MAIN PARAMETERS AND OPERATIONAL EXPERIENCE WITH NEW GENERATION OF ELECTRON ACCELERATORS FOR RADIOGRAPHY AND CARGO INSPECTION

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Abstract

We describe main parameters and operational experience with new generation of electron accelerators for radiography and cargo inspection developed with participation of scientists, engineers and technologists from Lomonosov Moscow State University and "Research and Production Enterprise "Toriy". Two accelerators are described: accelerator for radiography UELR-8-2D with beam energy regulated in the range 3-8 MeV and dose rate from 0.5 to 15 Gy/min and accelerator for cargo inspection UELR-6-1-D-4-01 with pulse to pulse energy switching between 3.5 and 6 MeV, with repetition rate 400 Hz and dose rate 4 Gy/min. Both accelerators use klystron as an RF source, which is fed by a solid state modulator.

INTRODUCTION

Main directions for perfection of electron accelerators for radiography are connected with the possibility of regulating the accelerated beam energy and dose rate of bremsstrahlung in a wide range to achieve optimum conditions for defects visualization for different thicknesses of material; with minimization of the electron beam spot size at bremsstrahlung target in order to improve spatial resolution; with extended life of the bremsstrahlung target; reduction in weight and size characteristics of the accelerator; increasing its resource; simplifying the operator work and servicing; in reducing parasitic radiation.

Electron accelerator for modern cargo inspection complex capable to recognize the effective atomic number of the contents of the container [1] in addition to the features listed above must be able to switch the energy of the accelerated beam from pulse to pulse between two or more values; must ensure high stability of the beam energy and dose rate; must have a short transient time after switching on X-rays; must be able to generate packages of closely spaced pulses of different energy [2], following with a high repetition rate.

The above requirements are the basis for the design of accelerators described in this report.

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COMMON FEATURES

Developed accelerators for radiography and cargo inspection have several common features. In particular, the change of the energy of the accelerated beam in both cases is done by changing the level of the accelerating field. To ensure the high quality of the beam at more than twice change of the energy the standing wave on-axis coupled accelerating structure was optimized in order to produce the transverse and longitudinal beam focusing with capture efficiency more than 60% in the whole range of the accelerating field variation. The sealed-off design of the accelerating system, consisting of an accelerating structure with RF antenna, electron gun, vacuum RF window, ion and getter pumps and intensively cooled bremsstrahlung target, is used. The electron gun is attached to the accelerating structure using Conflat joint that facilitates the repair in the case of cathode filament failure. Exterior view of the accelerating system is shown in Fig. 1.

Figure 1: Accelerating system.

Accelerating structure is fed by the pulse multi-beam klystron KIU-168 [3] operating under reduced high voltage. To power klystron and electron gun solid state modulator [4] is used. The parameters of the modulator

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provide the maximum output pulsed power of the klystron 3.5 MW.

Both accelerators have similar design of the radiation shielding, which provides precise positioning of the accelerating structure, shielding the electron beam from stray magnetic fields and allows for quick replacement of the structure. To reduce parasitic radiation a combination of lead and tungsten is used. The dose rate of the bremsstrahlung at a distance of 1 m from the bremsstrahlung target in all directions except the working area is reduced by 10^4 times for radiographic accelerator and 10^5 times for cargo inspection as compared to the dose rate on the axis.

The dose rate measurement is done by built-in ionization chamber. The pressure of the insulating gas in the waveguide is automatically maintained constant by means of the gas system, including besides other parts also a vacuum pump, pumping out waveguide before filling by gas. X-ray head and modulator are combined into a single module.

Both accelerators have the same principle of the control system. Control of the individual subsystems of the accelerator is produced by controllers coupled to the control computer via Ethernet. All controllers and control computer are located in the X-ray head cabinet in the vicinity of controlled objects. The remote control panel is connected to the control computer also using Ethernet. Control of the accelerator operation is done by the original software. The system of the accelerator interlocks ensures safe operation in accordance with the applicable rules. Control of the accelerator operation and fault diagnostic can be performed via remote access. Details of control system are described in [5].

ACCELERATOR FOR RADIOGRAPHY

Photo of accelerator for radiography is shown in Fig. 2, the basic parameters are given in Table 1. During accelerator commissioning its calibration is carried out. Built-in ionization chamber is calibrated by an external camera. Beam energy is determined by attenuation of bremsstrahlung by barrier. For each of the energy values in a fixed range of 3 to 8 MeV, following with steps of 1 MeV, parameters of RF system operation are calculated using theoretical models and measured data. The parameters of RF system such as the frequency of the RF generator, pulse repetition rate, the output power of the klystron depend on the set energy, dose rate, and the temperature of the coolant. In the operation of the accelerator parameters for the selected mode of operation, are installed automatically. Also the process of the accelerator on and off is fully automated.

