X-ray tubes for projection X-ray radiography of new generation

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X-ray tubes for projection X-ray radiography of new generation

A A Podimsky[1] and N N Potrakhov[2]

[1] JSC «Svetlana-X-Ray», 198095, Saint Petersburg, Russia
[2] Department of electronic instruments and devices, Saint Petersburg Electrotechnical University “LETI”, 197376, Saint Petersburg, Russia

E-mail: kzhamova@gmail.com

Abstract. This article presents the results of research in the field of creation of basic elements of high-voltage components for projection radiography. Design and characteristics of the three types of microfocus X-ray tubes of the new generation: with rotating and fixed anodes, and with external target are described.

1. Introduction

In the second half of last century for radiography of various objects in our country has become a widely used method of projection radiography, particularly in medical diagnostics [1, 2]. Clinical practice of those years has shown that for successful implementation of this method, the size of the focal spot of X-ray tubes should not exceed 0.1 mm or 100 μm. In accordance with GOST 22091.9-86 such X-ray tubes are classified as microfocus and in the future this method of projection radiography become called "microfocus X-ray radiography".

In the late '80s, thanks to the efforts of several schools of radiology, microfocus X-ray radiography emerged as an independent branch of medical diagnostics. And, one of the main roles was played by the Leningrad association of electronic instrument "Svetlana". Leading specialists of the individual design bureau of X-ray equipment "Svetlana" developed in association with radiologists of several large medical institutions in our country and successfully introduced into clinical practice microfocus X-ray machines of the family "Electronica", which until the end of the last century did not have foreign analogs.

2. Results and discussion

The researches, which were conducted at the department of electronic instruments and devices (Saint Petersburg Electrotechnical University “LETI”) in collaboration with a number of leading national experts in the field of X-ray radiography, showed that the use of microfocus X-ray tubes in the formation of the X-ray image appears a number of features (effects). Main of them are: the effects of increasing the sharpness depth and contrast, the effects of pseudo 3D-image and phase contrast, the effect of reducing the exposure dose. However, due to the limit of power supplied to the target of microfocus X-ray tube by the electron beam of small cross section, the intensity of the generated radiation, in comparison with the "standard" X-ray tube, is small. This significantly limits field of application of microfocus X-ray radiography in such socially important areas of medical diagnostics like angiography, mammography, fluoroscopy, tomography, etc.

As it is known intensity *I*, generated by the X-ray tube, is connected with the parameters of X-ray tube by the following expression:

$$I = kizU^2, \tag{1}$$

where *I* – is intensity of radiation, generated by the X-ray tube; *k* – coefficient of proportionality; *z* – atomic number of the material of the anode target; *i* – current of the tube; *U* – voltage on the tube.

In accordance with equation (1), the radiation intensity can be increased either by increasing a tube current, or by the voltage on it. Therefore, during the creation of new generation of microfocus X-ray tubes have been used both directions.

As it is known, on the tubes with a rotating anode current may be several orders of magnitude higher than in tubes with a fixed (stationary) anode [3]. Therefore, during the development of "high current" microfocus tube as base was chosen tube 15-40BD46-150, which is a kind of standard tubes in a class with a rotating anode. Modernization undergone two nodes of basic design – cathode and anode. As a result, in the cathode assembly has only one cathode, and to enable adjustment of the focal spot size the both outputs of cathode was electrically insulated from the focusing electrode. The composition of the modernized assembly includes: the cathode holder 1, directly heated cathode and the focusing electrode. The cathode 3 is made as a cylindrical spiral, two outputs of which are mounted in the holder, and both of outputs has ceramic insulators. Focusing electrode fixed on the cathode holder 1 (figure 1).

