PORTABLE X-BAND LINEAR ELECTRON ACCELERATORS FOR RADIOGRAPHIC APPLICATIONS

Aleksandr Saverskiy*, Hank Deruyter#, Michael Hernandez#, Andrey Mishin*, David Skowbo#,
AS&E, Mountain View , CA 94043, U.S.A.

Abstract

The MINAC series portable linear electron accelerator systems designed and manufactured at American Science and Engineering, Inc. High Energy Systems Division (AS&E HESD) are discussed in this paper. Each system can be configured as either an X-ray or electron beam source. The 4 MeV and 6 MeV linacs powered by a 1,5 MW magnetron permit operation in a dose rate range from 100 R/min to 600 R/min at 1 meter from X-ray target. Each MINAC is a self-contained source with standard radiation leakage less than 0,1% of the maximum dose. Along with these systems, an ultra-compact 1 MeV MINAC has been successfully tested. The unit is tested to generate up to 100 R/min @ 1 m in energy range from 1 to 3 MeV with radiation leakage less then 0.01%. The results of low and high power test are presented.

INTRODUCTION.

The X-band MINAC systems were originally built for radiographic applications by AS&E HESD. Each system can be configured as either an X-ray or an electron beam source. There are many successful applications where the MINAC systems have been utilized [1]. One of them is the AS&E Shaped Energy™ System which incorporates the MINAC-4 accelerator. It can be utilized to screen dense cargo and to identify dangerous loads or illegal traffic. The combination of Shaped Energy™ and radiation threat detection technology provides high penetration and precise material discrimination required to detect weapons of mass destruction and heavily shielded radioactive material including the components of dirty bombs and nuclear weapons.

The results of design and test of the MINAC-1 accelerator as well as an update on the existing MINAC-4 and MINAC-6 accelerating systems are presented in this paper.

MINAC-6 STATUS AND DEVELOPMENT

Typical requirements for 6 MeV accelerator systems and linac parameters

- The X-ray energy of the 6 MeV accelerator systems has been traditionally determined by measuring X-ray beam penetration in a water phantom. The value at 100 mm characterizes the energy and it has been specified for the 6 MeV accelerator system as D_{100} = [58…62] %.
- For the MINAC-6 the minimum dose rate has been specified as 300 cGy/min at 80cm at the nominal parameters of the magnetron: the peak power of P_0=1.4±0.1 MW, the RF pulse duration of t_p=4 µs, and the repetition frequency of f_r=166 Hz.
- Maximum radiation leakage for regions outside the central beam must be less than 0.1% compared to the dose

Since 2002, the accelerator design and production technology have been improved. Table 1 contains typical output parameters of the accelerator systems at 166 pps that have been put in service before 2002 and in the years 2002-2004.

Table 1. Parameters of 6 MeV accelerator.

Parameter	2002 Av./[Min-Max]	2004 Av./[Min-Max]
Dose Rate, cGy/min at 80cm	415 [300–550]	550 [430–680]
Energy (D_{100}), %	58.8 [58.2–59.5]	59.3 [58.6–60.0]
Radiation Leakage, % DR	0.08 [0.05–0.10]	0.05 [0.04–0.07]

The average dose rate for systems summarized in 2004 column has been increased by 30%. The minimum level of X-ray energy has been increased above 58.5%, and the output dose rate to 430 cGy/min at 80 cm at the nominal magnetron operating specification. The value for the dark current has also been reduced.

MINAC-6 Accelerator System Design and Low Power Characteristics.

The 6-MeV accelerating system has been designed and built based on the side-coupled standing wave structure. Table 2 contains experimental low-power parameters.

Figure 1 presents a typical “Stop band” graph, or reflection coefficient (dB) versus frequency (MHz), for the 6 MeV accelerator system. The ”Pass band” of this structure (complex reflection coefficient vs. frequency) is shown in Figure 2.

Table 2. 6 MeV accelerating structure specification.

Parameter	**Specification**
Mode	SW, off-axis $\pi/2$
Frequency, MHz	9290±10
Section length, cm	52
Accelerating cavities No.	34
Unloaded Q-factor	7600±200
Input coupling coefficient β	1.5±0.2

The acceleration and coupling cavities have been tuned with accuracy f_0±0.25 MHz and the field distribution has been maintained to better than 5% with respect to the design value. The conventional 6 MeV waveguide is not

*Currently with AS&E, Billerica, MA 01821, USA www.as-e.com
#Currently with Accuray, Sunnyvale, CA 94089 USA www.accuray.com

 0-7803-8859-3/05/$20.00

symmetrical with respect to the coupler location. A typical separation of main π/2 mode from the closest modes is more then 8.0 MHz. The "Stop band" asymmetry is less than 1.0 MHz after the complete manufacturing cycle that includes brazing, evacuation, bake-out and sealing.

