Some questions of designing installations for X-ray inspection

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Abstract. The problems of choosing the source of X-ray radiation for use as part of technological X-ray control installations are considered. The design and main characteristics of a domestic X-ray source based on a microfocus X-ray tube are described.

1. Introduction

Improvement of the electronic component base in terms of increasing the degree of integration and reducing the size of microchips, as well as passive RLC components, led to the creation of new technologies for their assembling on printed circuit boards. To ensure quality control of the assembling of printed circuit boards directly in production conditions, in the early 2000s, specialized X-ray units were developed [1].

At present, such an installation generally includes a radiation source based on an X-ray tube with a focal spot of micron sizes [2] and an image receiver based on a flat panel X-ray detector, which are located in a special chamber for radiographic work. During the control of printed circuit boards, two methods of obtaining an X-ray image are commonly used: contact and projection. To provide appropriate X-ray optical survey schemes, the camera is equipped with automated mechanisms that allow the X-ray tube, radiation detector and controlled object to move relative to each other along a given trajectory within the required limits. An important role in ensuring the claimed functional capabilities of the installation is carried out by specialized software for computer processing of acquired images.

2. Materials and methods

Leading manufacturers of X-ray inspection systems, for example, “Nordson”, currently design and manufacture installations exclusively on the basis of microfocus X-ray tubes with constant pumping. The advantage of this design, the foundations of which were proposed back in 1982 by German engineer A. Reingold, is the possibility of repeated replacement of the cathode and anode target. This makes it possible to operate the tube at the maximum loads – emission to the cathode and thermal to the target, but it causes a number of shortcomings in comparison with the vacuum tubes:

– large dimensions, weight and complexity of the construction, for example, the use of a metal-ceramic insulator assembly designed for the total working voltage of the tube, as well as vacuum-tight mechanical collapsible connections of a metal balloon of a tube with replaceable units;
– presence in the tube of an inalienable 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 subsequent alignment of its electron-optical system;
– high price.

Simpler in design and convenient to operate, and also cheaper, were three-electrode metal-glass tubes with a thin-film target of the BS series, taken out on a long anode pipe from a vacuum balloon, which were developed and mass produced in the Design Bureau of the LOEP “Svetlana” starting from the mid-70 of the last century.

In 2016 specialists of JSC “Svetlana-X-ray”, the current name of the Design Bureau of the LOEP “Svetlana”, mastered the serial production of the X-ray tube BS-16(III) of the third design, which, in its basic characteristics, is closer to collapsible tubes with a constant pumping out [3]. The maximum voltage is 150 kV, the maximum current is 150 μA, the diameter of the focal spot measured by the grid method (according to GOST 22091.9-86), at a voltage of 150 kV is 5 μm (figure 1).

![Figure 1. X-ray tube BS-16(III).](image)

The diameter and length of the glass balloon of the tube are 73 mm and 215 mm, the diameter and length of the copper anode tube are 10 mm and 100 mm. The tungsten target is deposited on a beryllium substrate (exit window of an X-ray tube) 0.2 mm thick. The minimum focal distance is 0.5 mm. During the development of the tube, the possibility of using an artificial diamond as an exit window material was investigated. An anode assembly based on a plate made of artificial diamond of a large area and 0.2 mm in thickness was constructed.

However, due to the higher cost of such a unit, the issue of serial production of a tube with a diamond exit window is under consideration. To ensure the specified diameter and position of the electron beam on the target, internal electrostatic (based on three-electrode EOS) and external magnetic (based on a permanent ring magnet) focusing systems are used.

The guaranteed service life of the tube in the nominal mode of operation is 300 hours. Practical service life can be up to 1000 h or more. The main reason for the final tube failure is the breakage (burnout) of the cathode due to the thinning and embrittlement of the filament due to the evaporation of tungsten from its surface.

Based on the BS16(III) tube, an X-ray source (IRI) of the monoblock type RAP150M-0.15N.3 was developed. The appearance of the IRI monoblock is shown in figure 2. It implements a high-voltage power circuit for an X-ray tube with a grounded anode; an accelerating voltage of negative polarity is applied to the cathode-grid tube assembly from the IRI generator device. In the generator set, in addition to the high-voltage source of accelerating voltage, there are power sources for the cathode and control (grid voltage) heating. The modern circuit technologies are applied in the IRI: direct rectification of the mains voltage, conversion of the rectified voltage to a frequency of several tens of kHz, the frequency-pulse operation of the converter (modulation of the rectified voltage), and multistage multiplication of the modulated voltage.

In the monoblock used a combined insulation is from solid component and oil. All elements of high voltage are filled with epoxy composition, and the gap between the walls of the balloon tube and the high-voltage socket of the monoblock is filled with transformer oil.
Control of the operating modes of the X-ray tube: voltage, heat current and current of the anode, exposure time, diameter and position of the focal spot on the target is carried out using a microprocessor device. The power consumed by RAP150M-0.15N.3, in the nominal operating mode does not exceed 200 W. Dimensions monoblock RAP150M-0.15.1 (without case and without a tube) are 110×220×260 mm, weight 6 kg.

3. Conclusion
In general, the experience gained in the work with RAP150M-0.15N.3, including in the microfocus X-ray computer tomograph MRKT-01, shows that, from the point of view of the “price/quality” ratio, it can compete with the most modern IRI designs based collapsible X-ray tubes with constant pumping in the development of industrial X-ray machines for X-ray quality control of PCB assembly.

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