ROBUST LINAC PLATFORM FOR WIDE REPLACEMENT OF RADIOACTIVE SOURCES*

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Abstract

To improve public security and prevent the diversion of radioactive material for Radiation Dispersion Devices, development of an inexpensive, portable, easy-to-manufacture linac system is very important. Tubular structure with parallel pairs of rods crossed at 90 degrees suggests as high as 36% inter-cell coupling due to inherent compensation along with still substantial shunt impedance. Simultaneously it offers simplified brazing process and may dramatically simplify tuning of the entire structure. A novel design of a multi-cell, single-section, X-band structure for replacement of Ir192 source is presented.

INTRODUCTION

Industrial linac systems are employed in a wide variety of applications, from radiography to sterilization. In general, such a conventional system consists of a low-gradient, usually S-band, linac with beam energy from a few to about ten MeVs, and average beam power in the range of few watts to 100 kW. As a rule these systems are rather expensive, bulky, heavy, and not portable. The MicroLinac technology originally developed at SLAC [1] employs a compact X-band linear accelerator powered by an inexpensive, low power, pulsed magnetron [2,3].

A considerable step forward has been made in the development of compact X-band MicroLinacs utilizing high-impedance, all-copper, multi-cell structures [2,4]. The biperiodic part of such a MicroLinac structure employs side [4] or on-axis [2] coupling cells enabling substantial number of cells sufficient to achieve beam energies exceeding 1 MeV within a single section at limited power supply (sub-MW in X-band). However, fabrication of a multi-cell, tapered MicroLinac structure remains a rather expensive and time consuming process not suitable for scaled-up production.

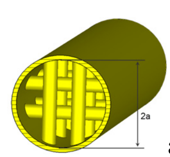
An attractive opportunity for eased fabrication of MicroLinacs is using of a tubular cross-bar or cross-rod type of linac structure. Early studies on the structure were carried out at the Hansen laboratories at Stanford. Such "jungle-gym" and "easitron" structures were mentioned as a candidate for accelerator applications among the backward-wave variants of the Stanford two-mile accelerator project [5]. A four-period, cross-rod, UHF-band structure was used for a long period in the Cornell electron synchrotron [6]. More detailed study of the cross-rod type periodic structure was performed in Los Alamos National Laboratory (LANL, [7]). Next interesting implication of this structure is related to its anomalous dispersion enabling so-called "inversed wakefields" forerunning the charge when group velocity exceeds charge velocity [8].

Attractive advantages of this structure are its relatively simple, mechanically rigid construction, large-error tolerances, ease of cooling and pumping, compactness and reasonable shunt impedance.

We have revisited fundamental properties of cross-rod structures to design a novel, ~1 MeV, multi-cell, single-section, X-band structure.

RF DESIGN OF A 37-CELL SECTION

This development is a continuation of the earlier single-section MicroLinac based on the so-called disk-and-ring (DaR), hybrid metal-dielectric, compensated structure [9]. Our preliminary performance study of a compensated cross-rod cell (see Fig. 1a) compared to a DaR cell with Sapphire rings at the same aperture and frequency indicates the following benefits of the cross-rod structure: a) more than twice higher group velocity (0.24c vs. 0.1c); b) lower overvoltage; c) much higher vacuum conductivity; d) five-fold lower frequency sensitivity to the temperature; e) eliminated charging and triple-point multipactor effects; and d) eased assembling. Simultaneously the cross-rod structure offers about the same shunt impedance (see Fig. 2) and very compact transverse dimensions (~λ/2). The cross-rod structure operates as a metamaterial-filled pipe having substantial effective dielectric constant at the same small diameter. Additional benefits gained over dielectric structures such as DaR are full command over the equivalent "permittivity" at eased cooling because most of the currents are concentrated close the structure periphery (see Fig. 1b).



a)

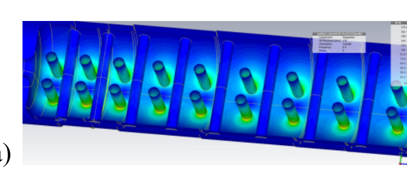

b)

Figure 1: Cross-rod structure (a) with surface currents (b).

The CST RF model for a ~1 MeV cross-rod MicroLinac section is shown in Fig. 3. The design employs elliptical shape of the RF coupler allowing wider range of coupling

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coefficients. S11 curve and the operating mode Ez profile along the section of Fig. 3 are shown in Fig. 4 and Fig. 5 respectively.

