Development of 120 kV X-ray Source

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Keywords Nondestructive inspection, Security, Medical care, Portable

Abstract

By making X-ray equipment compact and portable, it can be used in a wide range of applications, such as security and aging level infrastructure inspections, which are difficult to do with stationary equipment.

The cold cathode X-ray tube developed by our company is more suitable for compact design and portability than the conventional hot cathode X-ray tube. Since most of the X-ray equipment on the market is equipped with a hot cathode X-ray tube, a request to directly test the advantages of our cold cathode X-ray tube in an actual machine was made.

We, therefore, developed a 120 kV X-ray source demonstration machine equipped with a cold cathode X-ray tube that can be easily used and transported. As an example of its application, we took X-ray scanning indoors and outdoors undertaking infrastructure inspection, and obtained transparent images of concrete wall and gypsum board wall.

1 Preface

In recent years, the demand for compact portable X-ray equipment has increased in fields such as security, medical care, and investigation of aging infrastructure. The cold cathode X-ray tube developed by our company has a structure that is more compact than conventional hot cathode X-ray tubes, is suitable for mass production, and is expected to be applied to portable X-ray equipment[(1)]. Most X-ray equipment on the market is equipped with hot cathode X-ray tubes, as such, a request to directly test the advantage of our cold cathode X-ray tubes on actual equipment was made.

In response, we developed a 120 kV X-ray source demonstration machine equipped with a cold cathode X-ray tube that can be easily used and transported. This paper introduces the operating principle of the 120 kV X-ray source and an example of X-ray imaging.

2 Comparison of Power Supply Configuration between Hot Cathode X-ray Tube and Cold Cathode X-ray Tube

2.1 Principle of X-ray Generation

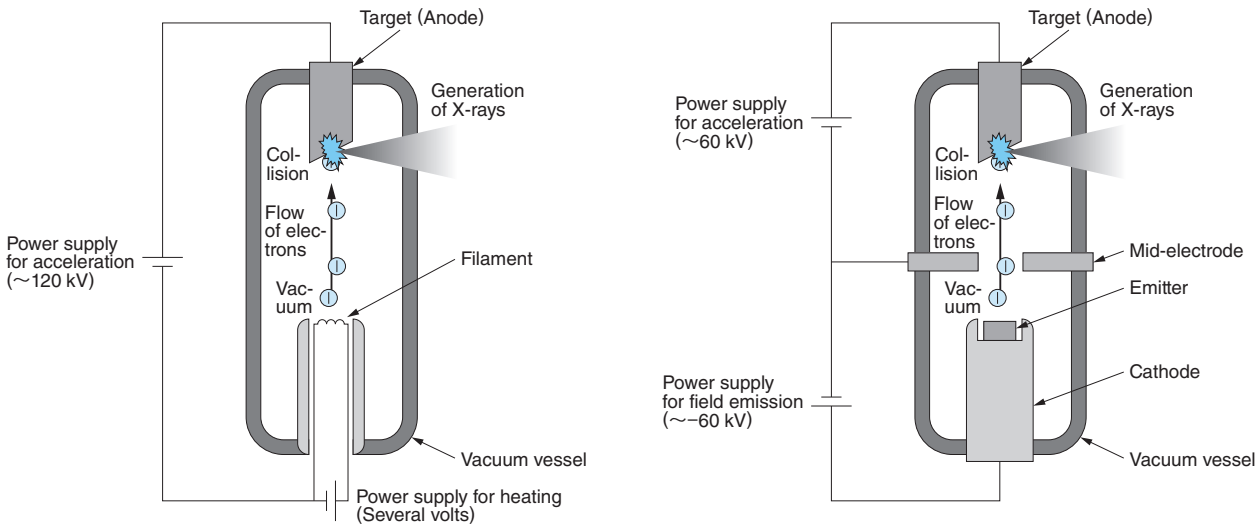
Fig. 1 (a) shows an outline of an operating principle of a hot cathode X-ray tube, and (b) shows the outline of the operating principle of a cold cathode X-ray tube. X-ray tubes, whether hot cathode or cold cathode, generate X-rays by accelerating electrons at high voltage in a vacuum chamber, making them collide with metal at a high speed.

The difference between hot cathodes and cold cathodes is the principle of electron generation. The hot cathode emits thermionic electrons by heating the filament※1. In contrast, the cold cathode emits field electrons by applying a voltage to the emitter※2. The cold cathode does not require the time to heat the filament, which is required for the hot cathode, so it has the advantage of being suitable for immediate irradiation or pulse irradiation.

2.2 Power Supply Configuration Comparison

The X-ray source consists of an X-ray tube and a power supply. A tube voltage of 120 kV, a hot cathode X-ray tube consists of a high voltage power supply of 120 kV for electron acceleration and a power supply of several volts for filament heating.

