Development of New Line of Cold Cathode X-ray Tube Products

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Abstract

X-ray tubes, 90 kV/1 mA and 180 kV/1 mA have been newly developed and commercialized. These products make a new model series in addition to the cold cathode X-ray tubes of the 120 kV/1 mA type developed and commercialized for security, infrastructure, and medical applications. Since each customer's required specifications differ according to applications and industrial fields, we made a series of model to enable us to provide the appropriate model to fit the needs of our customers.

In the field of analytical instruments, there is a demand for X-ray tubes with a cold cathode beryllium window. As a result, we developed low-voltage X-ray tubes with a beryllium window as an analytical instrument.

1 Preface

We manufacture 120 kV/1 mA cold cathode X-ray tubes for compact and portable application and for infrastructure testing. The customer's requirements for the X-ray tube specifications, however, differ according to the applied sectors or applications. Fig. 1 shows the distribution of specifications needed in respective fields. For infrastructures, X-ray tubes are required to be high voltage, compact, and a portable type. The tubes are for inspection of corrosions in steel bridges and thick metallic tubes. In the case of the X-ray tubes used in the factory inspection field, they are used to detect the small foreign materials and the focal size should be short to acquire sharp images. This paper introduces a new series of cold cathode X-ray tubes developed by our company.

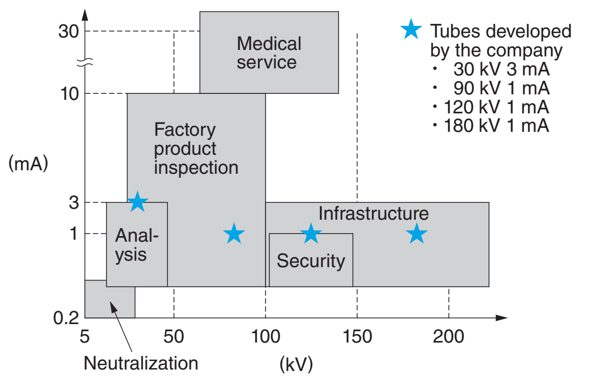

Fig. 1 Distribution of Specifications Needed in Respective Fields

Mark ★ indicates specifications of our developed products in this distribution. Since X-ray tube specifications may change according to the requirements relevant to servicing fields and applications, we are promoting to reinforce product lineups in conformance with our customer requirements.

2 Structure and Operating Principle of Cold Cathode X-ray Tube

The structure and operating principle of a conventional cold cathode X-ray tube and a cold cathode X-ray tube developed by our company are explained.

Fig. 2 shows an outline of the cold cathode X-ray tube. When a high voltage is applied to the carbon nanostructure (emitter)※1 installed in the vacuum vessel, electrons emitted from the carbon nanostructure by the effect of external electric field are made to collide with the target metal at a high speed to generate X-rays as a result. In the case of a conventional cold cathode X-ray tube, the emitter is fixed, therefore, the electric field affects the emitter at the time of withstand voltage testing on the vacuum vessel. As a result, a risk of damaging the emitter when discharges occur within the vessel was present.

The emitter of the cold cathode X-ray tube developed by our company, however, has a structure that enables the emitter to move. This type of structure makes it possible to move the emitter to a position where no effect of electric field exists

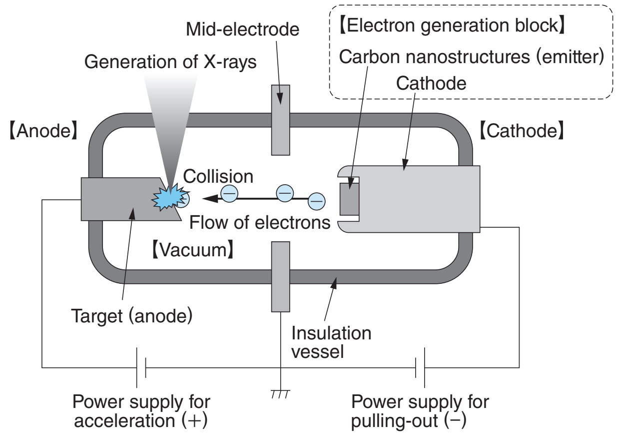

Fig. 2 Outline of Cold Cathode X-ray Tube

When a high voltage is applied to the carbon nanostructures (emitter) and electrons emitted from carbon nanostructures by the effect of the external electric field collide with the target at a high speed and X-rays are generated as a result. Unlike a filament of hot electrode, the heating is unnecessary, and radiation can begin almost immediately.

