ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME018

GLOBAL SEARCH METHODS FOR ELECTROMAGNETIC OPTIMIZATION OF COMPACT LINAC TANKS

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Abstract

A tank of a compact LINAC (Linear Accelerator), operating at 3 GHz, has been designed. It consists of six accelerating cavities, coupled together via a suitable side coupled cavity structure. An accurate model has been implemented in a home-made computer code to take into account the interaction of the proton beam with the resonant structures. Since a number of geometrical parameters needs to be optimized, ~~a~~ Particle Swarm Optimization approach has been employed to search the global solution. The CST PARTICLE STUDIO® (CST PS) tool has been employed to simulate the performance of the tank with the geometrical parameters optimized by the PSO-based code and a beam energy increase from 7 MeV to 8.21 MeV has been calculated.

INTRODUCTION

Several linear accelerators (LINACs) exhibiting different characteristics have been constructed and described in literature [1-2]. Based on the excellent results obtained from the these experiences, the 3GHz LINACs seem particularly promising to accelerate proton beams with the aim of obtaining compact systems for nuclear medicine and proton-therapy. The development of suitable tools giving the guidelines for the design of the above mentioned systems is very important.

In this paper the model of tank of a compact LINAC, operating at 3 GHz, has been implemented in a home-made computer code to obtain a preliminary identification of the main geometrical parameters.

THEORY

A home-made computer code has been developed in order to obtain a tool useful for the design of a Side Coupled LINAC, i.e. the accelerating cavities, are coupled along the beam axis direction; while the coupling cavities are placed off-axis [1-2]. The dispersion relation for 2N coupling cavities which alternate with 2N+1 accelerating cavities is:

$$k_{ac}{}^2\cos^2\varphi = \left(1-\frac{\omega_a^2}{\omega_q^2}+k_a\cos 2\varphi\right)\left(1-\frac{\omega_c^2}{\omega_q^2}+k_{cc}\cos 2\varphi\right) \qquad (1)$$

where:

ω_a is the resonant frequency of the accelerating cavities (ACs);

ω_c is the resonant frequency of the coupling cavities (CCs);

ω_q is the resonant frequency of the of the normal mode q;

k_a is the coupling constant between adjacent ACs;

k_{ac} is the coupling constant between neighbor ACs and CCs;

k_c is the coupling constant between adjacent CCs;

φ is the phase advance per cavity;

The coupling apertures are modeled according to the theory of Bethe and as in [3].

The optimization of each geometrical parameter depends on a large number of other physical and geometrical variables. For this kind of problems a global optimization method, as e.g. the Genetic Algorithm (GA) or the Particle Swarm Optimization (PSO) ones, is needed [4-7]. The PSO is an optimization approach inspired by the behavior of the bees during their search activity for food. Each of the N parameters of the model is optimized iteratively in a range of values (N-dimensional search space); a set of N parameters (bees) is a tentative global solution. The bees of the swarm move with initial random positions and velocities, then their position is up-dated since a suitable objective function is minimized/maximized [4-7].

In this paper, the implemented PSO multi-objective function is minimized when: i) the dispersion relation (1) is minimized; ii) the transit time is maximized; iii) the beam clearance is taken below 80 %; iv) the ratio Z/Q_a is maximized, Z being the shunt impedance per unit length and Q_a the unloaded quality factor of the mode TM_{010}; the ratio between the effective shunt impedance per unit length ZT^2 and Q_a can be optimized, too.

The shunt impedance per unit length is defined as:

$$Z = \frac{\eta^2 L_a}{R_s \pi R_a (R_a + L_a) J_1^2(k_c R_a)}$$

with

$\eta = \sqrt{\mu_0/\epsilon_0}$ intrinsic impedance of free space;

$R_s = 1/\sigma\delta_s$ RF surface resistance of ~~the~~ copper;

$\delta_s = \sqrt{\frac{2}{\omega_0\mu_0\sigma}}$ skin depth of copper;

$\omega_0 = 2\pi f$ resonant frequency;

μ_0 magnetic permeability of vacuum;

σ conductivity of copper;

R_a accelerating cavity radius

L_a accelerating cavity length.

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The unloaded quality factor of the TM_{010} mode being:

$$Q_a = \frac{\eta}{2R_s} \frac{2.405}{\left(1 + \frac{R_a}{L_a}\right)}$$

RESULTS AND DISCUSSION

The PSO is applied for the optimization of the first tank of a compact LINAC, operating at 3 GHz. The tank, made of six accelerating cavities, is designed in order to increase the proton beam energy from 7 MeV to higher values [8-11]. The design goal is the optimization of the following parameters:

- R_a radius of accelerating cavities;
- R_{ab} radius of the slot coupling adjacent ACs;
- L_a length of the ACs;
- h_a thickness of the slot coupling adjacent ACs;
- R_c radius of the CCs;
- R_{ac} radius of the slot coupling the ACs with the CCs;
- L_c length of the CCs;
- h_c thickness of the slot coupling the ACs with the CCs;
- R_{cc} radius of the slot coupling adjacent CCs;
- h_{cc} thickness of the slot coupling adjacent CCs.