Measurement of the size of the electron beam focal spot at the bremsstrahlung target is illustrated by Fig. 3 (a). Lead diaphragm (2) which is 10 mm thick with d = 2 mm hole is placed at distance s = 0.18 m from the target (1). Bremsstrahlung beam spot is registered by X-ray film (3) placed at L = 3 m from the target. Electron beam focal spot diameter in this geometry is defined by the:

$$d_b = \frac{S}{L} D_l - d \qquad (1)$$

Beam image recorded by film, is shown in Fig. 3(b) Image diameter can be estimated as, $D_l \approx 38$ mm, hence electron beam focal spot diameter at target is $d_b \approx 0.28$ mm, which well correlate with spot diameter measured directly using transition radiation during accelerator design stage.

Figure 2: Accelerator for radiography.

Table 1: Radiographic accelerator parameters

Parameter	Value
Beam energy	3 - 8 MeV
Dose rate	1 – 15 Gy/min
Beam spot size	< 1 mm
Dimensions W×L×H	640×1090×1460
Weight	1025 kg

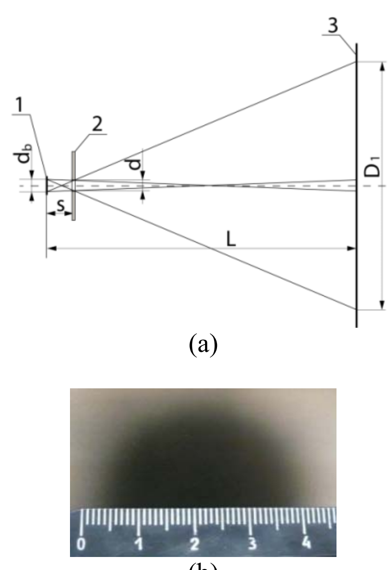

Figure 3: (a) Geometry for electron beam focal spot size measurements. (b) Bremsstrahlung beam spot registered by X-ray film.

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ACCELERATOR FOR CARGO INSPECTION

Photo of the accelerator for cargo inspection is shown in Fig. 4, the main parameters are listed in Table 2.

Figure 4: Accelerator for cargo inspection..

Table 2: Cargo inspection accelerator parameters.

Parameter	Value
Beam energy	3.5/6 MeV
Energy stability	0.5 %
Dose rate	4 Gy/min
Dose rate stability	2 %
Repetition rate	2×200 Hz
Beam spot size	< 1 mm
Dimensions W×L×H	640×1090×1460
Weight	1250 kg

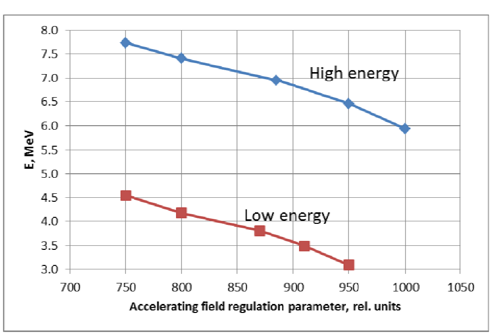
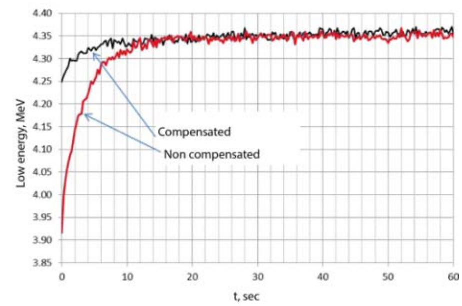


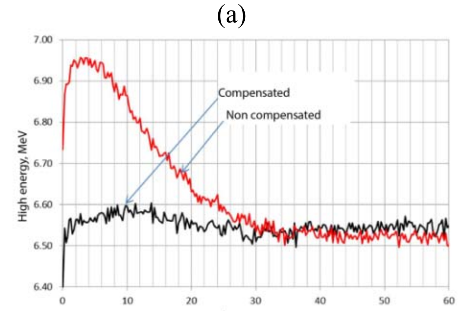
Figure 5: Low and high beam energy regulation.

Presented here accelerator is a fundamental modification of the accelerator prototype described in [6]. The accelerator can operate in a low-energy or high-energy mode with a pulse repetition rate up to 400 Hz, or in energy switching mode with a repetition rate of pairs of closely spaced pulses of 200 Hz. The interval between a pair of pulses in energy switching mode can be adjusted in the range of 200-600 μs [2]. The values of the low and high energy can be regulated independently over a wide range, as shown in Fig. 5.

Important for cargo inspection accelerators is reduced transient time after the X-rays switching on. To compensate for changes in the energy and dose rate caused primarily by thermal processes, we have developed a model describing the behavior of accelerating structure in the transient period taking into account a load by beam current, which is different for low and high energies. Based on this model and measurements the control algorithm for RF system was developed to compensate for changes in the energy and dose rate. Fig. 6 shows example of time dependencies of the values of the low and high energy when operating in the energy switching mode without and with compensation mechanism. To measure beam energy the detector line [1] was used.



(a)



(b)

Figure 6: Time dependencies of low (a) and high (b) energies in energy switching mode with compensating mechanism switched off and on.

CONCLUSION

We have developed a new generation of accelerators for radiography and cargo inspection. The authors are grateful to Mr. A.V. Nalivaev for support of this work and Dr. S.A. Ogorodnikov for measurements of the cargo inspection accelerator parameters.

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