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TITLE PORTABLE RADIOGRAPHY USING LINEAR ACCELERATORS

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PORTABLE RADIOGRAPHY USING LINEAR ACCELERATORS

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There are numerous instances where the availability of a portable high-energy radiography machine that could be transported to the inspection site with relative ease would save time, money, and make radiography of permanent installations, such as bridges, possible. One such machine, the Minac built by Schoenberg Radiation Inc., is commercially available. It operates at 0.3 GHz, has an electron energy on target of 3.5 MeV, and an output dose rate of 100 R/min. A second portable accelerator, recently completed at the Los Alamos National Laboratory, operates at 2.602 GHz, has electron energies on target of 6, 8, and 10 MeV, and an output dose rate of 800 R/min at 8 MeV. This paper discusses the need for and applications of portable accelerators for radiography. Physical characteristics and beam parameters of both machines are examined in detail. Problems of operating at higher frequencies to further minimize size and weight are discussed.

1. Introduction

X-ray radiography has been used in industry as a nondestructive testing tool for many years. It first began with the use of standard

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x-ray machines operating at 10's of kilovolts and progressed to the use of cobalt as a source of high-energy x rays. Development of betatrons and linear accelerators made high energy, greater dose rate, and smaller spot size available to the radiographer. These parameters translate to better detail in larger objects.

In the past, it has been necessary to transport an object requiring inspection to a radiographic machine. Only recently have linear accelerators been built small enough and/or packaged in such a way that the machine could be transported to the object.

2. Portable Accelerators

The first truly portable linear accelerator for radiography was developed by Schoenberg Radiation, Inc. under a contract with EPRI (1,2). The modulator power supply, the acceleration head, and the control console are the three modules that comprise the machine. The intended use was for nondestructive testing of various components of a nuclear reactor. The machine had a 100-R/min output at 3.5 MeV.

The machine operates at 0.3 GHz with a magnetron rf source. The accelerator guide is a traveling-wave structure. The accelerator beam produces a 1.7-mm spot size. The machine requires 15 kVA of primary ac power at 200 V, three phase. The prime power requirement does not include a portable water-cooling system, which is optional.

Following the initial development contract, two additional machines have been developed. One machine operates at 2-MeV, the other operates at 6 MeV. The 6-MeV machine has a standing-wave accelerator guide.

Group A1-5 at the Los Alamos National Laboratory recently completed the fabrication and testing of a high-energy, high-output, portable

radiographic accelerator for use within the Laboratory. Machine specifications are given in Table I.

The interconnected system is shown in Fig. 1. Seven separate boxes are interconnected as shown in Fig. 2. The system requires 115-V service and can run from either a 4 kVA motor generator or two separate 20-A wall circuits. All units are portable except the dc power-supply main modulator (Fig. 3), which is intended to be left in a transporting vehicle.

The accelerator enclosure is shown in Fig. 1. The accelerator guide is a standard Linatron 2000* side-coupled cavity standing-wave guide built by Varian Associates. It operates at 2.998 GHz and, with an input power of 2 MW, produces a nominal 8-MeV electron energy on target. In the Linatron 2000* configuration, the accelerator guide is enclosed in a solenoid and has a primary collimator. In the new configuration, the solenoid and collimator are eliminated. As a result, the spot size increased to ~3 mm. The accelerator cannot be used unless the area is cleared of personnel and shielded by obstacles already in the vicinity.

Figure 4 is the rf Power Enclosure 1, which contains the magnetron that supplies 2 MW of rf power to the accelerator guide. Note in Fig. 1 that the accelerator enclosure rests on top of rf Power Enclosure 1 to provide a compact x-ray head.

The magnetron is driven from a standard pulse forming network (Fig. 5) through a pulse transformer contained in the enclosure shown in Fig. 6. The high-voltage connections are made with standard RG-8 coaxial cable and commercially available high-voltage connectors.

Figure 7 shows the control console, which may be located up to 300 ft from the accelerator enclosure. In addition to standard safety

features, the control console contains thumbwheel switches for total dose, dose rate, and time. It also contains an interlock display and read-outs for dose rate, total dose delivered, and time.