Our 120 kV/1 mA cold cathode X-ray tube has a three-electrode structure including an intermediate electrode. It consists of two high voltage power supplies. High voltage power supplies for electron extraction and electron acceleration are set to



(a) Hot cathode X-ray tube

(b) Cold cathode X-ray tube

Fig. 1 **Outline of Operation Principle of X-ray Tubes**

The X-ray tube has a construction where a cathode and an anode are provided within a vacuum vessel. Electrons emitted from the electron generation source of the cathode are accelerated by a high voltage applied to a section between the cathode and the anode. X-rays are generated when the accelerated electrons collide with the target of the anode at a high speed. (a) The principle of electron emission for the hot cathode X-ray tube is attributable to heat. (b) For the cold cathode X-ray tube, electron emission is attributable to electric field.

−60 kV and 60 kV, respectively. In the case of a triode cold cathode X-ray tube, the tube voltage is the sum of the voltage of the high voltage power supplies for electron extraction and electron acceleration.

3 X-ray Source

3.1 Operating Principle of High-Voltage Power Supply

Fig. 2 shows the main circuit configuration of the newly developed 120 kV X-ray source. The 120 kV X-ray source boosts the input power supply voltage of 12 V to several tens of volts using a boost chopper and charges the electrolytic capacitor. The inverter voltage, after the electrolytic capacitor converts it to a square high frequency, is increased to several kV by inputting it to the transformer. Since several tens of kV or more are required to generate X-rays, the voltage is further boosted by a circuit called the Cockcroft-Walton (CW) circuit. A CW circuit is a ladder-like circuit composed of capacitors and diodes and can boost voltages from several tens to hundreds of kV with a simple configuration. In addition, the CW circuit can output with any polarity in the direction of the diode even with the same input. X-rays are emitted by applying positive and negative high voltage generated by the CW circuit to the X-ray tube.

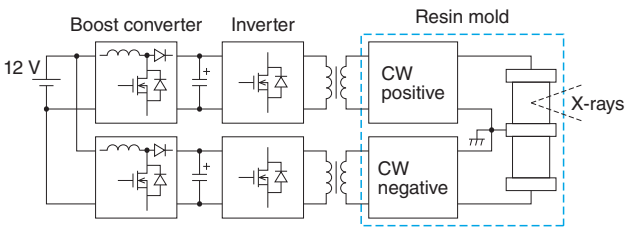


Fig. 2 **Main Circuit Configuration of Newly Developed 120 kV X-ray Source**

With an input of 12 V power supply determined for the anticipated battery driving, a rectangular RF voltage of several kV is generated by a boost converter, electrolytic capacitor, inverter, and transformer. The generated voltage is converted into a DC voltage of some tens of kV by the CW circuit. The boosted voltage is then applied to the X-ray tube. Even with the same input, the CW circuit can apply an output to any polarity in the direction of diode.

The 120 kV X-ray source has an input power supply voltage of 12 V battery drive in the future. The CW circuit and X-ray tube are resin-molded for insulation.

3.2 120 kV X-ray Source Demonstration Machine

Fig. 3 shows the basic test configuration when using the 120 kV X-ray source demonstration machine. The 120 kV X-ray source demonstration machine consists of an X-ray source that emits X-rays and a console that controls various settings during X-ray irradiation. The subject is placed in the X-ray

irradiation direction, and an image receiver such as a Flat Panel Detector (FPD) is placed behind the subject. The X-ray source connects the main unit and the console with the attached harness and connects the separately prepared 12 V power supply and the signal source that triggers the X-ray irradiation to the main unit. X-rays can be emitted by turning on the 12 V power supply, and various settings can be made on the console. When X-rays are emitted by the trigger input of the signal source, a transmission image can be acquired by the FPD. Since it is equipped with a cold cathode X-ray tube, it does not require the warm-up operation called aging, which is necessary for X-ray source equipped with a hot cathode X-ray tube, and can be used immediately.

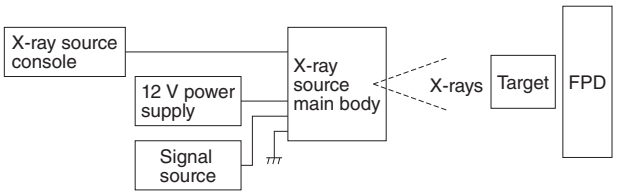


Fig. 3 Basic Test Configuration when Using 120 kV X-ray Source Demonstration Machine

A target is arranged between the irradiation port of the X-ray source and the FPD. The X-ray source connects with the 12 V power supply and the signal source. When the irradiation conditions are set up at the X-ray source console, X-rays begin to be irradiated with a trigger signal from the signal source. Upon the irradiation of X-rays, a transmission image can be acquired by the FPD.

