SMALL-SIZE 2.5 MEV ELECTRON ACCELERATOR WITH LOCAL RADIATION SHIELDING

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A novel design of a 2.5 MeV small-size linear electron accelerator with local radiation shielding is presented in the paper. The accelerator is intended for the use in mobile introscopic facilities. The main design approaches, weight / dimensions and results of factory tests are given.
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A small-size 2.5 MeV linear electron accelerator for the X-ray dose rate up to 0.5 Gy/min with local radiation shielding is intended for the use in mobile introscopic facilities for non-destructive inspection of metal structures under field conditions as well as for customs inspection of cargoes transported by land, air and sea.

Proceeding from the requirement of the inspection system mobility, a series of rather stringent requirements should be met when designing the facilities to be used without additional radiation shielding and under all-weather conditions:

- minimum weight and dimensions of the accelerator components;
- local radiation shielding;
- vibration strength up to 2 g;
- ambient temperature from -25°C to + 45°C and humidity from 5% to 95%.

The accelerator consists of an irradiator, magnetron modulator, heat exchanger unit and control system; and all these accelerator components can be located on chassis of a truck.

Main performances of the accelerator:
Energy of electrons in the nominal mode, MeV.……2.5
X-ray dose rate 1m from target, Gy/min…….. up to 0.5
Effective focus spot diameter on target, mm…. no more than 2
Dose rate of X-ray radiation leakage 1m from irradiator jacket with closed collimator, μSv/hour………. no more than 5

Nominal operating conditions of the accelerator:
- magnetron pulse power - 1.8 MW;
- pulse repetition rate - 300Hz

When implementing the project, much attention was paid to the design of the irradiator and especially the designing of radiation shielding, the component upon which primarily weight and dimensions of the irradiator depend.

When computing the local radiation shielding, we used the Monte Carlo method for simulation of X-ray photon absorption. The main criterion was the requirement of minimum weight and dimensions of the irradiator with minimum leakage dose rate (no more than 5 μ Sv/hour in any point of 4π angle 1 m from the irradiator jacket with closed collimator slit). Several versions of the radiation shielding were computed with various layouts of the irradiator units, and different shielding configurations and materials were considered. Radiation losses in the design elements were taken into account.

As the basic version we have taken a block design of the radiation shielding in which tungsten, lead and steel were used. Such a design of the shielding ensures free access to the electron gun, X-ray target and other units for maintenance/repair works in the process of operation. For example, when replacing the target, the slit collimator is removed from the central block of the radiation shielding; and when replacing the electron gun, the radiation shielding of the gun is rotated through 90° (Fig. 1).

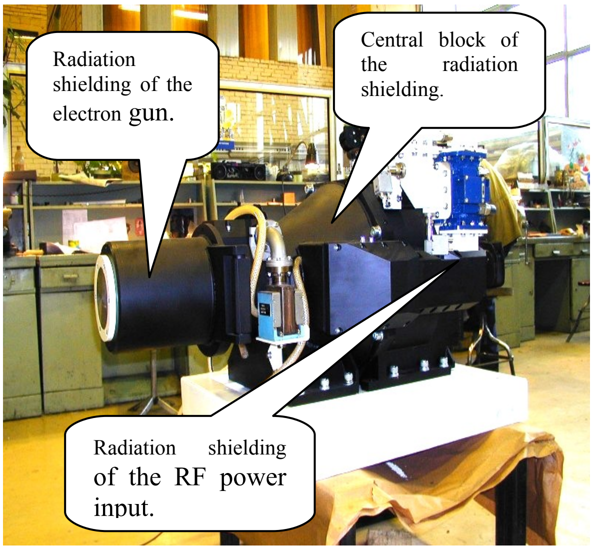

Fig. 1. Radiation shielding.

Inside the radiation shielding located are: the electron gun, accelerating structure and target. The waveguide line, feeding RF power to the accelerating structure, and vacuum pumping collector are connected to the accelerating structure through the labyrinths made in the radiation shielding. Cable feeding the electron gun is also installed in these labyrinths. The equipment enumerated above as well as the unit of pulse transformer with a magnetron located outside the radiation shielding is housed inside a cabinet. To ensure proper temperature inside the cabinet (from 5°C to 30°C) when the accelerator operates under all-weather conditions, the cabinet is ventilated with air supplied from the air-conditioning system.

As a result of such an integrated design approach, we succeeded in constructing rather a compact irradiator with dimensions of 850·700·975 mm and 1480 kg in weight (Fig. 2).