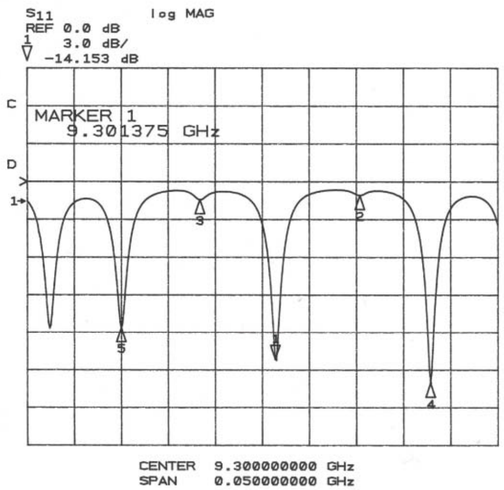

Figure 1: MINAC-6 Linac Stop Band.

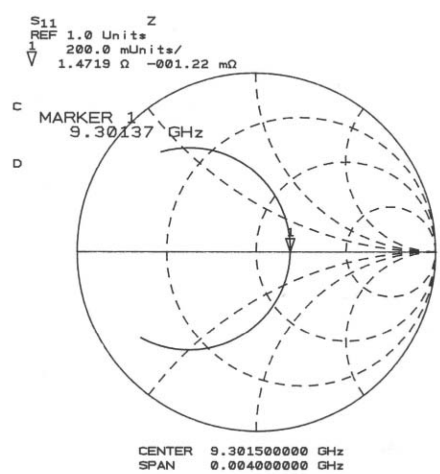

Figure 2: MINAC-6 Pass Band.

Extended Accelerator Design and Cold Test.

In order to further improve the output dose rate and beam energy of the accelerator systems, a new 6 MeV accelerator section has been developed.

The length of the new designed accelerator has been increased to 58 cm. The coupler in this design has been placed in the center of the accelerator section. Figure 3 represents the Stop-Band after the complete manufacturing cycle. The closest modes are completely suppressed. The separation of the main π/2 mode from closest π/2 ±2 modes is more then 15.0 MHz. The main RF characteristics for this accelerator are very close to its predecessor The coupling coefficient of the section is k_c=3.7%, input coupling is β=1.5 and Q_0=7700.

Extended 6 MeV Guide High Power Test

The extended accelerator has been tested with the standard 1.5 MW magnetron and the standard accelerator system. The results of high power testing are shown in Figure 4.

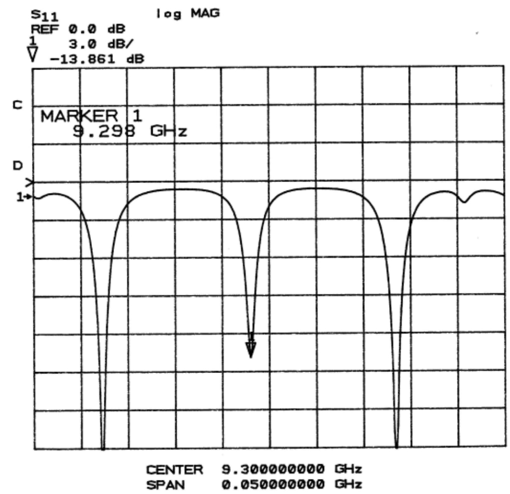

Figure 3: Extended 6-MeV Linac Stop Band.

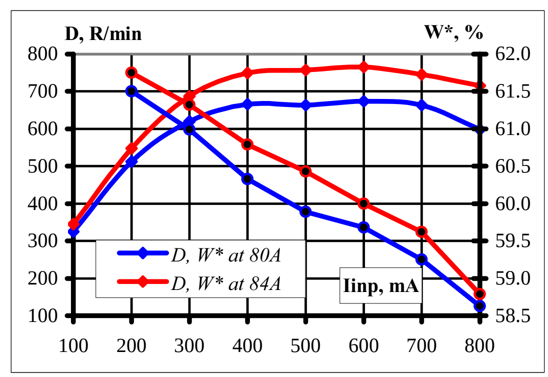

Figure 4: Extended 6-MeV accelerating system prototype output characteristics.

The output dose D (R/min) measured at 80 cm from the target at repetition frequency 166 pps and the X-ray energy W*(%) versus input pulse current is plotted for two values of magnetron current: 80A and 84A. At this power level and input current [400…600] mA the Extended 6-MeV accelerating system deliveries D = (710±40) R/min with energy W* = [59.7…60.8] %. At the upper level of magnetron specification (88 A, 4 µs, 200 pps) the system has produced D = 1050 R/min at 80 cm.

