ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-MOPC22

LATTICE OPTIMIZATION OF RF ELECTRON LINAC DESIGNED FOR VEGA LCS GAMMA-RAY SOURCE

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Abstract

The Variable Energy Gamma (VEGA) System is under implementation in Bucharest-Magurele Romania as one of the major components in the project of Extreme Light Infrastructure Nuclear Physics (ELI-NP). The VEGA System is designed as an advanced Laser Compton Scattering gamma-ray source with unique parameters in terms of high spectral density, monochromaticity, high polarizability, and energy tunability. It brings new opportunities and is dedicated for photonuclear research in both applied and fundamental physics, and will be open for worldwide users. Optimization of spectral density and guaranty of monochromaticity of the gamma-rays impose the necessity to control both, transverse emittance and energy spread, putting strong requirements on electron beam dynamics. The paper presents results from computer simulations carried out for the injector of the LCS gamma-ray source based on a normal-conducting RF LINAC, and investigation of a lattice configuration to optimize the electron beam parameters at the transfer line and storage ring entrance.

INTRODUCTION

The schematic layout of the VEGA System is presented in Fig. 1, and the design specification in Table 1. The e^- beam, initially shaped in the RF electron source, will pass through the LINAC, be injected into the storage ring and delivered to the Compton interaction point.

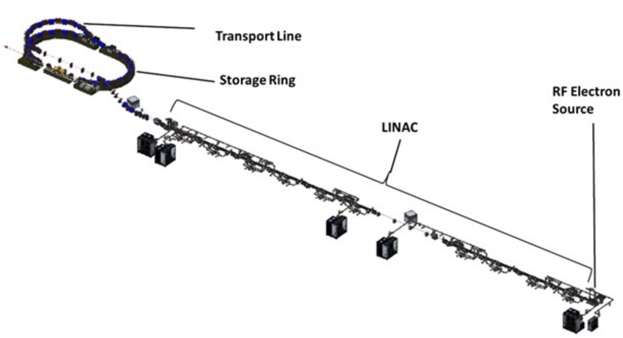

Figure 1: VEGA System layout.

Table 1: VEGA System Design Specification

Photon energy (max) [MeV]	≤ 20
Tunability of photon energy	Yes
Polarization	≥ 95%
Divergence at FWHM of beam spot	$\leq 1.5 \cdot 10^{-4}$
Relative bandwidth avg. (FWHM)	$\leq 5 \cdot 10^{-3}$
Total intensity [γ/s]	$\geq 10^{11}$
Total flux [γ/s]	$\geq 4 \cdot 10^{8}$
Peak spectral density [γ/s/eV]	$\geq 5 \cdot 10^{3}$

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The VEGA LINAC is the S-band (2856 MHz) system. The accelerating cavities will be connected to SLED system to be fed with high power RF pulses.

The analyses of different configurations of the LINAC lattice were carried out to optimize the electron beam before injection to the storage ring. LINAC was modelled with the ASTRA software package designed for modelling, simulating and computing charge particle beams travelling through a particle accelerator system [1]. The analysed model was based on four accelerating modules, each with four travelling-wave cavities. The quadrupole magnets were implemented to compensate radial dispersion of the beam. The schematic layout of the accelerating module is presented in Fig. 2. The electrons are released from a planar cathode, pre-accelerated in the system of the RF electron source [2, 3], and injected into LINAC to gain ultra-relativistic energy. Figure 3 depicts the one accelerating module designed for the VEGA LINAC currently being installed at ELI-NP.

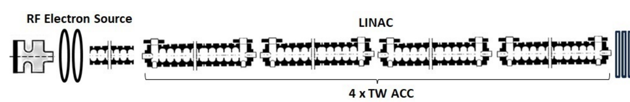

Figure 2: Schematic layout of accelerating module.

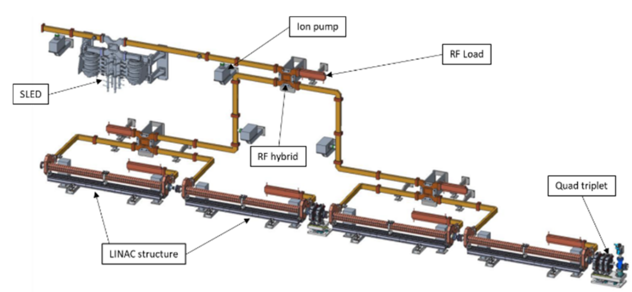

Figure 3: VEGA LINAC, one accelerating module.

Table 2 presents the settings of TW cavities and quadrupole magnets.

