

## Microfocus X-ray tubes with increased power

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**Abstract.** The designs and fundamentals of the three types of microfocus X-ray tubes for increased power and voltage are described, including those with a rotating anode, a stationary internal anode, and an anterior-impaired anode. Areas of application of these tubes are indicated.

Improvement of the electronic component base in terms of increasing the degree of integration and reducing the size of microcircuits, as well as passive *RLC* components led to the creation of new technologies for their mounting on printed circuit boards [1–3].

To ensure quality control of printed circuit boards mounting directly in production conditions, in the early 2000s, specialized X-ray units were developed [4, 5].

At present, such an installation generally includes: a radiation source based on a collapsible X-ray tube with a constant pumping out with a microscopic focal spot and an image receiver on the basis of a flat panel X-ray detector located in a special chamber for radiographic work. When controlling printed circuit boards, two methods of obtaining an X-ray image are commonly used: contact and projection [6].

The leading manufacturers of X-ray inspection systems currently design and manufacture plants only based on microfocus X-ray tubes with constant pumping. The advantage of this design is the possibility of repeated replacement of the cathode and anode target. This makes it possible to operate the tube at the maximum loads – emissive to the cathode and thermal to the target, but it causes a number of disadvantages in comparison with the tubes sealed off from the vacuum (pumping) system:

- large dimensions, weight and complexity of the construction, connected, for example, with the use of a metal-ceramic insulator unit designed for the total working voltage of the tube, as well as vacuum-tight mechanical collapsible connections of a metal tube of a tube with replaceable units;
- presence in the tube of an integral constructive element – a specialized pumping system;
- need for high-voltage tube training after the replacement of individual units, which imposes additional requirements on the generator device of the power source of the tube, and the subsequent alignment of its electron-optical system;
- high cost.

However, three-electrode metal-glass tubes with a long-term anode tube from a vacuum cylinder of a thin-film target of the BS series, which were developed and mass produced in the OKB RP of the LOEP “Svetlana” RP, were made simpler in design and convenient in operation and also cheaper, starting from the mid- X of the last century [7].



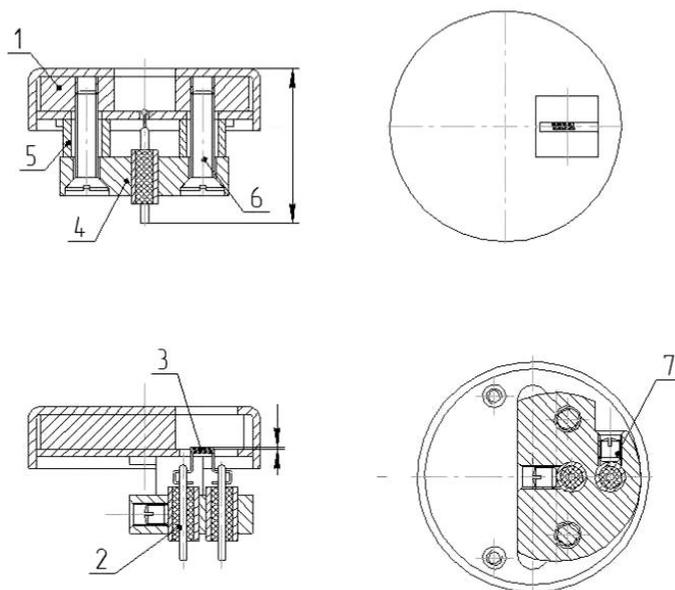
This significantly limits the scope of microfocus radiography, implemented on sealed-off tubes. As is known intensity  $I$ , generated by the X-ray tube, connected with the parameters of X-ray tube by the following expression:

$$I = kizU^2, \quad (1)$$

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

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

As 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. Therefore, during the development of “high current” microfocus tube as base 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).

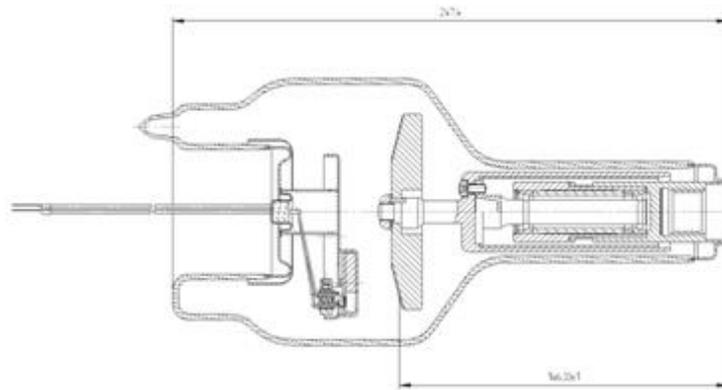


**Figure 1.** Cathode head of X-ray tube 0.75BD63-150.

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  $0.6 \times 0.6$  mm with a control voltage equal to zero to the minimum  $0.1 \times 0.1$  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 numerical estimates of allowable rotation speed of the anode assembly was chosen unseparated ball-bearing assembly with a temperature-compensating gap type ZYS99.

