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Electron Accelerators for Novel Cargo Inspection Methods

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Abstract

One of the main factors limiting the performance of conventional x-ray cargo inspection with material discrimination (MD) is the interlaced mode of system operation. Such systems use pulsed linac or betatron x-ray generators and produce alternate bremsstrahlung pulses with lower- and higher- end-point energies. Consequently, these systems provide about 50 mm lower penetration than a system operated in a non-interlaced mode, have a limited range of cargo areal densities with valid MD, and cannot perform MD of objects smaller than the pulse separation. Also, the limited pulse repetition rate of x-ray generators in interlaced mode limits the radiographic image quality at nominal commercial speeds of vehicles or trains.

Several new methods of cargo inspection with MD were recently introduced to address the above-mentioned limitations: dual-energy methods based on Scintillation-Cherenkov detectors [1]; multi-energy method based on intrapulse time-varying of spectral content of x-ray [1, 2]; multi-energy method utilized ramping-up energy packet of short x-ray pulses [3, 4]; and methods based on multi-energy betatron [5, 6]. All of these methods have electron accelerators as a core element. However, the accelerator requirements and, thus, their designs, are different for each system. In this paper, we will discuss the requirements for the accelerators, provide some details about their designs, and present several novel solutions for current and future projects.

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Keywords: Cargo inspection, radiography, material discrimination, electron accelerator, linac, betatron, ramping energy, homeland security.

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Introduction

Modern cargo inspection systems can be divided into three types according to their applications: railroad, stationary portal and mobile systems. The security market requirements for x-ray imaging performance of these systems include contrast sensitivity better than 4%, penetration greater than 400 mm of steel equivalent, line pair resolution better than 3.5 mm, 3 Z-groups of MD (organic, inorganic, high Z) over a range of thicknesses up to 200 mm, low dose and small radiation exclusion zone.

Conventional dual-energy interlaced cargo inspection systems are lacking the ability to scan cargo at high speeds, precluding efficient x-ray scanning of, for example, railroad cargo for illicit materials such as explosives, drugs and special nuclear materials with minimal interference with the stream of commerce. They demonstrate lower penetration than single energy systems, provide MD only at low speed, and inefficiently utilize x-ray power. They cannot perform Z-discrimination for objects smaller than pulse separation. The maximum penetration is only achieved with the high energy pulse. Finally, these systems have a limited range of areal densities with valid MD due to fixed values of lower and higher interlaced pulse energies.

To relieve the aforesaid limitations, RadiaBeam Technologies, LLC is developing several pilot systems that implement the novel inspection methods:

- Adaptive Railroad Cargo Inspection System (ARCIS) [4]. This system is based on a multi-energy method utilized a ramping-up energy packet of short x-ray pulses [3], and utilizes a ramped energy source of packets of short (~400 ns) x-ray pulses, a new type of fast X-ray detectors, and rapid processing of detector signals for intelligent control of the linac. The system will allow scanning with MD for speeds up to 45 km/h.
- Mobile Intelligent X-ray Inspection System (MIXI) [7]. MIXI relies on a similar concept as ARCIS, but utilizes a compact linac-based X-Ray source, which allows MIXI to be placed on a lightweight truck chassis.
- Inspection system with Miniaturized High Energy X-ray Source (MXS). MXS is a compact, high repetition rate linac-based X-ray source that can generate short (~100 ns) pulses with energies up to 9 MeV. The MD algorithm is based on temporal separation of the Scintillation and Cherenkov signals [1].
- Multi-Energy Betatron-based Cargo Inspection System (MEBCIS) [5, 6] relies on an innovative technique of extracting two X-ray pulses with lower and higher energies within a single betatron acceleration cycle. The multi-energy betatron in conjunction with fast X-ray Scintillation-Cherenkov detector will allow a very compact inspection system with intelligent MD.

All of the above-mentioned systems have electron accelerators as a core element. However, the accelerator requirements and, thus, their designs are different for each system. The particular requirements for each system type are summarized in Table 1.

Table 1. Core parameters of accelerators for novel inspection systems under development at RadiaBeam Technologies (prospective parameters are specified in brackets).

System Name	System Type	Beam energy range, MeV	Power source	Pulse repetition rate, pps	Pulse/packet duration, µs	Anticipated average dose per raster line, cGy
ARCIS	Railroad	Ramping 2 - 9	Klystron	1,000	16	0.125
MIXI	Portal, mobile	Ramping 4 - 6 (2 - 6)	Magnetron (Amplitron)	400	4 (8)	0.055
MXS	Mobile	4/6 (6/9)	Magnetron	500 (2,000)	0.5 (0.1)	0.028
Bx-CIS	Backscatter; mobile, portal	Ramping 0.5 - 1.5	Magnetron (Amplitron)	400 (4,000)	4 (8)	-
MEBCIS	Mobile	Multi-energy 2 - 7.5	Betatron	500	4	0.018