COMPLEX FOR X-RAY INSPECTION OF LARGE CONTAINERS

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Abstract
The X-ray inspection complex is intended for non-intrusive inspection of large containers in the seaport. To provide two projections of irradiated container and ensure reliable inspection, the complex includes two sets each containing self-shielded X-ray source and detector array. The X-ray source includes electron linear accelerator with 7.3 MeV energy, conversion target, local radiation shielding, and alignment means. The accelerator uses standing wave bi-periodic structure fed by magnetron generator with 2.8 GHz frequency. It provides intensive electron beam without application of external magnetic field for the beam focusing. This feature makes it possible to use massive local radiation shielding made from iron. The radiation shielding provides large attenuation of scattered X-rays and ensures the radiation safety for personnel as well as high sensitivity of detecting system and good penetrability of the complex.

INTRODUCTION

The Poliscan-3 inspection complex is intended for the X-ray inspection of fully loaded trucks and sea-land containers in the seaport. The examination method is based on exposure of the objects to be inspected to X-ray and formation of the direct-shadow image on the computer screen. The X-ray source is based on the compact self-shielded linear electron accelerator. To ensure reliable inspection, the complex provides for high penetrability and two projections of irradiated container.

Peculiar features of the Poliscan-3 complex are the development and application of the following devices:

- Compact linear electron accelerator without magnetic focusing devices;
- Electron injector forming beam with designated specific phase portrait;
- Local radiation shielding for the accelerator ensuring low level of stray radiation;
- Two-position collimator for X-ray providing a possibility to calibrate radiation detectors.

CHARACTERISTICS OF THE COMPLEX

The Poliscan-3 inspection complex includes following components:

- Two X-ray sources;
- Two arrays of radiation detectors;
- The apparatus for data processing and forming images;
- The apparatus for the complex control;
- Means for transportation of inspected objects;
- The power supply apparatus;
- Radiation monitoring means.

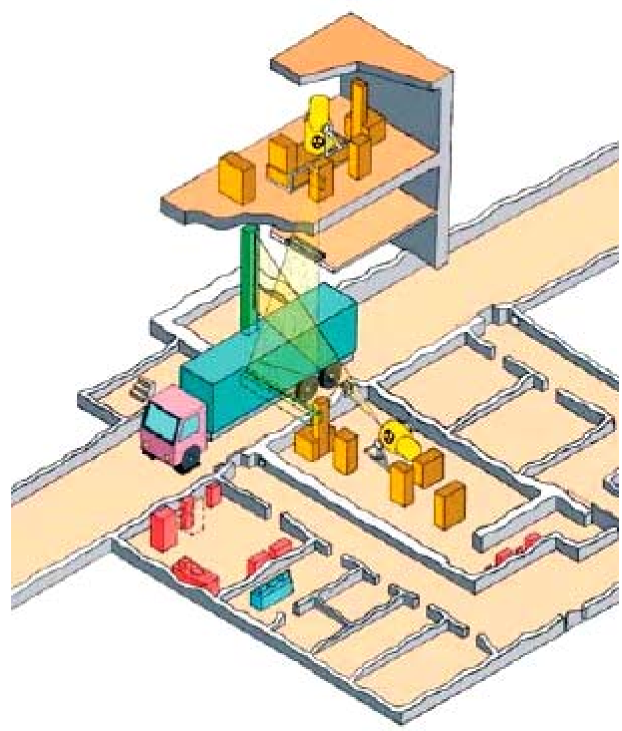

Figure 1: Location of apparatus of the inspection complex.

The Poliscan-3 complex is located in the stationary building (Fig. 1). The complex includes two X-ray sources generating fan-shaped X-rays transirradiating the container in horizontal and vertical directions thus providing side and top views of the container.

Each X-ray beam is generated by the pulsed electron beam produced by the linear microwave electron accelerator and subsequently converted to the X-ray with the conversion target. The accelerating structure and target are placed inside the local radiation shielding with the collimator forming narrow fan-shaped X-ray.

