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PORTABLE, X-BAND, LINEAR ACCELERATOR SYSTEMS

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SUMMARY

Three light-weight, x-band, electron accelerators have been developed to provide a series of highly portable sources of x-rays and neutrons for non-destructive testing. The 1.5 MeV x-ray unit has a 200 kW magnetron for an RF source and an air-cooled, traveling wave accelerating structure to minimize its weight. The 4 and 6 MeV units share the same drive system which contains a 1.2 MW magnetron. The 4 MeV unit uses a traveling-wave guide to produce x-rays and the 6MeV unit uses a standing-wave guide to produce x-rays or neutrons. The choice of 9.3 GHz was dictated by the availability of a high power coaxial magnetron and by the obvious dimensional and weight advantages of a higher frequency over the more common S-band frequencies around 3 GHz.

INTRODUCTION

Over the years, various attempts have been made to make linear accelerators at C-band[1] and X-band[2,3] frequencies. Advanced accelerator design discussions usually re-open the issue based upon the advantage that, the higher the RF frequency, the higher the accelerated beam energy will be for a fixed RF input power[4]. The catch of course is that high power RF sources or amplifiers are harder to come by at higher frequencies. Therefore, the early X-band units disappeared from the market as the more powerful S-band units were improved. Now S-band units, mostly klystron driven at 2856 MHz or magnetron driven at 2998 MHz, dominate both the therapy and radiographic fields. Interest in bore hole investigation of geological formations has led to the recent development of a telemetry operated compact X-band linac system.[5] Renewed interest in x-ray inspection of nuclear power plant piping welds in situ caused the Electric Power Research Institute (EPRI) to let a developmental contract for a 3 MeV, 9300 MHz, man-portable radiographic linac.[6] In 1981, Rochester Gas and Electric, Rochester, New York, successfully inspected some welds in the field with the first 3 MeV unit. Since then several versions of that system, operating at 1.5, 3 and 6 MeV have been built using travelling-wave and standing wave accelerator sections. This paper describes these systems, and mentions some applications for this budding family of Minacs. A companion paper discusses the use of alternating RF phase focusing in the design of the linac structure.[8]

SYSTEMS DESCRIPTION

Two portable, X-band, radiographic systems have been developed: the MINAC 1.5, a low power, 1.5 MeV, ultra-light weight instrument and the MINAC 4/6, a medium power, light-weight instrument that can be used interchangeably with a 4 MeV or a 6 MeV linac tube or x-ray head, as it is alternately referred to. Both systems are in modular form to minimize the weight of a single component package and keep operating personnel at a safe distance from the radiation source and any device or material that is being examined. Figures 1 and 2 show the two systems as packaged. The modules consist of the following: an x-ray head, an RF head (or source), a modulator/power supply, a cooling water supply, a control console and accessories.

The x-ray head contains the accelerator guide and its demountable electron gun, tungsten target, waveguide vacuum window, and 1/2 ℓ/s appendage vacuum ion pump. The gun is an 18kV, gridded, dispenser type that typically delivers several tens of mA on the target. The x-ray head is surrounded by a magnetic shielding, strong back on which an x-ray or neutron (6 MeV unit only) collimator is mounted. Steering coils and internal water cooling passages (4 and 6 MeV only) are part of the package. The 1.5 MeV system is completely air cooled. The 1.5 MeV head uses a 46 cm long, disk loaded, traveling-wave guide operating in the $2\pi/3$ mode. The 4 MeV head uses a 36 cm long similar guide, except the bunching/capture section at the front of the guide has a different taper. The 6 MeV head uses a 52 cm long, side-coupled, standing-wave guide, for which the RF fields see a $\pi/2$ mode and the beam sees a π mode. Figure 3 shows a brazed standing wave guide. Precision machining and tuning before and after brazing is required on all cavities. The travelling-wave guides have a 6.4 mm diameter beam hole and the standing-wave guide a 4.8 mm hole.

Three different bolt-on collimators offer a straight-ahead, a 90 degree or a 360 degree panoramic radiation pattern. If the straight-ahead collimator is used in conjunction with a beryllium radiator, a modest number of neutrons can be obtained from the 6 MeV head. Table 1 lists the performance specifications for the two systems set up for the three straight-ahead x-ray modes.

The RF head contains a coaxial magneton (200 kW peak for 1.5 MeV and 1.2 MW peak for 4 and 6 MeV), high power waveguide circulator, RF power monitoring and AFC (6 MeV only) circuitry, pulse transformer with windings for both the magnetron and accelerator cathodes and filaments, and a waveguide sulfur hexafluoride pressurization subsystem. The magnetron pulse width is 4 us and the repetition rate is variable from 50 pps to 250 pps to allow control of the dose rates.