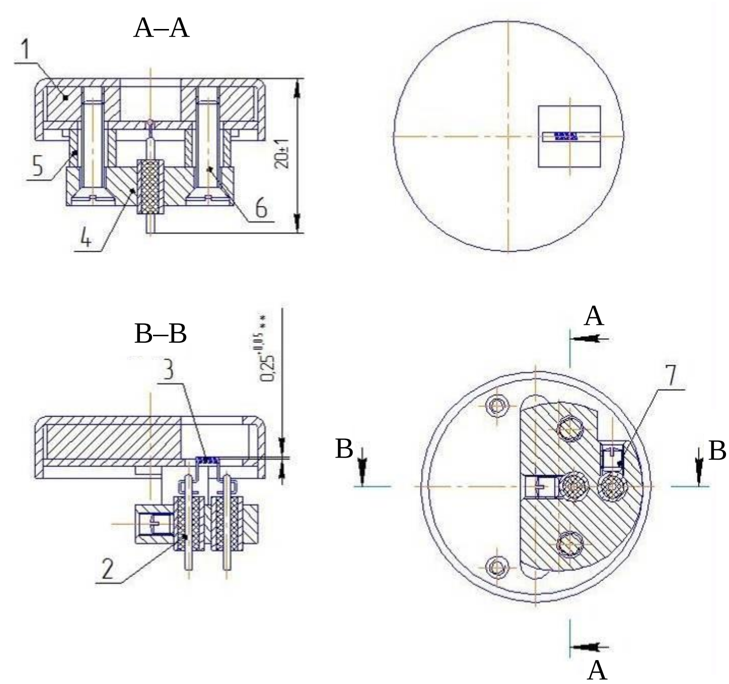

Figure 1. The cathode head of X-ray tube 0,75BD63-150.

To adjust the focal spot size the control voltage U_{adj} (negative polarity with respect to the cathode) is supplied to the focusing electrode. Depending on the magnitude of the voltage, the effective focal spot size will vary from a maximum 0.6×0.6 mm with a control voltage equal to zero to the minimum 0.1×0.1 mm with a control voltage to 100 V.

When upgrading anode node were tightened requirements to the value of bounce at node in the longitudinal and lateral (radial bounce) directions, and also to the magnitude of vibration and noise. Studies have shown that one of the causes of these effects – the lack of rigidity of the bearing housing and of the axis of the assembly rotation in the specified directions. In this basic design of the tube the radial clearance is comparable with the desired size of the focal spot. As a result of analysis and

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numerical estimates of allowable rotation speed of the anode assembly was chosen unseparatored ball-bearing assembly with a temperature-compensating gap type ZYS99.

The construction of the first domestic X-ray tube with a rotating anode with smooth adjustment of effective focal spot size 0.7BD64-150 shown in figure 2. Main characteristics of the tube:

– maximum voltage of 150 kV;
– maximum current of 12 mA;
– size of the focal spot at a bias voltage of 0 V – 0.6×0.6 mm;
– size of the focal spot at a bias voltage of 55 V – 0.1×0.1 mm;
– maximum rotation rate of the anode 9000 Hz.

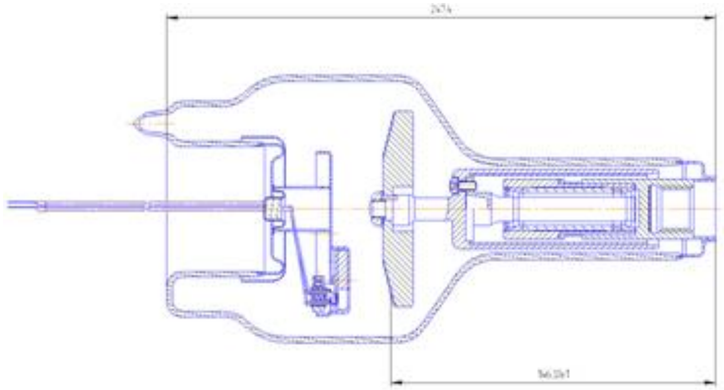

Figure 2. Microfocus X-ray tube with a rotating anode 0.7BD63-150.

For the development of microfocus X-ray tube at a higher voltage with a massive target located inside the vacuum container, was chosen tube design 1.2BPK21-200. Modernization has undergone the cathode assembly of basic design. Firstly, in order to provide the micron size of focal spot, instead of the cathode filament in the form a cylindrical spiral was used filament in the form of V-shaped loop. Secondly, in order to enhance the electron beam focusing capability by independent adjustment of the filament current and voltage on the focusing electrode, a second output of the cathode is also insulate from the focusing electrode. For this, both the cathode outputs is mount in the holder by screws, as in the tube with a rotating anode on ceramic insulators. The construction of the first domestic microfocus X-ray tube with a massive internal anode voltage of 200 kV 0.2BPM64-200 is shown in figure 3.