Fig. 2. Irradiator.

The magnetron modulator is intended for supplying pulse power to the magnetron and electron gun. A single pulse forming line (PFN), discharging through a thyratron switch, is used for energy storage and pulse formation. Present-day electronic components applied in the modulator allowed reduction of its dimensions and weight.

The equipment of the modulator is housed in a cabinet, which, similar to the irradiator, is ventilated with air supplied from the air conditioning system to maintain constant temperature and humidity.

Dimensions of the modulator cabinet are: 850·600·1375 mm, weight – 425 kg (Fig. 3).

On the strength of the mobility requirement, when designing the irradiator and modulator much attention was given to the vibration strength of the equipment installed in the cabinets.

To maintain a specified temperature of the accelerating structure and magnetron over a wide temperature range (from -25°C to +45°C) a refrigerating unit of the RITTAL firm model Best Nr SK 3335.075 is used. An inhibited antifreeze, with the freezing temperature of -30°C, is used as a cooling liquid. Necessary temperature monitoring and diagnostics of the status of the refrigerating unit are performed with a microprocessor.

Fig. 3. Magnetron Modulator.

Comprehensive tests of the accelerator confirmed that parameters obtained comply with specified ones. Below given are the radiation parameters for the nominal operating conditions of the accelerator.

Electron energy in nominal mode, MeV…………..2.5
X-ray dose rate 1m from target, Gy/min……..up to 0.5
Dose rate stability on the central axis, %…… ……2.2
Effective diameter of focus spot on target, mm…..
no more than 2

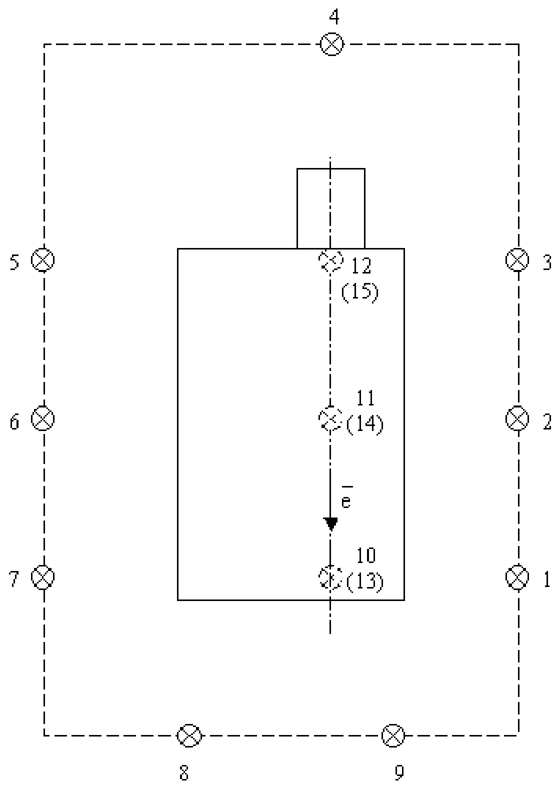

Fig. 4. Schematic of X-ray leakage measurements.

When testing the accelerator, special attention was given to measurements of X-ray radiation leakage, i.e. quality of the radiation shielding. Leakage dose rate was measured with the output collimator closed in 15 points shown on the schematic diagram of the irradiator (Fig. 4) 1m from the irradiator jacket. The measurements were done at 2.5 MeV energy of electrons and 20 µA average current of accelerated electrons.

Averaged results of the measurements are tabulated below:

№ of point	1	2	3	4	5
D(µ Sv/hour)	0.875	1.74	2.03	0.503	1.9
№ of point	6	7	8	9	10
D(µ Sv/hour)	2.19	0.62	0.364	0.367	0.74
№ of point	11	12	13	14	15
D(µ Sv/hour)	0.718	0.701	0.05	0.14	0.47

Note: points 10, 11, 12 are located in the upper part of the irradiator; points 13, 14, 15 are located at the bottom of the irradiator.

The results of leakage measurements indicate rather good coincidence with the calculated data. It is seen from the table that the X-ray radiation leakage is more than half as much as an allowable value even in the most “dangerous” directions (points 2, 3, 5, 6) where labyrinths for connection of vacuum pumping elements, waveguide line, water cooling system and cables to the accelerating structure are provided in the radiation shielding. In other directions the thickness of the radiation shielding walls ensures even the higher attenuation of radiation.

Thus, the results of testing the prototype of the small-size accelerator with local radiation shielding have demonstrated that the machine may go into small-scale production.