Some of the electronics and console switches that are seen in the figures provide energy switching between 6, 8, and 10 MeV. The machine also has the capability to vary the dose rate per pulse from 0.2 to 0.002 R/pulse.

3. Future Developments

In the last 30 years, development of accelerator technology has brought accelerators from the physics laboratory to practical devices for portable radiography. One can logically ask the question what does the next 10 to 15 years hold for developments that will improve the prospects of smaller, lighter accelerators.

To answer this question let us start with a paper design using the following parameters.

- Standing-wave accelerator guide
- Frequency = 30 GHz
- Electron energy on target = 9 MeV
- Electron current = 40 mA peak (approximately 1000 R/min at 1 m at 200 pps)
- Beam pulse length = 5 μ s

If the paper design is simplified by selecting a standard pillbox cavity with on-axis coupling, SUPERFISH gives a Q of 5100 for a cavity that is 5 mm long and 7.7 mm in diameter with a 1-mm-diam beam aperture.

Assuming that a 3-MW source of rf power is available, the structure length will be 16.9 cm to accelerate electrons to 9 MeV. If the

structure is copper, cooled to liquid nitrogen temperatures, the length to produce the same electron beam energy would be 5.6 cm.

If one keeps the same beam parameters but reduces the frequency to 10 GHz, the cavity diameter increases to 2.3 cm, the length to 1.5 cm, and the Q to 8900. Assuming a 2-MW source at this frequency, the structure length would be 47 cm to produce a 9-MeV beam of electrons. The structure length to produce the same electron beam energy would be 1.3 cm for a copper structure cooled to liquid nitrogen temperatures.

Although these two crude paper designs appear attractive from an accelerator point of view, one must also examine the problems associated with the generation of the rf power. At 30 GHz, the only potential megawatt source that is available is the gyrotron. With its superconducting magnet and large dc power supply, the gyrotron is hardly an attractive candidate for a portable linear accelerator.

The situation is somewhat better at 10 GHz. Although the accelerator is larger, megawatt-level rf sources are available in small size and weight. In both the 30- and 10-GHz cases, there is a problem with the power supply. It takes the same magnetics and capacitance to produce a 5- μ s rf pulse regardless of the frequency of operation.

4. Conclusions

Portable linear accelerators for radiography have been built. One series of accelerators, which operates at 9.3 GHz, is commercially available at 2, 3.5, or 6 MeV. A larger portable accelerator has been built at the laboratory at 3 GHz with an output energy of 6, 8, and 10 MeV from the same system.

Preliminary design calculations indicate that an accelerator guide of attractive dimensions for use in a portable accelerator could be built at 30 GHz. However, currently available or projected rf power sources make a portable accelerator at this frequency unattractive. A more attractive frequency would be 10 GHz, where rf power in compact packages is available. In both cases, it appears that cooling the accelerator guide to liquid nitrogen temperatures is an attractive way to substantially decrease the length of the accelerator for the same input power. One must weigh this decrease against the added complications associated with liquid-nitrogen cooling. In all cases, the power supply is a major contributor to size and weight.

Acknowledgment

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TABLE I

LOS ALAMOS PORTABLE ACCELERATOR SPECIFICATIONS

<u>Parameter</u>	<u>Specification</u>
Electron beam energy	6, 8, and 10 MeV
Beam intensity (unflattened)	
At 8 MeV	800 R/min @ 1 m
At 10 MeV	400 R/min @ 1 m
Dose per pulse at 8 MeV	0.2 to 0.002 R/pulse
petition rate	10 to 100 pps
Multiple pulse operation	1 to 999 pulses
Radiographic quality	2-2 T in steel
Utilities	115 V, 60 Hz, single phase 30 A including water cooling system
Weight per module	Capable of being carried by 2 men

Fig. 1 Los Alamos portable accelerator.

Fig. 2. Los Alamos portable accelerator interconnection diagram.

Fig. 3. Power-supply enclosure.

Fig. 4. The rf power enclosure, Number 1.

Fig. 5. The rf power enclosure, Number 2.

Fig. 6. Pulse transfer enclosure.

Fig. 7. Console.

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Fig 2

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