X-ray inspection of arduous welds in rocket and space technology with the use of a microfocus X-ray apparatus

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Abstract. The article presents the design of a specialized X-ray machine to perform circumferential weld inspections various structural elements of air and space technology. Shows the main specifications of the device and describes a particular application of the apparatus. The results of the use of the device in conditions of real production on one of the local engine companies in the aircraft and space industry.

1. Introduction
Welds, which used in the products of rocket and space technology (RST), characterized by not only the variety of designs, brands of materials, methods of welding, but also, in some cases, is difficult access in the welding and control zone. Examples of such areas are circumferential welds of pipes mounted inside all sorts of tanks (figure 1). As it is known, to assess the quality of welded connections used radiation monitoring techniques, and in the first place, X-ray radiography [1]. However, the wide range of materials to be welded, a large variation of geometric dimensions and complex form of structural elements in many cases do not allow to be used for their control mass-produced X-ray machines based on conventional X-ray tubes. In this case, advantageously may be used a specially designed technical equipment of X-ray diagnostics.

Figure 1. Circular welded joint.
Typical specifications of known circular welded joints are:

- the type of welding – argon-arc unconsumable electrode;
- material – aluminum alloy;
- the type of welded joint – butt joint;
- radiation thickness of one wall, mm – from 5 to 10;
- the control sensitivity corresponds to the first class according to GOST 75.12 – 82;
- the inner diameter of the weld joint, mm – 100...170;
- the depth of the weld plane relative to the outer surface of the tank, mm – 80;
- the volume of non-destructive control – 100% of the weld length.

Since the tank design does not allow to place X-ray machine in its cavity for radiography “two walls” of the welded joint (figure 2(a)), it is advisable to use a scheme of panoramic X-ray radiography (figure 2(b)).

![Figure 2](image1)

**Figure 2.** The scheme X-ray radiography of circular welded joint: (a) – “two walls”; (b) – panoramic X-ray radiography.

As is well known, section 3.5 GOST 75.12 – 82 defines the requirements for the size of the focal spot of X-ray tube used for the implementation panorama scheme of shooting.

\[
\theta \leq \frac{Kd}{2(D - d)} \text{ [mm]},
\]

where \(\theta\) – focal spot size of X-ray tubes; \(K\) – sensitivity control; \(d\) – inner diameter of the controlled joint; \(D\) – outer diameter of the controlled joint.

In accordance with expression (1) at the required value of contrast sensitivity: \(K \leq 0.1; d = 100; D = 110\); focal spot size must not exceed 0.5 mm. In view of these requirements by the specialists of JSC “Svetlana-X-ray” was developed a specialized X-ray tube [2] with the imposition target of the vacuum balloon and “reverse” output panoramic beam 0.144BPV33-120.

![Figure 3](image2)

**Figure 3.** X-ray tube 0.144BPV33-120.

The maximum operating voltage of the tube is 120 kV, the maximum current – 1 mA, the minimum focal spot diameter – 0.1 mm. The tube has a three-electrode cathode assembly, so the electric circuit of the high-voltage power of the tube additionally contains the source of grid (control) voltage. In contrast to the traditionally used in conventional panoramic tubes conical target in the described tube
used flat tungsten target on the aluminum anode tube outside of the vacuum balloon. This target provides the necessary uniformity of the intensity of the generated radiation beam around the corner of his solution – 360×40 degrees and therefore, the entire length of the controlled weld.

2. Experiment
On the basis of this X-ray tube in JSC "ELTECH-Med" was developed and mastered in serial production monoblock type X-ray apparatus RAP-120PM (figure 4).

![Monoblock of X-ray apparatus RAP-120PM on a tripod](image1)

![A complete set of the apparatus in the transport bag](image2)

**Figure 4.** Monoblock of X-ray apparatus RAP-120PM on a tripod (a) and a complete set of the apparatus in the transport bag (b).

The experimentally obtained radiation diagram, which generated by the X-ray apparatus shown in figure 5. Zero count on the horizontal axis in figure 5 is the outer end of the X-ray tube target.

![Diagram directivity radiation intensity of the X-ray apparatus RAP-120PM](image3)

**Figure 5.** Diagram directivity radiation intensity of the X-ray apparatus RAP-120PM.

The apparatus RAP-120PM was successfully tested at one of the domestic enterprises of the aerospace industry. As an example, figure 6 is an X-ray image of the weld of an aluminum component with a diameter of 140 mm. The total thickness of aluminum walls in the weld region is 14 mm. The picture was taken on a roll X-ray film D7 and “digitized”. Shooting modes: voltage – 70 kV, current – 0.1 mA, exposure time – 90 s.
Figure 6. Fragments of an X-ray image of an annular welded seam of an aluminum body part with the image of a standard (a) and welding defects (b).

To assess the radiographic sensitivity, a standard № 1 was used. With a standard technique for analyzing X-ray images using a negatoscope, the sixth groove of the standard (the groove dimensions 0.1×0.1 mm) differs confidently on the image of the annular welded seam.

3. Conclusions
The technical and technological solutions tested during the development of the X-ray tube 0.144BPV33-120 and the apparatus RAP-120PM allow satisfying any “reasonable” requirements for voltage, current, focal spot size, and also dimensions and weight of an X-ray source intended for monitoring circular welded seams of rocket and space technology products according to a panoramic scheme of shooting.

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