MINAC-1 DEVELOPMENT

Many different applications including radiography may require an X-ray source based on an accelerator system with high radiation dose output in energy range of 1 MeV to 3 MeV. This system has to be nearly "hand-held" or extremely portable.

MINAC-1 Design and Low Power Test.

The RF characteristics of the MINAC-1 accelerator are shown in Table 4.

Table 4. MINAC-1 accelerating structure microwave characteristics.

Parameter	**Specification**
Mode	SW, off-axis
Frequency, MHz	9290
Section length, cm	8.5
Accelerating cavities No.	7
Unloaded Q-factor	7000
Input coupling coefficient β	2.5
Section coupling coefficient k_1,%	3.9

Figure 5 presents the Stop – Band of this waveguide after the brazing and tuning have been completed. The main mode separation from neighbouring modes is more than 40 MHz. The latter has been achieved with dispersion curve symmetry better then 1.0 MHz.

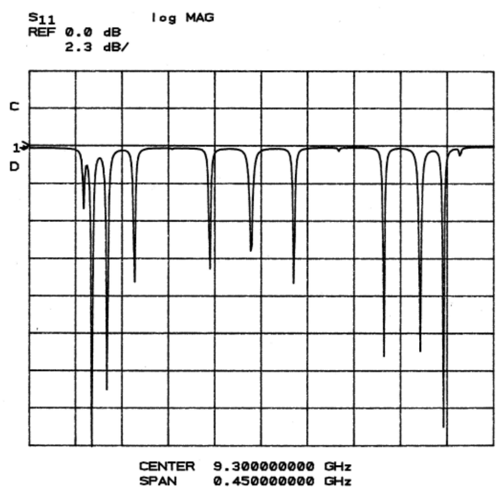

Figure 5: MINAC-1 Stop-band.

MINAC-1 High Power Test.

MINAC-1 accelerating system has been tested with the standard MINAC-6 power supply system. In Figure 6 the output dose rate D, R/min at the distance of 1 m at repetition frequency 100 pps (duty cycle of 0.0004 is 50% of nominal) is shown versus the injection current Iinj, A. The accelerating system has been tested at different values of magnetron current in the region Im= [60-80] A. The adjustment of the injection voltage for maximum dose rate has been performed for each value of the input current. The region of injection voltage Uinj = [7.5 – 10.0] kV for the Iinj = [0.4-1.4] A. The maximum dose rates have been achieved at Iinj=1 A.

The penetration of X-Rays in the steel has been measured for Iinj=1.0 A and Iinj=1.4 A at different values of the magnetron current Im = [60 - 80] A. The lowest magnitude of half value level HVL=0.6 inches (corresponds to 1 MeV X-rays) was achieved at Im=60 A and Iinj = 1.4 A. The highest value HVL = 0.87 inches has been reached at Im=80 A and Iinj = 1.0 A (corresponds to 3 MeV X-rays)

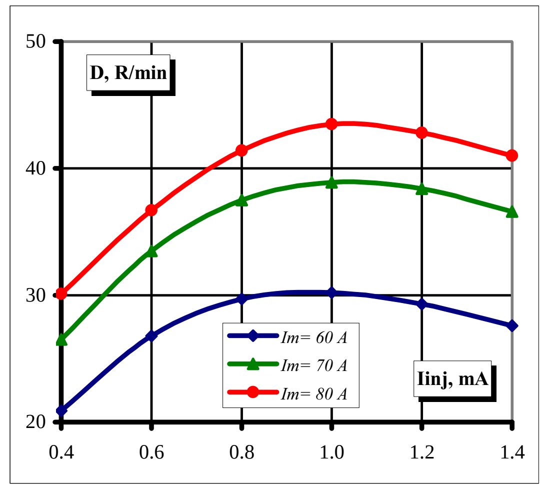

Figure 6: Dose at 1 m and 100 pps (50% of nominal RF power) versus input current for MINAC-1.

CONCLUSION

The MINAC-6 accelerator performance has been substantially improved

- The minimum radiation output level has been specified as 400 cGy/min at 80cm with energy not less than 58.5 % for the standard accelerator section.
- We created a new 6 MeV accelerator design, that produces up to 1050 cGy/min at 80cm.

The portable X-band linacs produced by AS&E in MINAC series generate X-ray beams in typical energy range 1 MeV to 6 MeV with Output Dose Rates from 50 R/min at 1 m at 1 MeV to a maximum 750 R/min at 1 m at 6 MeV. The typical value for the radiation leakage for X-ray machines is less then 0.1% of main Output Dose Rate. The new ultra-portable 1 MeV linac can be used for a variety of applications and can be performed with radiation leakage less then 0.01%.

REFERENCES

[1] A.V. Mishin, Advances in X-Band and S-Band Linear Accelerators for Security, NDT and Other Applications. PAC05, May 2005.