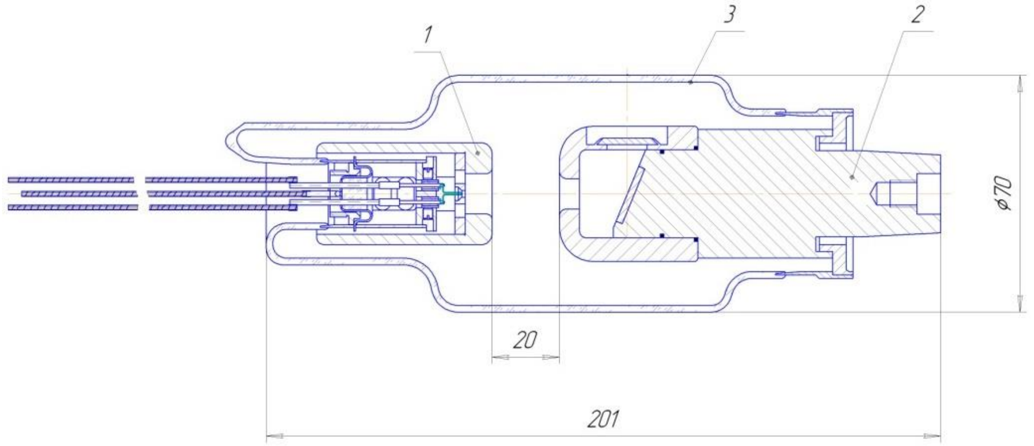

Figure 3. Microfocus X-ray tube with a massive internal anode 0.2BPM64-200.

The main characteristics of the tube:
– maximum voltage of 200 kV;
– maximum current of 1 mA;
– minimum size of the effective focal spot of 0.1 mm;

– dimensions: length 210 mm, diameter 70 mm.

For the development of microfocus X-ray tube at a higher voltage with the external target from the vacuum cylinder as a base was chosen tube BS16(I) with maximum operating voltage of 135 kV. During modernization of the base construction in order to increase the operating voltage to 150 kV by minimizing the electric field intensity in the high voltage gap of the tube were refined dimensions of the outside diameter of the focusing electrode of the cathode node and inner diameter of the anode screen. With the same purpose in the assembly of the tube was introduced the operation autofrettaging abrasive medium. Furthermore, in order to increase heat removal from external target and increase its loading capacity the anode material of the tube instead of stainless steel is replaced by copper. The design of microfocus X-ray tube with the external target from the vacuum cylinder for voltage 150 kV BS16(III) shown in figure 4.

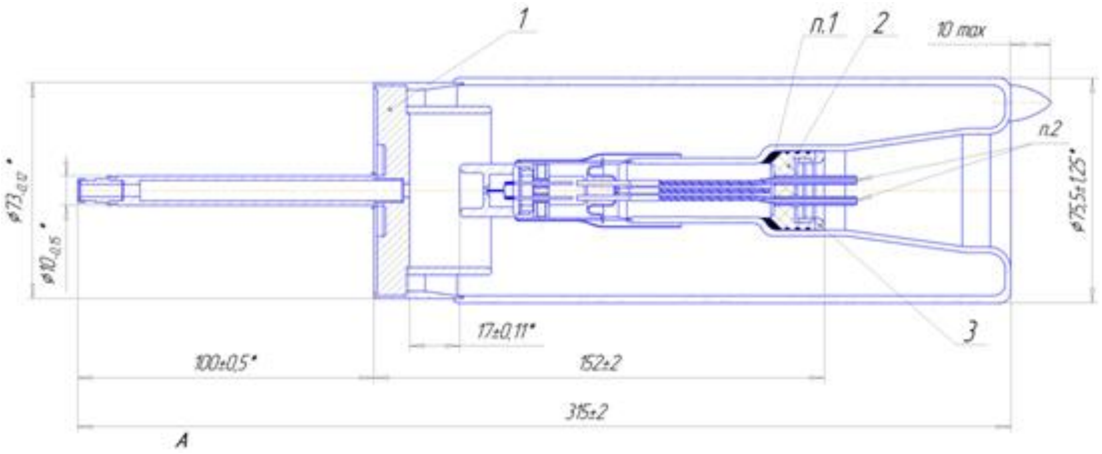

Figure 4. Microfocus X-ray tube with the external target BS16(III).

The main characteristics of the tube:
– maximum voltage of 150 kV;
– maximum current of 150 μA;
– minimum size of the real focal spot – 20 μm;
– dimensions of the balloon: length – 252 mm, diameter – 75 mm;
– dimensions of the external anode: length – 100 mm, diameter – 12 mm.

3. Conclusions

All three tubes of the new generation are designed for operation as part of a specially developed X-ray sources and devices: 0.7BD63-150 in the source IRD46 intended for medical diagnosis, 0.2BPM64-200 in a monoblock unit RAP-200M, BS16(III) in a monoblock unit RAP-150M.1 intended, in particular, for microfocus X-ray CT scanners family MRKT-01.

According to the preliminary assessment the implementation of these technical means will allow essentially extend the scope of Microfocus X-ray radiography in socially important fields of medical diagnostics, in the monitoring of the products and electronic components of the micro- and nanotech in all sorts of research.

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