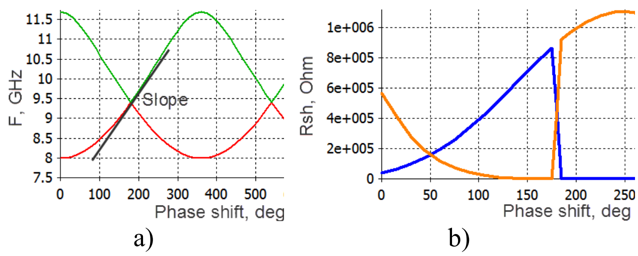


Figure 2: Brillouin diagram (a) and shunt impedance (b) vs. phase advance for a compensated cross-rod cell at 0.9c phase velocity, 3 mm aperture, and ∅1.75mm rods.

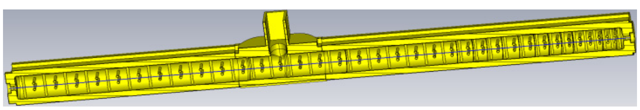


Figure 3: Cut-view for RF model of a ~1 MeV X-band MicroLinac with elliptical RF coupler.

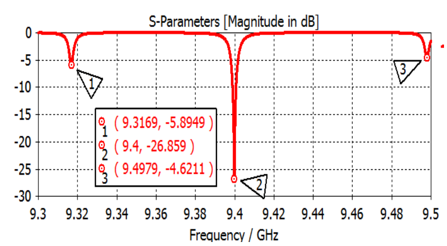


Figure 4: S11 curve simulated for the RF model Fig. 1.

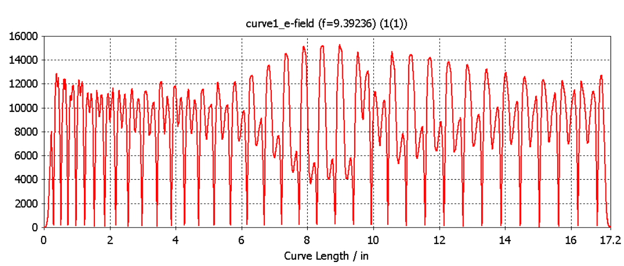


Figure 5: Absolute value of the longitudinal electric field profile plotted along the RF model of Fig. 1 for operating mode.

BEAM DYNAMICS

Beam dynamics results simulated with ASTRA code [10] for the design of Fig. 3 are shown in Fig. 6 and Fig. 7 using the same solenoidal type focusing implemented with permanent magnet blocks in our prior MicroLinac designs [4] with on-axis magnetic field magnitude 0.15 T.

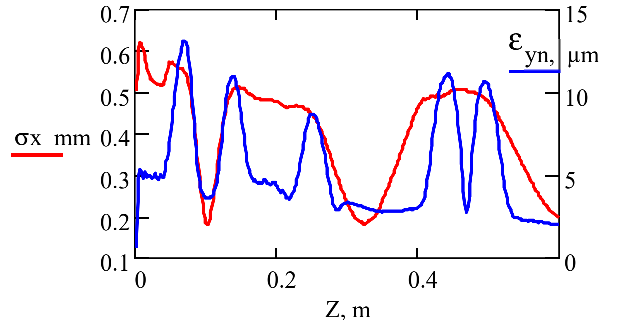


Figure 6: RMS Emittance (blue, right ordinate) and beam rms dimensions (red, left ordinate) simulated with ASTRA code for the field profile of Fig. 5 with ~7 MV/m Ez field magnitude.

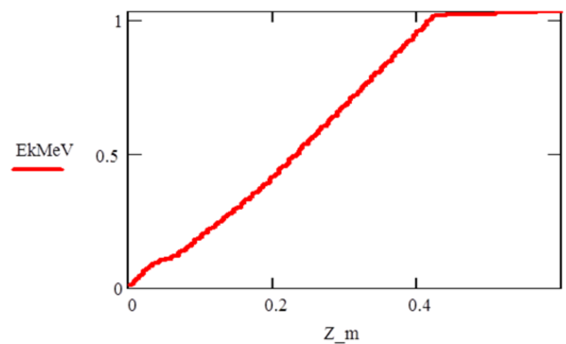


Figure 7: Beam energy gain [MeV] along the structure simulated with ASTRA code for the field profile of Fig. 5. Ez field magnitude is ~4.5 MV/m, RF power ~100 kW, capture ~15%.

Note ASTRA code has been employed in 2D configuration, whereas the RF structure is not axially symmetric. Therefore we have undertaken 3D PIC simulation of the beam dynamics using corresponding CST Suite solver. The ASTRA 2D results above have been confirmed (see Fig. 8).