Table 1 Main Specifications of 120 kV X-ray Source Demonstration Machine

Major specifications of the 120 kV X-ray source demonstration machine are shown.

Classification	Item	Specifications and ratings
Input conditions	Input voltage	DC12 V (11～17 V)
	Input current	7 A or below
	Inrush current	10 A or below
Output conditions	Repetitive frequency	0.1 Hz Max.
	Output voltage	±40～±60 kV
	Output pulse width	0.1～1 s
X-ray output	Tube voltage	80～120 kV
	Tube current	1 mA or below
	Irradiation angle	40 deg
Cooling	Casing construction	Enclosed, natural air-cooled
	External casing heat discharge	Casing surface temperature: 50℃ or below
Shape	External dimensions (Excluding protruded parts)	Main body: W220 × H80 × D250 mm Console: W180 × H105 × D46 mm
	Mass	Main body: 5.4 kg Console: 0.5 kg

Table 1 shows the main specifications of the 120 kV X-ray source demonstration machine. Since it is assumed to be battery driven, it operates with an input power supply of 12 V and the average current consumption is about 0.4 mA. In addition, the size of the main body is W220 × H80 × D250 mm with the main body mass of 5.4 kg. It is easy to carry due to the compact design and light mass. The CW circuit has a structure that achieves a compact design and ease of mounting through a unique three-dimensional element arrangement. As a result, the volume of the resin mold part, including the CW circuit, was reduced to approximately 28% of the volume of the X-ray source body (excluding protrusions).

4 Examples of Radiography

As an example of imaging with the 120 kV X-ray source demonstration machine, we performed X-ray imaging of the inside of indoor and outdoor walls assuming infrastructure inspection. In accordance with the Ionizing Radiation Hazard Prevention Regulations (Ionizing Radiation Regulation), a 5 m radius around the X-ray source was off-limits during imaging.

4.1 Shooting inside Wall Outdoors

Fig. 4 shows an outline of external wall photography outdoors. The outer wall is made of concrete blocks, which is 180 mm thick (including the cavities), and the distance between the X-ray source and the outer wall is about 100 mm. **Fig. 5** shows the result of the external wall photography outdoors. The imaging conditions were a tube voltage of 115.3 kV, a tube current of 1 mA, and an irradiation time of 0.2 s. Straight steel frames and curved wiring pipes can be seen in the concrete outer wall, making it suitable for pre-construction structural surveys.

4.2 Shooting inside a Wall Indoors

Fig. 6 shows an outline of inside wall photography indoors. The gypsum board inner wall, which is about 19 mm thick, and the distance between the X-ray source and the air conditioner control panel is about 1000 mm. **Fig. 7** shows the result of inside

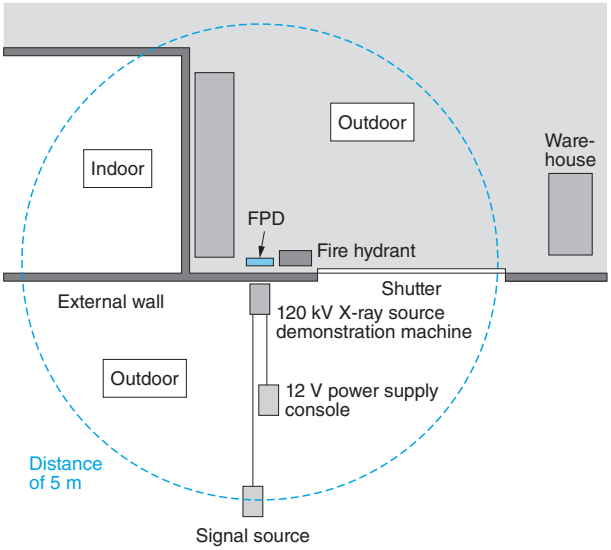
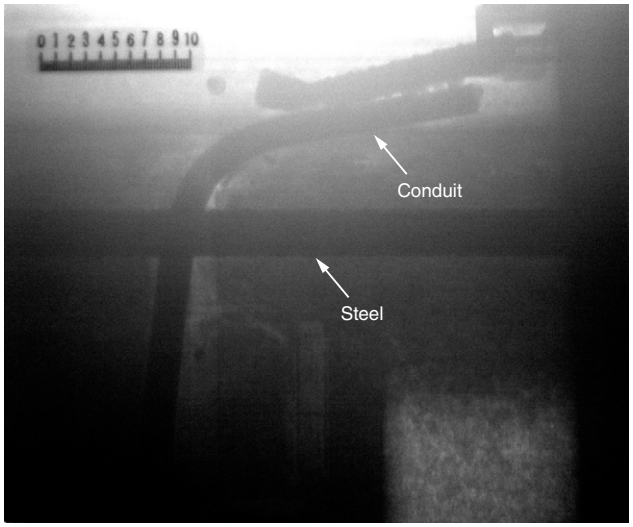


Fig. 4 Outline of External Wall Photography Outdoors

The external wall made of concrete blocks has a thickness of approximately 180 mm (including cavity). The FPD is installed on the indoor side and X-rays are irradiated from the outdoor side. The distance between the X-ray source and the external wall is about 100 mm.