The modulator/power supply consists of a conventional dc, resonant-charging, line modulator. Included in it are the steering coil and ion pump power supplies. The self-contained cooling water supply provides temperature controlled water for the accelerator section in the x-ray head and the magnetron, the RF circulator and the high power RF load in the RF head.

The control console allows convenient control and monitoring of the critical system parameters, including the dosimeter (a remotely place ion chamber), the personnel and machine protection interlocks, the AFC circuit and the x-ray head PRF. The x-ray head can be placed 7 m away from the RF head and connected by water lines, high voltage cables and a flexible H-band, rectangular waveguide. The modulator/power supply can be another 60 m away as can the water supply. Finally, the control console can be another 30 m away, for a total of almost 100 m from the source of x-rays to the control console.

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SYSTEM APPLICATIONS

The MINAC was designed for nuclear power plant inspection, where conventional, low-level, x-ray or gamma ray sources are not useful since typical background levels at weld joints vary from 0.5 R/hr to 2 R/Hr during shutdown. Film such as Kodak A or Dupont 75 requires from 1.5 to 2.5 R to the film from suitable exposure densities. Objectionable fogging of the film occurs for 0.25 to .5 R of background radiation. Thus, a weld putting out 2 R/hr will fog the film in 6 to 10 minutes. Slower film gets around this and also has higher resolution. Dupont 45 requires 15 R for an exposure, so it is a preferred film for nuclear in service inspection.

The 4 MeV MINAC produces x-rays with a half value layer (HVL) of 2.4 cm in steel and 20 cm in water. Typical exposures have been made through a water-filled, 30.5 cm diameter by 1.9 cm wall stainless steel pipe. The net equivalent attenuation is 7, so that with a 4 MeV source of 100 R/min at 1 m, the dose rate at the film on the far side of the pipe is 14 RMM. Since the actual distance is usually only about 0.5 m, the rate at that distance is 56 RMM. For NDT 45 film a 16 s exposure would be required, but in practice the dose rate would be decreased so the time could be more easily controlled.

Often a straight-ahead x-ray inspection is not possible because of geometric interferences. With the removal of three bolts, a 90 degree or a panoramic collimator may be substituted. The dose rate drops to 15 RMM and the effective energy is 2.9 MeV for a 90 degree collimator. In addition the HVL for steel drops to 2.1 cm and for water to 17.8 cm. The dose rate at the film then becomes 6.5 RMM, which means a 140 s exposure.

Radiographs of water filled stainless steel pipes of up to 71 cm in diameter and thicknesses of steel of up to 29 cm have been made with exposures times of up to an hour. Reinspection of reactor pump body welds is through 18 to 28 cm of steel. A common flaw in 30 cm pipe in BWR plants is Intergrandlar Stress Corrosion Cracking (IGSCC). It is characterized by small Christmas tree-like crack growth, and thus requires exceptionally high resolution to detect. Crack widths of 13 to 130 um are typical and depths to 30% of the pipe wall thickness are possible. The focal spot size of the MINAC's electron beam is small enough (1.7 mm) for the necessary resolution. Vacuum cassettes are typically used to ensure intimate enough contact between the film and the lead intensifier screens. With the MINAC system, 2% contrast sensitivity on a single pipe wall can be consistently maintained. This requires that the total integral path of the first wall plus the water have a contrast sensitivity approaching 0.3 to 0.4% overall.

Other uses of the MINAC have been for inspection of missile motors of up to 76 cm in diameter in the field and of rocket motor nozzles during static firing tests. The system works well with real time x-ray imaging set ups, such as tangent viewing of pipe walls to assess corrosion or erosion without removal of thermal insulation. Computerized tomographic images of missile motors are possible, as well as strobe imaging of rotating aircraft engine turbines or electrical motors and generators.

The Capitol building in Washington, D.C., had its foundation explored with a MINAC prior to starting work on shoring up that sagging edifice. The position of some steamline valves in another nuclear power plant was determined while the plant was kept on-line. Thus, shut down expenses were saved and the plant's efficiency was increased. In short, the light-weight, portable MINAC system increasingly is being used for more and more hitherto unimagined in situ inspections.

