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Dedicated detector for verification of X-ray energy in the linear accelerators for cargo screening and industrial radiography

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The novel type of detector for X-ray energy evaluation has been developed. Thanks to a simultaneous analysis of the attenuation of X-rays by different thicknesses of well known material, the maximum energy of electrons on the conversion target can be deducted. Fast operation allows for pulse-to-pulse measurement, which is a must for modern, interlaced-energy cargo inspection systems. In this article the construction of the detector and software description are presented.

Key Words: electron linear accelerator, energy detector, X-ray.

Introduction

Applications of electron accelerators cover a number of areas, from cancer treatment, industrial processing and radiography, environmental protection, to safety and security. Accelerator based techniques are increasingly used in luggage and cargo inspection, as well as smuggling detection of explosives and of nuclear materials. One common Accelerator-based system consists of an electron accelerator with a conversion target and a slit collimator to produce a narrow, fan X-ray beam in MeV energy range for sufficient penetration [1]. Radiation attenuated in the tested object, like cargo container or truck load, is detected by a detector array. Obtained images depend on thickness and type of materials inside inspected contents; typically, the shape and size of different elements is clearly visible. The type of the material can be deduced only in some cases. However, to enhance the recognition of material type, so-called ‘interlaced-energy’ technique is used [5]. In this technique a linear accelerator alternates its energy from pulse to pulse. Typically, 4/6 MeV or 6/9 MeV machines are used. In effect, the object is tested by two different energy spectra that interact differently with tested materials. Lower energy X-ray beam is attenuated differently than higher energy beam and this effect depends on the atomic number of tested material. Thus, the ratio between attenuations can be indicative for the type of element. Typically, the following groups can be identified: organic, inorganic, light metals, heavy metals.

New methods based on new accelerators require additional equipment for Quality Assurance (QA) of the alternating X-ray fan beam. In this article a novel type of detector for pulse-to-pulse measurement of the energy of an X-ray beam is presented.

X-ray energy measurement

To present the energy of X-ray beams, several different methods can be used. One technique, commonly spread in industrial applications, is the measurement of the half value layer (HVL) parameter [4], i.e. the thickness of well known material, which attenuates the dose rate by 50%. Result can be translated to typical bremsstrahlung spectra and the energy of electrons on the conversion target. Typically the results of this indirect measurement are presented in MV units instead of MeV.

Medical applications use the water-phantom, in which a traveling ionization chamber produces a chart of full percentage-depth-dose curve [6]. An example of such a PDD curve is presented in Fig. 1.

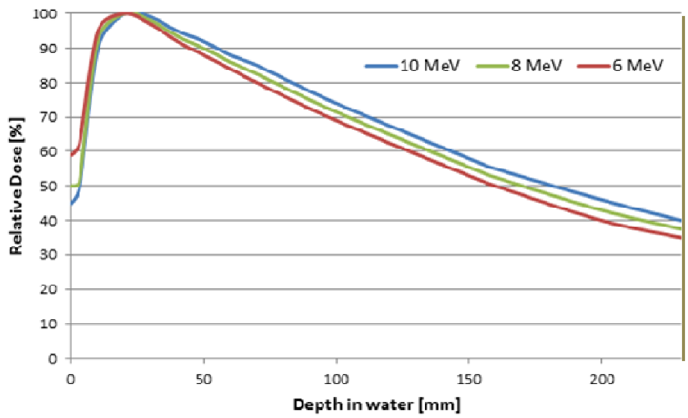

Figure 1. Example of percentage-depth-dose (PDD) curves created by X-ray beam obtained with 6 MeV, 8 MeV and 10 MeV electrons

One of the possible methods for indication of the beam energy is to define the depth of maximum dose deposition and dose deposition at known depth, for example 100 mm. The other scenario is to calculate a ratio between dose deposition at 100 mm and at 200 mm: D_{100}/D_{200} [2, 3]. Such ratio is then related to X-ray spectra.

The second method was adapted for fast energy verification in the detector described in this article.

New X-ray energy detector - construction and physical fundamentals

The detector consists of:

- Detector head
- Measure box and data transfer unit
- USB to PC connector
- Cable for data transfer (30 m) and cables for detector head connection
- USB cable to connect the device to PC.

Schematic diagram of the measurement setup is presented in Fig. 2.