Distance: approx. 100 mm

※Distance: Distance between X-ray source and external wall

Fig. 5 Result of External Wall Photography Outdoors

The conditions of imaging are the tube voltage of 115.3 kV, tube current of 1 mA, and irradiation time of 0.2 s.

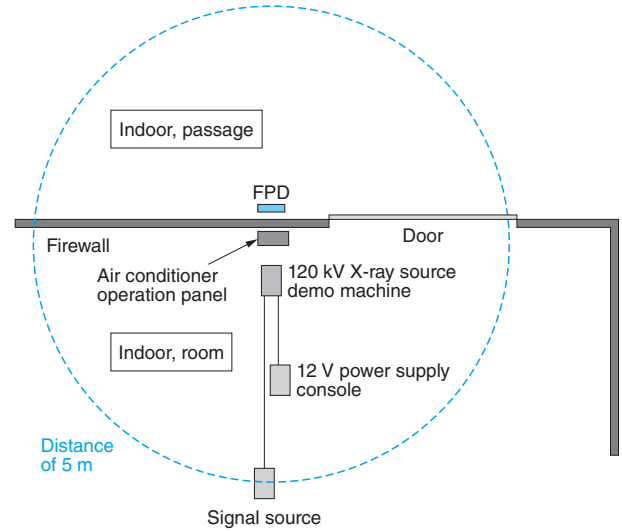
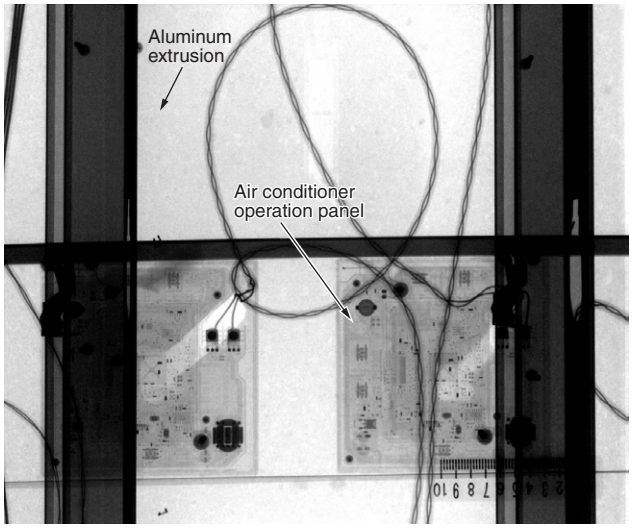


Fig. 6 Outline of Inside Wall Photography Indoors

The wall made of plaster has a thickness of about 10 mm. The FPD is installed on the passage side and X-rays are irradiated from the room side. The distance between the X-ray source and the air conditioner operation panel is about 1000 mm.



Distance: approx. 1000 mm

※Distance: Distance between X-ray source and air conditioner operation panel

Fig. 7 Result of Inside Wall Photography

The conditions of imaging are the tube voltage of 100.5 kV, tube current of 0.7 mA, and irradiation time of 0.2 s.

wall photography. The imaging conditions were a tube voltage of 100.5 kV, a tube current of 0.74 mA, and an irradiation time of 0.2 s. We confirmed the aluminum extrusions in the wall and even the circuit pattern of the air conditioner control panel attached to the wall. In addition, since the wiring of the air conditioner operation panel in the wall can also be photographed, it is expected to be applied to the detection of disconnection points.

5 Postscript

We introduced the operating principle of our 120 kV X-ray source demonstration machine and an

example of X-ray imaging. Since this is a demonstration machine, it has general-purpose specifications. We will develop specifications more suitable for portability in the future, according to the application, a further compact design, battery support, and a wireless console.

(Notes)

※1. Filament: A thin metallic wire through which a current is carried to irradiate light or thermal electrons within a light bulb or an electron tube.
※2. Emitter: A source of electron emission based on the operation principle of tunneling effect between vacuum and metal caused by a strong electric field.

《Reference》

(1) Takahashi, Fukai, Nishikiori, Takahashi: "Development of Cold Cathode Movable X-ray Tube", Meiden Review Vol.177, No.3/2019, pp.28-30