The local radiation shielding provides large attenuation of scattered X-rays. It ensures the radiation safety for the operating personnel and low level of stray radiation at the radiation detectors. The application of local shielding

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makes it possible to simplify building design and construction, to decrease the wall thickness from 2–3 m to 0.5–1 m, and to reduce significantly the object cost.

Table 1: Main characteristics of inspection complex

Electron energy	7.3 MeV
Penetration	350 mm steel
Maximum dimensions of container	12×2.5×2.5 m
Maximum scan speed	0.4 m/s

X-RAY SOURCE

The X-ray source is based on the self-shielded compact linear accelerator of the electron beam (Fig. 2).

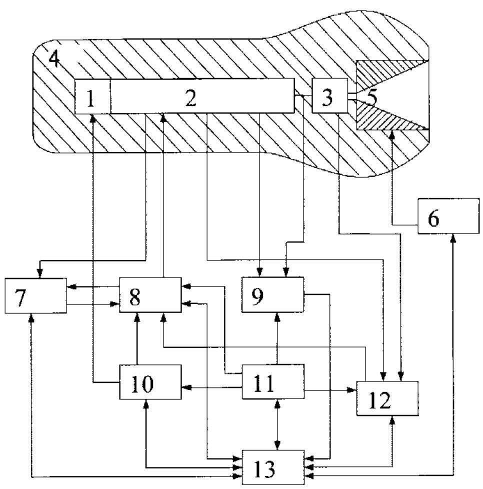

Figure 2: Scheme of the X-ray source.
1 – Electron injector 2 – Accelerating resonator
3 – Conversion target 4 – Radiation shielding
5 – Two-position collimator 6 – Drive for collimator
7 – AFC control block 8 – Microwave generator
9 – Vacuum pumping means 10 – Pulse modulator
11 – Power supply apparatus 12 – Water cooling means
13 – Control apparatus

Measured characteristics of the electron accelerator are given in Table 2. The pulse duration and beam energy in pulse are of importance for obtaining required signals from the radiation detectors. The pulse repetition rate determines spatial resolution of the inspection system.

Table 2: Characteristics of electron accelerator

Operating frequency	2.8 GHz
Full number of cells	33
Resonator length	0.9 m
Pulse beam current	150 mA
Pulse duration	12 mcs
Pulse repetition rate	100 pps
Coupling coefficient	3 %
Pulse power of RF generator	2.5 MW

In the accelerators, standing wave bi-periodic structure is used. Main cells have optimized cross-section, coupling cells are narrow cylindrical volumes (Fig. 3). Two initial cells perform the electron beam bunching, they have specific dimensions. Neighboring cells are coupled through two windows. The electron injector is connected directly to the resonator so that the first cell wall acts as the injector anode. The resonator is cooled by water circulating inside the water casing and ensuring a good uniformity of temperatures and frequencies of the cells at high power operation.

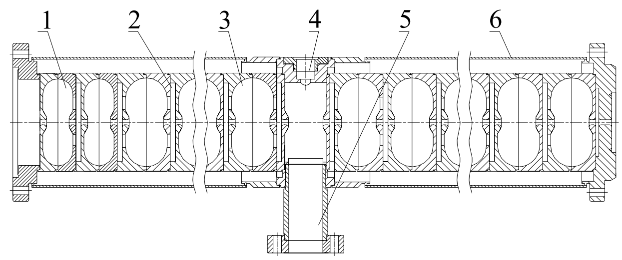

Figure 3: Accelerating resonator.
1 – Bunching cell 2 – Coupling cell
3 – Accelerating cell 4 – RF probe
5 – Waveguide 6 – Water casing

RF field in the resonator provides transverse focusing as well as longitudinal bunching and acceleration of the beam. Since the resonator is located inside the radiation shielding made from iron, no special magnetic device for the beam focusing is applied [1]. The major problem of development of such type accelerator is obtaining acceptable capture of the injected electrons into the acceleration process and required beam at the conversion target. The problem is solved mainly by proper selection of phases of particles passing the resonator gaps, for which purposes the cells dimensions and the field levels in the cells have been carefully calculated.

As beam dynamics calculations show, the beam at the output of an accelerator with RF focusing has a peculiar distribution: its major part ("core") is located in a central area with very small diameter, and another part ("halo") is rather widely expanded. Since the "core" can burn through the conversion target, this hampers application of such type accelerator with high power.