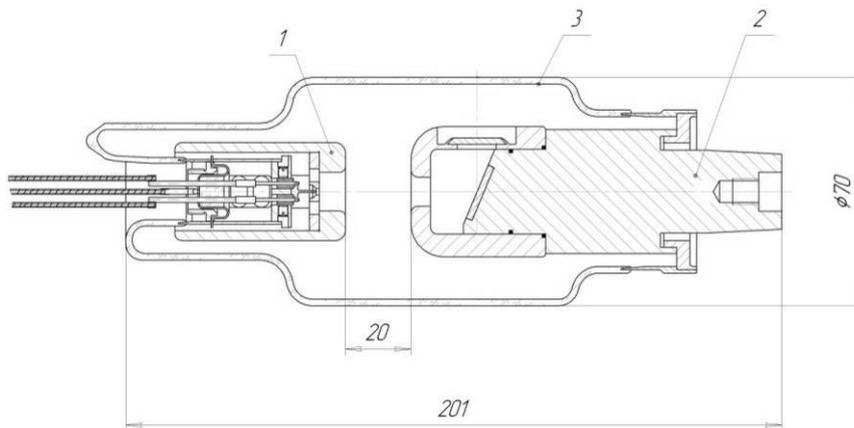
The construction of the first domestic X-ray tube with a rotating anode with smooth adjustment of effective focal spot size 0.7BD64-150 shown in figure 2.



**Figure 2.** Microfocus X-ray tube with a rotating anode 0.7BD63-150: max. voltage 150 kV; max. current 12 mA; size of the focal spot at a bias voltage 0 V – 0.6×0.6 mm; size of the focal spot at a bias voltage 55V – 0.1×0.1 mm; max. rotation rate of the anode 9000 rot/s.

In 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.

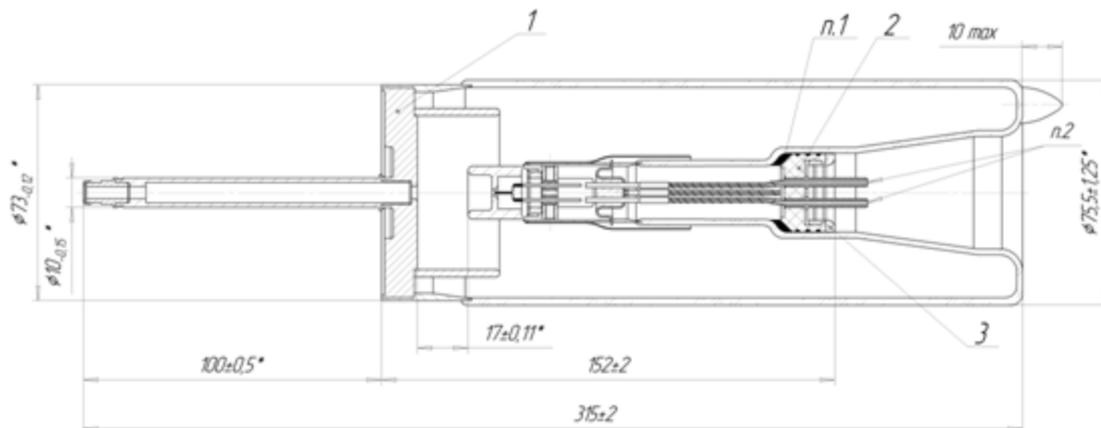


**Figure 3.** Microfocus X-ray tube with a massive internal anode 0.2BPM64-200: max. voltage 200 kV; max. current 1 mA; min. size of the effective focal spot 0.1 mm; diameter 70 mm; length 210 mm.

In 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) – 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 autofretting 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.

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.



**Figure 4.** Microfocus X-ray tube with the external target BS16(III): max. voltage 150 kV; max. current 150  $\mu$ A; min. size of the real focal spot 20  $\mu$ m; dimensions of the balloon – length 252 mm, diameter 75 mm; dimensions of the external anode – length 100 mm, diameter 12 mm.

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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