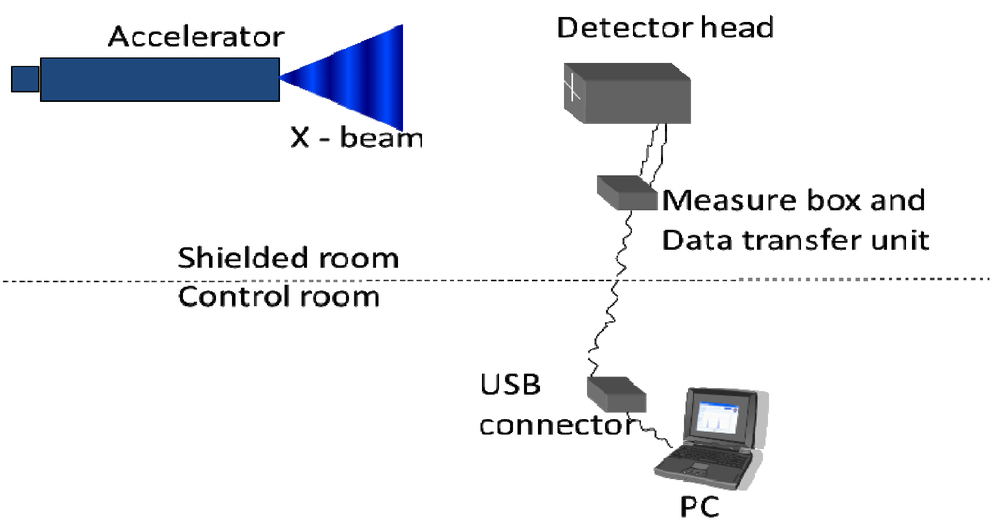

Figure 2. Schematic diagram of detector setup

A PMMA block, 200 mm length, defines the detector head. It is equipped with two 20 mm × 5 mm × 5 mm CsI(Tl) scintillating crystals, located at 100 mm and at the end of the block, i.e. at 200 mm, respectively (see Fig. 3).

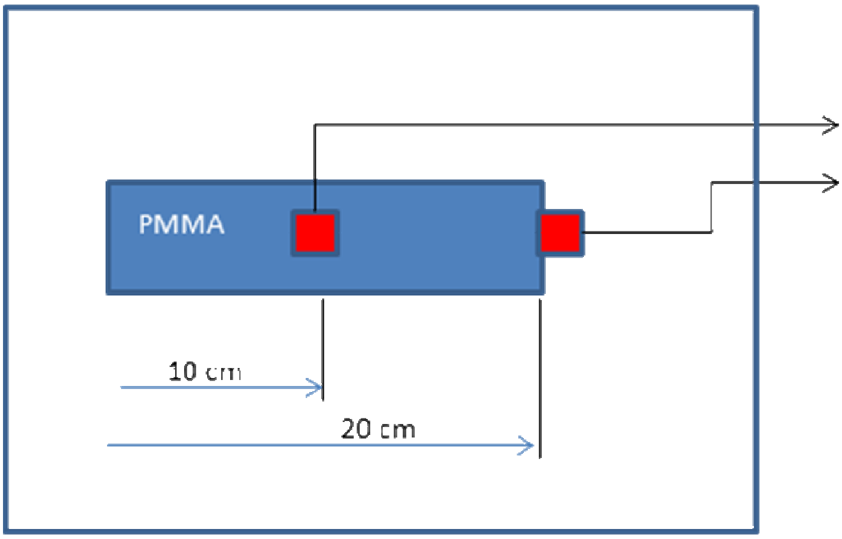

Figure 3. Construction of the detector head. Note a position of scintillators with photodiodes (red rectangles)

Light emitted from each crystal is read by two photodiodes. One of the crystals is used as a beam trigger source.

When X radiation is detected, the signals from both photodiodes are transferred to the Measure box and data transfer unit and amplified. During 100 μs window the signals are recorded, then sent to a PC, where the ratio is calculated, while the detector is waiting for a next radiation pulse. For user convenience, a standard USB port is used, which is readily available in all modern PCs.

As a result one gets two values which correspond to dose depositions at 100 mm and 200 mm, respectively. After correct calibration, X-beam energy can be found.

Software description

The main screen of the detector software is presented in 4.