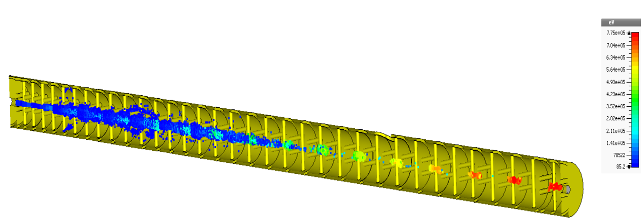


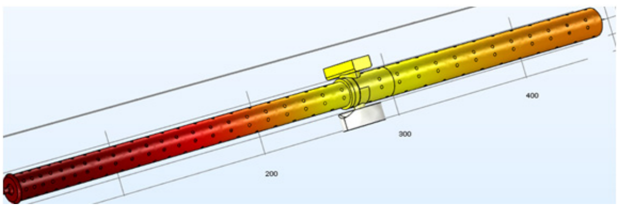
Figure 8: 3D PIC beam dynamics simulated for design of Fig. 1 with Particle Studio solver of CST Suite. Maximum on-axis longitudinal electric field is 5 MV/m, RF power is ~70 kW.

MICROLINAC SECTION ENGINEERING

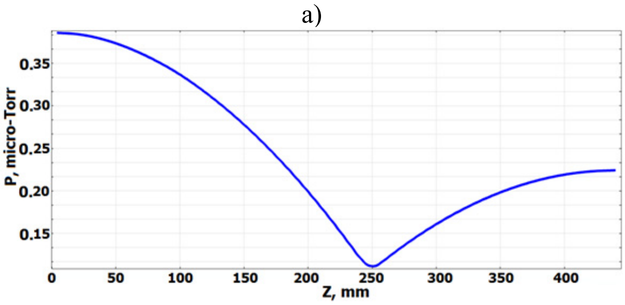
The structure of Fig. 1 suggests significant vacuum conductivity exceeding most of RF structures at comparable shunt impedance. It may use one or more vacuum ports. We have numerically evaluated vacuum performance of the structure with just one vacuum port as shown in Fig. 9. For vacuum simulations we applied thermal model using the same approach applied earlier

[11,12]. The model parameters of temperature, heat, heat conductance, and heat density on the boundaries correspond to pressure, gas flow rate, vacuum conductance, pumping speed, and outgassing rate respectively. Important to note that this approach can be applied only if mean free path for molecules is smaller than the internal diameter of the vacuum tube.

The results for the pressure distribution are presented in Fig. 9. The simulations are performed for 35 l/s pumping speed and $6{\cdot}10^{-8}$ Torr·cm^2·l/s outgassing rate for all surfaces. One can see the maximum pressure simulated is $3.8{\cdot}10^{-7}$ Torr.



a)



b)

Figure 9: "Negative" volume model (a) for vacuum simulations of the cross-rod MicroLinac section of Fig. 3 having just one port for pumping. Pressure distribution simulated along the section (b).

SolidWorks design of the linac cross-bar structure with focusing is shown in Fig. 10.

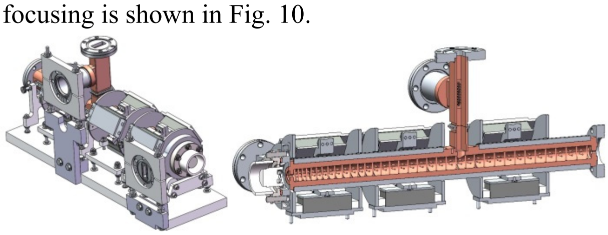


Figure 10: Finalized design of the cross-bar accelerating section.

CONCLUSION

The multi-cell SW cross-rod structures considered here demonstrate a strong potential for beam energies 1 MeV and above at limited power of RF source by simple increasing number of compensated cells due to extraordinary wide bandwidth. A particular feature of the structure is capability of a very high group velocity exceeding well 0.2c. For standing wave (SW) linacs that capability may allow to avoid tuning of structure cells as well simplify design and ruggedize operation the automatic frequency control (AFC) system. The wide bandwidth suggests simplified tuning of the structure and eased tolerances. A high vacuum conductivity of the structure suggests effective usage of non-evaporable getter pumps (NEGs): low pumping speed required can make such a system very compact (from one to three discrete ports can be used).
Thus the cross-bar and cross-rod structures can be considered as candidates for MicroLinacs capable of replacing of a wide spectrum radioactive sources.

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