Table 2: Components Settings

TW Cavity	
Position [m]	various
Number of cells / lengths [m]	54 / 2.0
Field gradient (max) [MV/m]	28
Input phase [◦]	0.0 and 0.5
Quadrupole	
Configuration (doublet or triplet)	
Field gradient [T/m]	various
Effective length [m]	0.065
Distance between magnets [m]	0.12
Position [m]	various

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The electron beam at the exit of the RF electron source had following characteristics: charge $\mathrm{Q} = 1$ nC, longitudinal rms length $\sigma_z = 0.6$ mm, energy $E_0 \approx 14$ MeV, energy spread $\Delta E/E_0 \approx 0.18\,\%$, and transverse emittance $\varepsilon \approx 3.5$ μm.

The computer simulations have been run with extra attention directed to minimize of the β-function. In systems with predominance of linear focusing forces, the beam phase-space contour has a shape of an ellipse with general equation:

$$\gamma x^2 + 2\alpha x x' + \beta x'^2 = \varepsilon$$

where α, β and γ are Twiss parameters, and ε is the area enclosed by the ellipse contour and states the beam emittance [4] (Fig. 4).

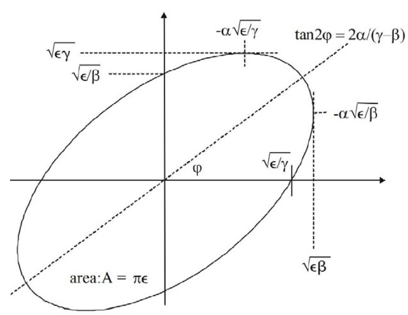

Figure 4: Phase space ellipse.

RESULTS OF COMPUTER SIMULATIONS

The extensive numerical simulations were performed, gradually adding succeeding TW cavities and quadrupole magnets to find the optimal beam parameters at the LINAC end. First, just one accelerating module was simulated and analysed, then two modules, free modules, and lastly, the entire LINAC. Figure 5 presents the β-function ($\beta_x = x^2_{rms}/\varepsilon_{x,rms}$) from the photo-cathode exit down to the transfer line entrance.

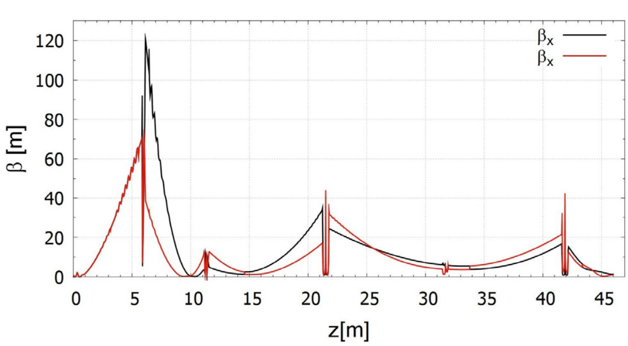

Figure 5: β-function.

Figure 6 presents the LINAC lattice given with indication of the location of TW cavities and quadrupole magnets with field gradients. Figure 7 reports the α-function along the LINAC.

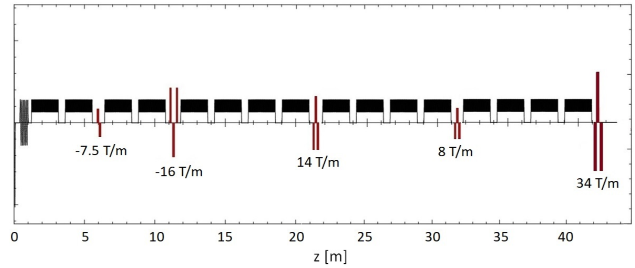

Figure 6: Schematic position of TW cavities and quadrupole magnets.

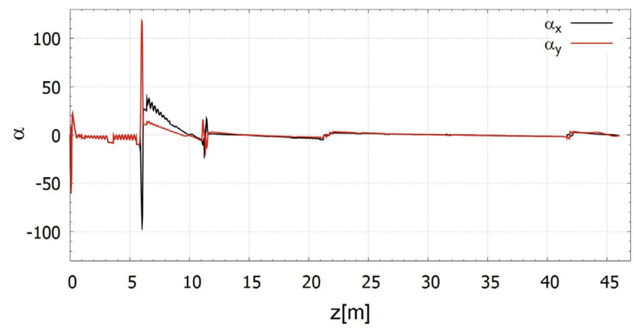

Figure 7: α-function.

The emittance is conserved approximately at 3.5 πmrad mm (90% particles), (Fig. 8). The oscillations in the emittance when the beam traverses the TW cavities arises, in addition to physical originate, by a method of emittance calculation in the program ASTRA. The standard emittance calculation with ASTRA is not local i.e., the code takes a snapshot of the bunch at a certain time. When the bunch enters a structure with transverse forces the head 'sees' the forces before tail, which leads to correlated emittance oscillations [5, 6].