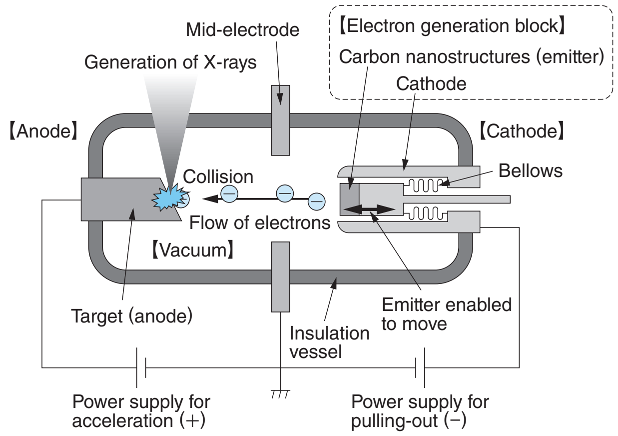

Fig. 3 Outline of Newly Developed Cold Cathode X-ray Tube

The newly developed cold cathode X-ray tube is devised to have a structure where the emitter can be moved. When confirming the withstand voltage of a vacuum vessel, the emitter can be moved to a position where the emitter is free from the effect of electric field. As such, X-ray tubes can be manufactured while damage of emitter is avoided.

while a withstand voltage test is conducted on a vacuum vessel. Accordingly, the risk of damaging the emitter can be avoided. In other words, the productivity of vacuum vessel manufacturing can be increased. **Fig. 3** shows an outline of the newly developed cold cathode X-ray tube.

3 Development of New Line of Cold Cathode X-ray Tube Products

After the release of the 120 kV/1 mA X-ray

Fig. 4 New Series of Cold Cathode X-ray Tube Products

An external appearance of the cold cathode X-ray tube series is shown. From left to right, 120 kV/1 mA, 90 kV/1 mA, and 180 kV/1 mA types.

Table 1 Specifications for New Series of Cold Cathode X-ray Tube Products

The new series of products introduced in this paper is shown in a bold-line box. Development began based on the 120 kV/1 mA type and the compact design was successfully realized. As a result, we can supply suitable X-ray tubes suitable for compact and portable equipment.

Item	Specifications and ratings		
	120 kV/1 mA	90 kV/1 mA	180 kV/1 mA
Maximum operating tube voltage (kVdc)	120	90	180
Maximum operating tube current (mA)	1	1	1
Mass (g)	240	340	580
Total length (mm)	100	95	135
Outer diameter (mm)	ϕ32.5	ϕ41	ϕ56
Focus size (mm)	0.8	0.4	1
Target	Tungsten (Angle 20°)	Tungsten (Angle 20°)	Tungsten (Angle 23°)
Fixed filter (mm)	Alumina 3.3	Alumina 3	Alumina 4
Emitter (Electron source)	Carbon nanostructures	Carbon nanostructures	Carbon nanostructures

tube, 90 kV/1 mA and 180 kV/1 mA X-ray tubes were developed as a new series for application to infrastructure testing and factory product inspections. **Fig. 4** shows an external appearance of products and **Table 1** shows their specifications. Our development was promoted based on the construction of the 120 kV/1 mA product. Compared with volume of market available products in the market as 100%, our 90 kV/1 mA product achieved a successful compact design of 80% in volume ratio and the 180 kV/1 mA product to 75% in volume ratio. As a