ACKNOWLEDGMENTS

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NOMINAL PERFORMANCE	1.5 MEV	4 MEV	6 MEV
Electron Energy, MeV	1.5	3.9	6.0
Output Radiation, R/min @ 1m	2.0	120	300
Radiation Cone, degrees	30	30	30
Target Spot Size, mm dia.	1.7	1.7	2.0
Half Value Layer, Steel, mm	16.5	24.4	30
X-ray head weight, kg	16	25	41
System weight,kg	114	311	334
Service Rating	continuous duty		

Table 1 - System specifications

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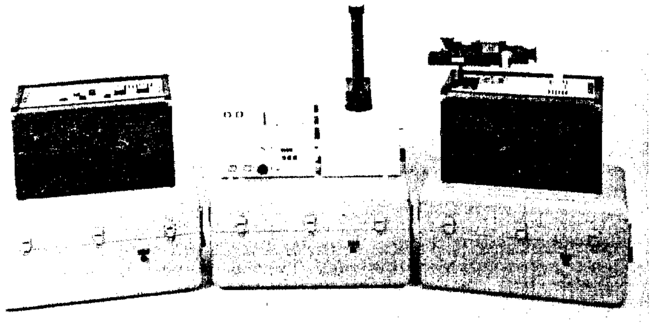

Figure 1 — 1.5 MeV MINAC SYSTEM

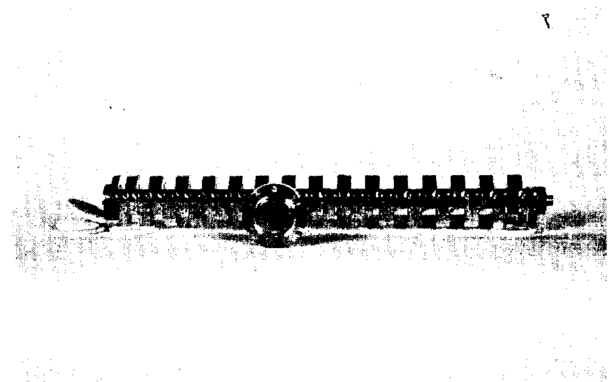

Figure 3 — 6 MeV standing-wave guide

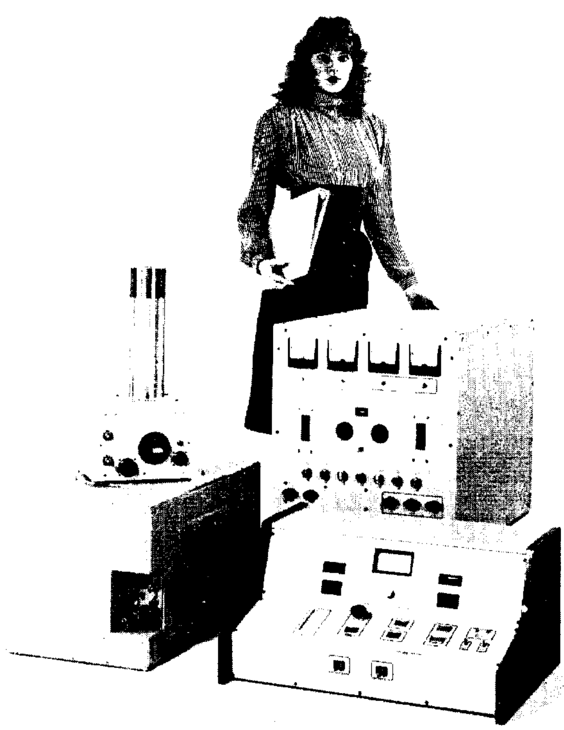

Figure 2 — 4/6 MeV MINAC SYSTEM

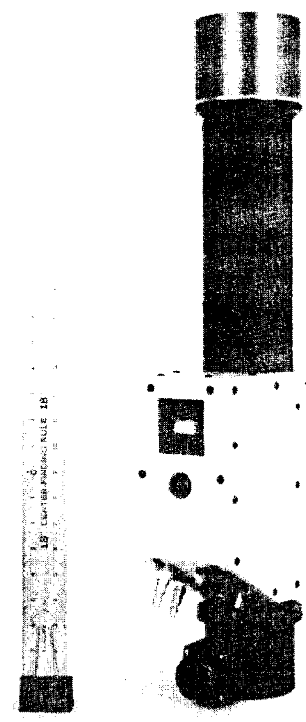

Figure 4 — 6 MeV x-ray head

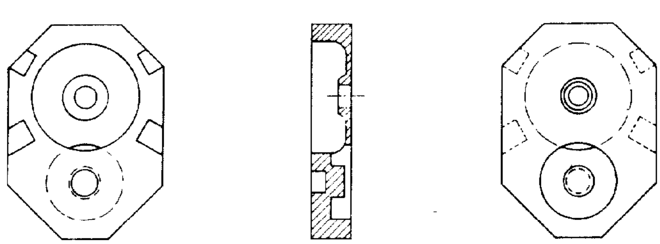

Figure 5 — 6 MeV standing-wave half cells