In order to form, accelerate and bring to target the electron beam with required radius and good distribution, the beam has certain "phase portrait". The beam takes required "phase portrait" in the electron injector having specific design and then passes all the resonator keeping the radius and distribution approximately constant [2].

The resonator is fed by microwave generator built around the magnetron. MI-456A tunable magnetron is applied operating in "lock-on" regime, with operating frequency being stabilized by the resonator. Microwave generator also contains the waveguide, circulator, and block for automatic frequency control. The Y-junction ferrite circulator is applied to protect the magnetron from a damage or unstable operation.

RADIATION DETECTORS

The radiation detection system forms electric signals needed to obtain the radiographic image. The system contains radiation detectors arranged in the array, channels for conversion of the signals, and commutation and control circuits.

Table 3: Characteristics of detection system

Number of X-ray detectors	1024
Full length of detector line	5.1 m
Detector aperture dimensions	4.3×5 mm^2
Dynamic range of detecting apparatus	$6.5 \cdot 10^4$

Radiation detectors containing scintillators + photo diodes are applied. $CdWO_4$ scintillators are used because they have good sensitivity, small afterglow time, low level of residual afterglow, and high radiation tolerance.

RADIATION SHIELDING

The accelerators of Poliscan-3 system are entirely self-shielded. The radiation shielding consists of blocks manufactured from cast iron. It surrounds the electron injector, accelerating resonator, and conversion target. The shielding has the most thickness around the target. The shielding has narrow slit cut in the wide end intended to form fan-shaped X-ray. The source is mounted on the frame and has a possibility to turn (Figs. 4 and 5).

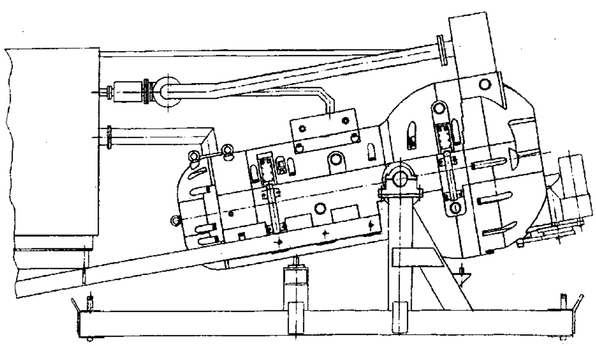

Figure 4: Design of X-ray source.

Table 4: Characteristics of radiation shielding

Length of shielding	2.3 m
Maximum diameter of shielding	1.1 m
Attenuation of leakage radiation	10^4 - 10^5
Weight of shielding	13 t

Thick radiation shielding ensures large attenuation of leakage radiation in the location of detectors and makes it possible to obtain good sensibility of detector apparatus.

Further increasing the sensibility and dynamic range of the detecting apparatus is achieved due to application of two-position collimator for X-rays. The collimator has special design [3] and can take two positions: in the first position it operates as X-ray collimator and provides narrow fan-shaped X-ray, and in the second position it completely covers X-ray.

Figure 5: X-ray source.

The two-position collimator gives a possibility to calibrate the radiation detectors during operation of the accelerator and compensate stray signals on the detecting apparatus: signal caused by dark current of photo-diode in the detector and signal caused by scattered radiation in the location of detectors. Proper calibration of the detectors increases the penetrability and improves the quality of images.

CONCLUSION

By now the equipment of the Poliscan-3 inspection complex has been manufactured, mounted, and tested. All innovations have been verified and are validated.

Further improvement of the inspection complex involves the following:

- Development and application of multi-beam klystron for RF power supply in place of the magnetron. "Istok" is the deviser of such type klystrons. Multi-beam klystron has low beam voltage (60 kV) that is close to magnetron beam voltage, but the klystron has much more service life and better stability of parameters.
- Development of sealed-off electron accelerator that is pumped out and sealed-off in the course of manufacturing. Such type accelerator is a compact and long-life device which does not require an application of complicated vacuum pumping system and needs a short time to be prepared for service.

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