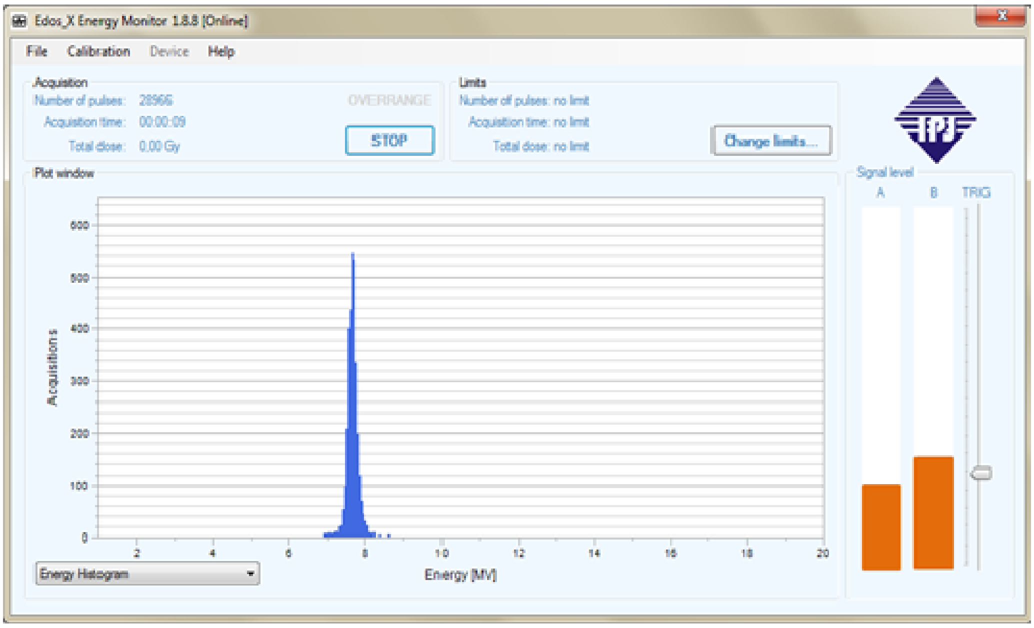

Figure 4. Main screen of the detector software

When the calibration file is correctly defined, D_{100}/D_{200} ratio is recalculated to the value colloquially called "X-ray energy", which means the maximum energy of electrons on the conversion target.

In the detector software this value is plotted as a histogram, clearly visible in Fig. 4. In the right part of the software window two orange bars correspond to the two signals from scintillators/photodiodes.

Acquisition panel also displays number of pulses detected during the measurement, acquisition time and the indication of total dose delivered.

Recorded data allows for additional observations:

- Energy stability in time,
- Dose rate stability in time,
- Accelerator repetition rate stability in time.

Calibration

The direct measured values by the detector are D_{100} and D_{200}, thus the D_{100}/D_{200} ratio in consequence. In order to find the required value of the electron energy on the conversion target, the proper calibration procedure must be applied.

The optimum method would be to observe signals created by photons emitted during radioisotopes decays. However, it is not possible for higher energies. Therefore suggested procedure consists on the comparison of the measured D_{100}/D_{200} ratio with the same ratio measured by water phantom on the same accelerator for different energies. The D_{100}/D_{200} ratio obtained from water phantom can be easily compared with electron energy based on tabularized data in the literature [7]. Based on such measurements the calibration file can be created, where D_{100}/D_{200} ratio is referred to the real energy value for wide range of measured energies. Such file can be used for real-time calibration during the measurements.

Results and discussion

An example of D_{100}/D_{200} value measurements for single energy accelerator 10 MV is presented in Fig. 5.

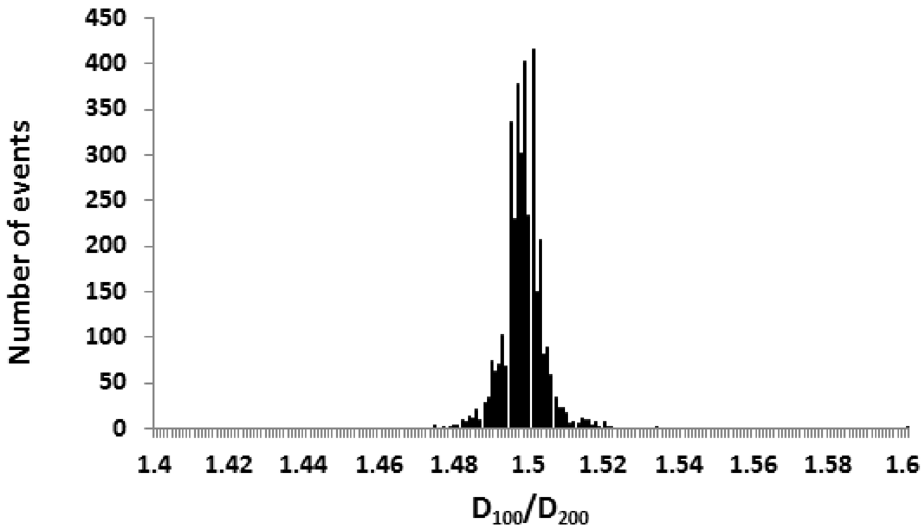

Figure 5. Histogram of D_{100}/D_{200} ratio for 10 MV accelerator measured by energy detector, 3576 points in total

The main unique feature of this detector is, however, the possibility of observation of the fast, dynamic energy changes in so-called interlaced energy accelerators, dedicated for cargo screening applications. Example of the measurement of such an accelerator is presented in Fig. 6 and Fig. 7. One can observe the energy instability at the beginning of accelerator work.