In the simulation, the input energy of the proton beam is 7 MeV. For each parameter to be optimized, a range of ± 60% with respect to its nominal value taken from literature has been used as solutions search space in the PSO algorithm. In Tab. I the first column lists the geometrical parameters of the tank to be optimized; the second column reports the range taken from literature or arbitrarily fixed [2][8-9]; the third column reports the PSO-optimized values. The injector 'Accsys - PL7' is considered as beam source [2][8-11]. The PSO settings are the following ones: population dimension N = 80, cognitive parameter c_1 = 1.2, social parameter c_2 = 0.12 [5-7].

Table 1. Values of the Parameters related to the Tank

Parameters	PSO Search range (mm)	PSO optimized value (mm)
R_{ab} (mm)	1.6 - 6.4	3.65
R_a (mm)	12.24 - 48.96	30.600
L_a (mm)	5.04 – 19.44	12.2451
R_{ac} (mm)	1.2 – 4.8	2.746
R_c (mm)	12.892 – 51.568	33.375
R_{cc} (mm)	1.4 – 5.6	3.415
L_c (mm)	4.44 – 17.76	10.689
$h_a(mm)$	0.2 – 0.8	0.456
$h_c(mm)$	0.2 – 0.8	0.445
$h_{cc}(mm)$	0.2 – 0.8	0.462

The CST PARTICLE STUDIO® (CST PS) tool has been employed to simulate the performance of the PSO-optimized tank. The simulated proton beam energy increases from 7 MeV to 8.21 MeV. Therefore, in general, a preliminary geometrical optimization of a LINAC tank can be performed by following the described approach. The simulated proton beam energy increase encourages a further work in order to improve the model. As example, the thermal effects could be taken into account.

CONCLUSION

A model of a LINAC tank has been implemented in a home-made computer code. Since a number of geometrical parameters needs to be optimized, a Particle Swarm Optimization-based approach has been exploited to find the optimized global solution. The CST PARTICLE STUDIO® (CST PS) tool has been employed to simulate the performance of the PSO-optimized tank. The beam energy increase encourages a further work in order to improve the model.

ACNOWLEDGEMENTS

This work has been partially supported within the MIUR plan: PON02_00576 _3329762 DD MIUR n.818/Ric.-26/11/12 "Sistemi avanzati mini-invasivi di diagnosi e radioterapia"_AMIDERHA.

REFERENCES

[1] T. P. Wangler, 2008. RF Linear Accelerators. Canada, WILEY-VCH Verlag GmbH & Co.KGaA, Weinheim.

[2] L Picardi, L.; Ronsivalle, C.; Vignati, A. (ENEA, Centro Ricerche Frascati, Rome (Italy). Dip. Innovazione); ENEA, Centro Ricerche Frascati, Rome (Italy). Dip. Innovazione-http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/29/029/29029212.pdf.

[3] J. Gao. Analytical formulas for the resonant frequency changes due to opening apertures on cavity walls, Nucl. Instrum. Methods Vol. A311, No. 3, pp. 437-443, 1992.

[4] F. Prudenzano, L. Mescia, A. D'Orazio, M. De Sario, V. Petruzzelli, A. Chiasera, M. Ferrari: "Optimization and Characterization of Rare Earth Doped Photonic Crystal Fiber Amplifier Using Genetic Algorithm". Journal of Ligntwave Technology vol. 25, pp. 2135-2142, 2007.

[5] L. Mescia, A. Giaquinto, G. Fornarelli, G. Acciani, M. De Sario, F. Prudenzano, "Particle swarm optimization for the design and characterization of silica-based photonic crystal fiber amplifiers" Journal of Non-Crystalline Solids 357 (2011), pp 1851–1855, ISSN 0022-3093, doi:10.1016/j.jnoncrysol.2010.12.049

[6] G. Palma, P. Bia, L. Mescia, T. Yano, V. Nazabal, J.Taguchi, A. More´ac, and F. Prudenzano, "Design of fiber coupled Er3C: chalcogenide microsphere amplifier via particle swarm optimization algorithm", Opt. Eng. 53, p. 071805, Accepted November 27, 2013.

[7] J. Robinson, Y. Rahmat-Samii, "Particle Swarm Optimization in Electromagnetics," IEEE Transaction

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME018

on Antennas and Propagation, 52 (2), pp. 397-407 (2004).

[8]http://www.frascati.enea.it/accelerators/Repository/TOP-IMPLART/TOP-PDF/

[9] Gregory A. Loew, Richard Talman. Elementary principles of linear accelerators. SLAC-PUB-3221. Sept 1983.www.slac.stanford.edu/cgi.../slac-pub-3221.pdf

[10] U. Amaldi et al "LIBO – a Linac Booster for protontherapy: construction and tests of a prototype", NIM A, 2004 (vol. 512/2-3 pp. 512-529).

[11] V. G. Vaccaro et al., "Some Relevant Aspects in the Design and Construction of a 30-62 MeV Linac Booster for Proton Therapy", LINAC 2004, Lubeck, Germany (August 2004).