass enclosed type is quite convenient for medical diagnosis since it is compact utilizing no pump and increases the heat durability of the x-ray tube.

In order to increase the output of the high-voltage pulser, since it is not easy to increase the charging voltage to more than 100kV by
using a DC power supply, a pulser which produces the twice the potential of the charging voltage is necessary for obtaining higher voltages of 100 to 200kV.

For this research, we developed a new type of compact flash x-ray tube with a glass body and performed the fundamental studies for producing twice the potential of the charging voltage by using a Blumlein circuit.

2. Experimental Configuration

The diagram of a Blumlein circuit is shown in Fig. 1. In an ideal model such as the line pulser, the circuit produces twice the potential of the charging voltage. Since the ceramic condensers of the C1 and C2 were charged from -40 to -100kV, the ideal output voltage ranged from +80 to +200kV. Fig. 2 shows the equivalent circuit of the main transmission line of this circuit. Since two condensers were connected in series, the total capacity of the transmission line had a very small value of about 430pF.

The compact flash x-ray tube for fundamental studies was of the diode type which was connected to the turbo molecular pump and consisted of the following major parts (see Fig. 3): a rod-shaped anode tip made of tungsten with a diameter of less than 3.1mm, a plane cathode made of aluminum of 0.5mm thickness which works as the x-ray window, a vacuum vessel (tube body) made of glass with a diameter of 50mm and a length of 500mm, and others. The anode-cathode (A-C) space was regulated by rotating the anode rod to control the tube impedance and the tube voltage.

Fig. 1 Diagram of a Blumlein circuit.

Fig. 2 Equivalent circuit of the main transmission line of this Blumlein circuit.
3. Radiographic Characteristics

The output voltage and the tube voltage were measured by a voltage divider. The peak voltage of this Blumlein circuit increased when the charging voltage was increased (see Fig. 4). But this circuit produced about 1.6 times the impulse voltage of the charging voltage due to the degree of voltage inversion of the condenser (C1). Since the ceramic condensers, C1 and C2, were charged from -40 to -100kV, the output voltage ranged from +70 to +160kV. In contrast, the tube voltage was regulated by the A-C space since the rise time of the output from this pulser was comparatively long compared to that obtained by using the line pulser. Thus, the tube voltage increased according to increases in the A-C space (see Fig. 5).
The flash x-ray output was measured by using a combination of a toluene scintillator and photomultiplier. The pulse height saturated when the charging voltage was increased because of the constant tube voltage (see Fig. 6(a)). In contrast, the pulse height and the width tended to increase as the A-C space was made larger (see Fig. 6(b)). The pulse widths ranged from 20 to 50ns, and the time integrated x-ray intensities were less than 1.0μC/kg at 0.3m per pulse. The tube current was regulated within a range of 5.0 to 10.0 kA, and the effective focal spot size was determined by the diameter of anode rod and ranged from 0.5 to 3.0mm in diameter.

**Fig. 5** Variations in the tube voltage: (a) the effect on the charging voltage; (b) the effect on the A-C space.
4. Flash Radiography

Flash radiography was performed by using this experimental generator and a CR system.

A radiograph of two test charts are shown in Fig. 7; the radiographic condition were as follows: a charging voltage of 60kV, an output voltage of about 65kV, an A-C space of 1.25mm, an anode diameter of 3.0mm, 10 shots, and a film-focus (F-F) distance of 0.4m. They indicated a low image resolution since a large focal spot and a short F-F distance were employed. Fig. 8 shows a bone of the dorsal with an output voltage of 70kV, an A-C space of 1.0mm, 15 shots, an F-F distance of 0.3m, and the other conditions as in Fig. 7. The fine structure inside of a bone were comparatively visible.

By using this generator, it was possible to obtain these radiographs by using 3~7 flash x-ray shots.

Fig. 6 Flash x-ray output measured by using a combination of a toluene scintillator and a photomultiplier: (a) charging voltage dependence; (b) A-C space dependence.

Fig. 7 Radiograph of two test charts.
5. Discussion

This simple flash x-ray tube with a glass body of 50mm in diameter in conjunction with a Blumlein pulser using ceramic condensers described in this paper was constructed in order to develop a compact flash x-ray system for biomedical radiography with a range of tube voltages from 50 to 200kV.

In an ideal Blumlein circuit if we assume that the charging voltage, the A-C voltage, and the A-C impedance are the constant value of $V_C$, $V$, and $Z$, respectively, in order to simplify an equation, then the x-ray intensity rate of the bremsstrahlung spectra can be given by the following equation:

$$\frac{dI}{dt} = AX \frac{Z^a V^{a+1}}{(Z+Z_o)^{a+1}}$$  \hspace{1cm} (1)

where $X$ is the atomic number, $Z_o$ is the body impedance of the generator, $A$ is some factor, $a=2.0$, and $V_o=2V_C$. Thus, the x-ray intensity increases in proportion to about the third power of the charging voltage, and spectra with higher photon energies can be easily obtained. In these experiments, since the tube voltage was primarily determined by the A-C space due to the long rise time of the output voltage from the pulser, the x-ray intensity tended to saturate according to increases in the charging voltage.

For the bremsstrahlung spectra, since this aluminum cathode of 0.5mm thickness works as the x-ray window, the permeating spectrum distribution $\Phi_p(E)$ and the attenuation $I(x)$ can be represented by $^{11,12}$:

$$\Phi_p(E) = \Phi(E)e^{-\mu(E)x} \hspace{1cm} (2)$$

$$I(x) = \int_0^{\infty} \Phi(E)e^{-\mu(E)x} dE \hspace{1cm} (3)$$

were $\Phi$ is the incident spectra, $E$ is the photon energy, $\mu(E)$ is the linear attenuation coefficient, and $x=0.5mm$. Thus, the x-ray qualities were harder compared to those obtained by using the other flash x-ray generator designed by the authors, because these utilized Mylar windows for soft radiography.

In the application of this single flash x-ray generator to the repetition type, it is necessary to increase the heat durability of the cathode plane made of aluminum. For clearing up this...
problem, a cathode plane made of beryllium or a carbon attached aluminum cathode is desired. By using this generator, since it is possible to change the charging polarity, a relativistic electron and x-ray beam generator for x-ray preionized lasers can be realized.

Acknowledgements

The authors wish to thank P. Langman, K. Nakadate and R. Ishiwata of Iwate Medical University, and many researchers of Japanese Association of Applied Radiation for helpful support in this research. This work was supported by Grants-in-Aid for Scientific Research from the Iwate Medical University-Keiryokai Research Foundation, the Private School Promotion Foundation, and the Ministry of Education and Culture in Japan.

References