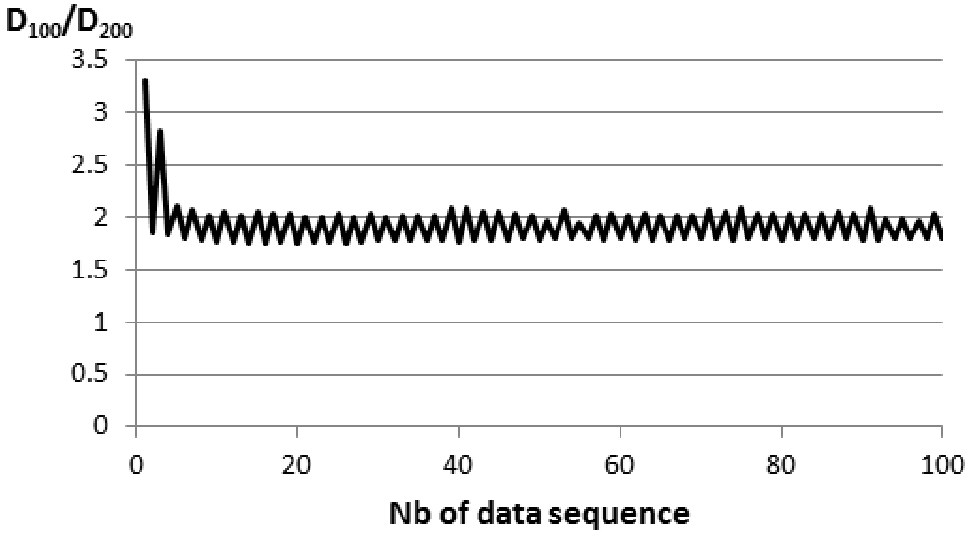

Figure 6. The value of D_{100}/D_{200} ratio for a sequence of measurements of the interlaced energy accelerator

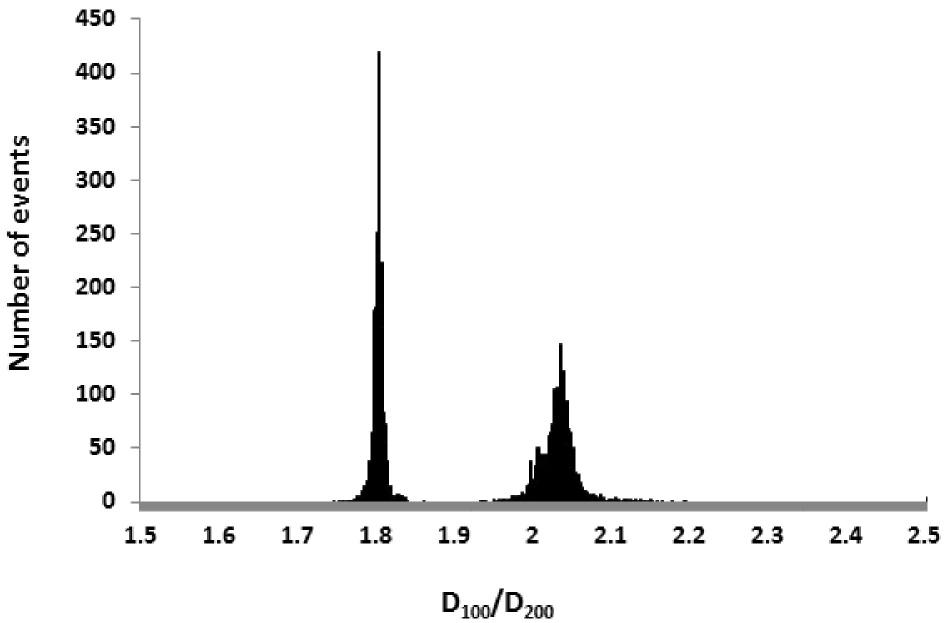

Figure 7. The D_{100}/D_{200} ratio for 4/6 MV dual energy accelerator, measured by energy detector, 7174 counts in total

Conclusions

The novel type of detector for X-ray energy evaluation has been developed. Fast operation is its unique feature that allows for pulse-to-pulse analysis of an accelerator beam at a typical repetition rate of few hundred Hz. Recorded data can be used for total dose measurement and analysis of all measured parameters in time.

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