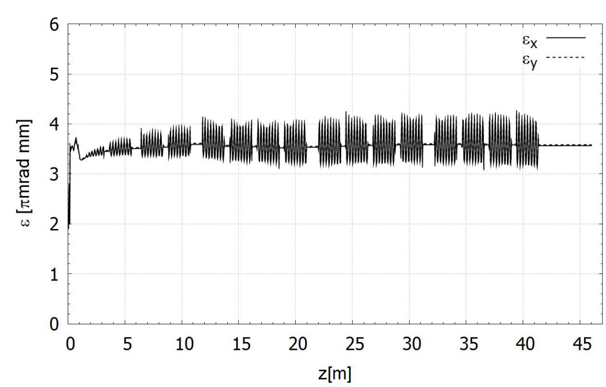

Figure 8: Transverse emittance.

In Fig. 9 the transverse and longitudinal beam distribution are reported at the LINAC exit, while Fig. 10 presents the current distribution along the bunch.

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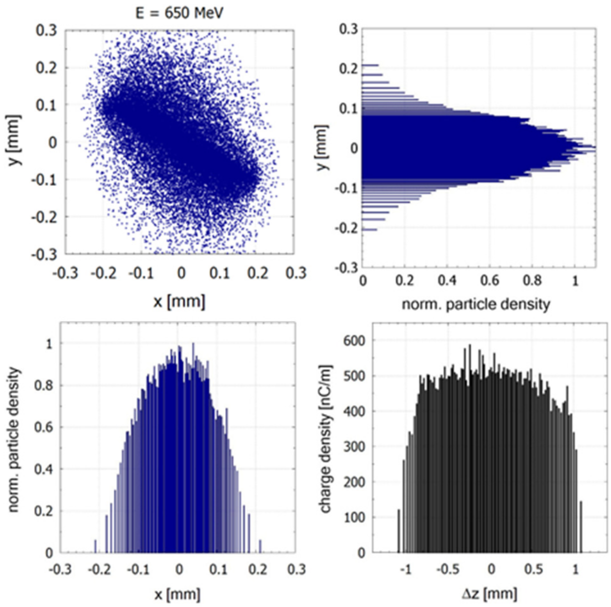

Figure 9: Transverse beam size and particle distribution, plus longitudinal charge density.

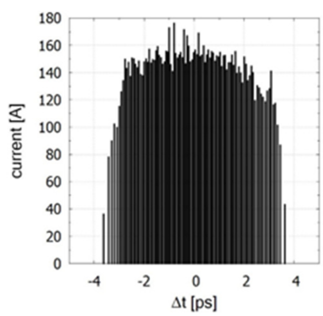

Figure 10: Beam current distribution.

Figures 11 and 12 the average beam energy the rms energy spread.

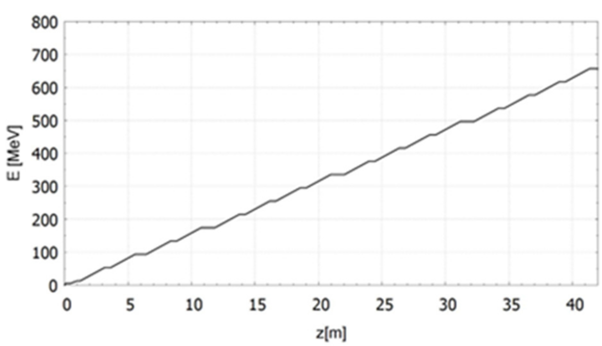

Figure 11: Beam energy.

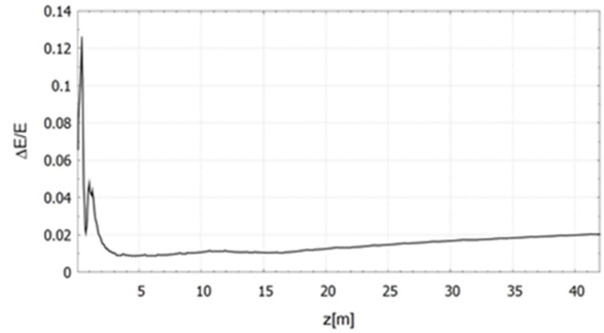

Figure 12: Beam energy spread (rms).

CONCLUSION

The different configurations of the LINAC's components and the settings of parameters were investigated in the numerical simulations. The optimal lattice was determined to optimize the electron beam parameters. Considerable attention was directed to the optical focusing function β, which drives the rms beam size. The achieved results are useful and sufficient for transporting the beam into the storage ring [7] via the transport line [8] as well as it will be used as a guidance during the commissioning of the VEGA Linac and in succeeding research for future developments.

ACKNOWLEDGEMENTS

This work was carried out under the contract PN 23.21.01.06 sponsored by the Romanian Ministry of Research, Innovation and Digitization.

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