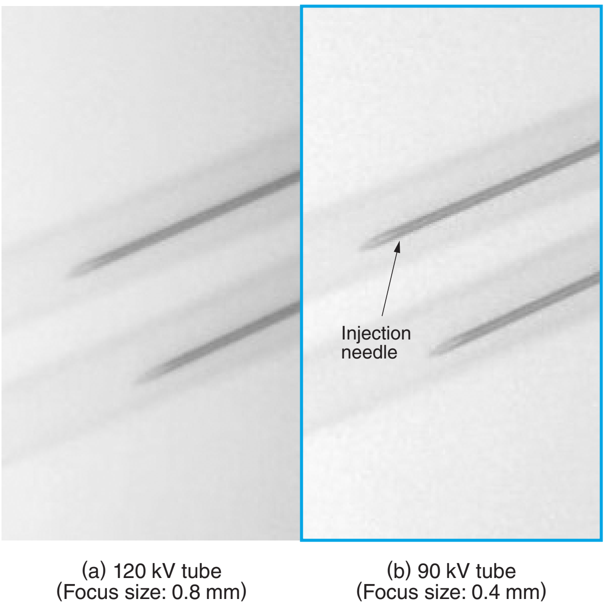

Fig. 5 **Transmission Image Taken with 90 kV/1 mA Type X-ray Tube**

When the focus size is reduced, a fine object like a needle can be recognized clearly.

result, we can supply X-ray tubes suitable for compact and emitter movable type.

Fig. 5 shows transmission images taken with a 90 kV/1 mA type X-ray tube. Small objects such as needles and fluids can be clearly taken as images and in the field of factory inspection, and can contribute to the space saving of inspection equipment and the introduction of portable inspection equipment. In various industrial fields, increased demand for higher voltages and higher currents is anticipated in the future.

As such, the demand for higher voltage and higher current is expected to further increase in various industrial fields. Especially for infrastructure inspection, due to the challenges of inspection in narrow places and securing power supply, there is a need for a compact portable inspection device that can be immediately operated. We are not limited to a single series, but are expanding our lineup to meet the applications and specifications of each industrial field.

4 Development of X-ray Tube with Beryllium Window

In addition to fields of infrastructure testing and security, the analytical field also demands for cold cathode X-ray tubes with a beryllium window for analytical services※2 by using fluorescent X-rays. As a result, we developed 30 kV/3 mA cold cathode X-ray tubes with a beryllium window for application to analytical equipment. Fig. 6 shows an external appearance and Table 2 shows specifications. Unlike the new series of three models, this type of X-ray tube comes in a bipolar structure (grounded anode structure) where the outer periphery is surrounded by metallic parts. In such a structure, the cooling efficiency is raised. The specification of the analyzer side is such that it can be operated with a single power supply unit. The size has been reduced by 40% in volume ratio compared to products on the market.

Fig. 6 **X-ray Tube with Beryllium Window**

The beryllium window is a round plate attached to the lower part of the X-ray tube side surface. It has a bipolar structure on the outer surface of which is composed of metallic parts to increase cooling efficiency. It is used for anode grounding.

Table 2 **Specifications of X-ray Tube with Beryllium Window**

Since this type of X-ray tube has a bipolar structure (anode grounding construction), the cooling efficiency is favorable, and the equipment side is capable of X-ray irradiation with a single power supply. Downsizing is outstanding.

Item	Specifications and rated values
Tube voltage	30 kVdc (Bipolar)
Tube current	3 mA
Mass	170 g
Total length	85 mm
Outer diameter	ϕ25 mm
Focus size	0.7 mm
Target	Chromium (Angle 5°)
Specific filter	Beryllium window (t0.2)
Emitter (Electron source)	Carbon nanostructures

By establishing a manufacturing method for X-ray tubes with a beryllium window, entry into a wide range of fields is expected in the future. Development will proceed with a focus on a compact design and larger current model. We also aim for mass production.

5 Postscript

As a result of a new line of cold cathode X-ray tube products, we have established the offering of X-ray tubes for use in a variety of industrial fields.

Herein, we will promote to increase our product lineups and secure a market through the development of high-voltage and high-current products.

Lastly, we would like to express our sincere gratitude to the National Institute of Advanced Industrial Science and Technology, Life Technology Research Institute, Inc. and many others who have cooperated in the development of a new series of cold cathode X-ray tubes and that of an X-ray tube with a beryllium window.

(Notes)

※1. Carbon nanostructure (emitter): When a microstructure caused by geometrical bonding of carbon atoms is applied with an electric field under vacuum, emission of electrons is performed. The emitter is a product where this phenomenon is utilized.

※2. X-ray analysis utilizing fluorescent X rays: While X-rays are irradiated upon an object material, fluorescent X-rays are generated reflecting from the object. These fluorescent X-rays can be utilized for elemental analysis, structural analysis, stress/strain measurement, and other analytical services.

《Reference》

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