OPTIMIZATION OF THE RF CAVITY OF THE MEDICAL PURPOSE ELECTRON LINAC BY USING GENETIC ALGORITHM *

S.W. Shin, Department of Energy Science,
Sungkyunkwan University, Gyeonggi-do, Republic of Korea
J.S. Chai#, College of Information & Communication Engineering,
Sungkyunkwan University, Gyeonggi-do, Republic of Korea

Abstract

A compact electron linear accelerator for the medical application has been developing at Sungkyunkwan University. Due to this electron linac is attached on the robot arm or gantry, it should be compact enough to be held by the structure. An X-band technology has been used to meet the requirements for the compact linac. Because the particle accelerator is complex and sensitive machine to design it takes a lot of time to get a good performance accelerator. In this research, a special technique named single-objective genetic algorithm for the optimization process has been applied to achieve a better RF cavity design by changing various geometric parameters.

INTRODUCTION

Because X-band electron accelerator has a better mobility than the C-band or S-band electron linac, it is mainly used at the medical treatment machine such as Stereotactic Radiosurgery (SRS), Intraoperative radiation therapy (IORT) or cyberknife where mobility and compactness is needed.

To develop a dual-head gantry radiotherapy machine using X-ray, a compact 6 MeV electron linac using X-band technology has been developing at Sungkyunkwan University.

GENETIC ALGORITHM

Due to the particle accelerator is composed of a complex structure where many components are controlled simultaneously, it is not easy to achieve a guaranteed best design. It can be reached by putting a lot of time into an optimization process but it is not a good way. There are lots of optimization techniques to help designers to get a good quality machine. Among them the genetic algorithm (GE) is a good candidate for the accelerator field where the non-linear problem is dominant. The genetic algorithm adapted a nature's biological evolution mechanism such as mating (including selection and competition), mutation and generation. Because each individuals of the each population is generated randomly, diversity of this algorithm is very wide so that it is easy to find a global maximum (minimum) point for the optimization problem. Another advantage of the genetic algorithm is its calculation speed. As a generation goes by, it converges to the local maximum (minimum) point very quickly. That is why genetic algorithm is suitable to the accelerator field where non-linear problem is dominant.

#jschai@skku.edu

OPTIMIZATION PROCESS

We adapted a π/2 - mode nose-cone introduced structure to increase the transit time factor (TTF) for the high beam acceleration efficiency. The Poisson/Superfish [1] has been used to design a single cell of the RF cavity.

General Layout of the RF cavity

Optimization process was done by changing several geometric parameters of the RF cavity: Nose cone angle, Outer corner radius, Inner corner radius, Outer nose cone radius, Inner nose cone radius while a length of the RF cavity (to get the synchronism between RF phase and beam), a gap distance between two nose cones (trade-off between high transit time factor and minimum distance for the electrical breakdown happen), a septum thickness (fabrication issue) are fixed. A Fig. 1 shows a general layout of the RF cavity sing cell.

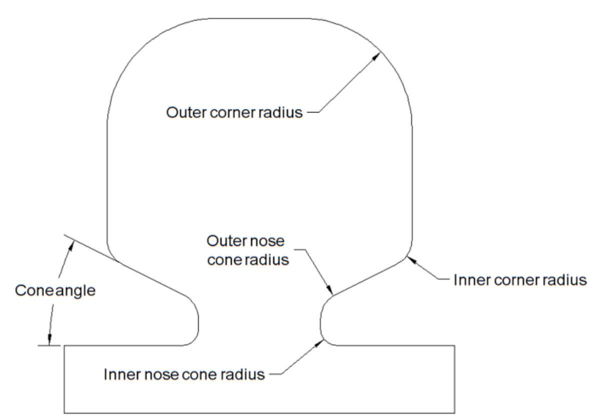

Figure 1: Layout of the RF cavity single cell.

Table 1: Parameters and Constraints for the Optimization Process

Parameters	Constrains
Cone angle	0 ~ 60 °
Outer corner radius	0 cm ~ 5 cm
Inner corner radius	0 cm ~ 1.5 cm
Outer nose cone radius	0.25 cm ~ 1.5 cm
Inner nose cone radius	0.25 cm ~ 1.5 cm

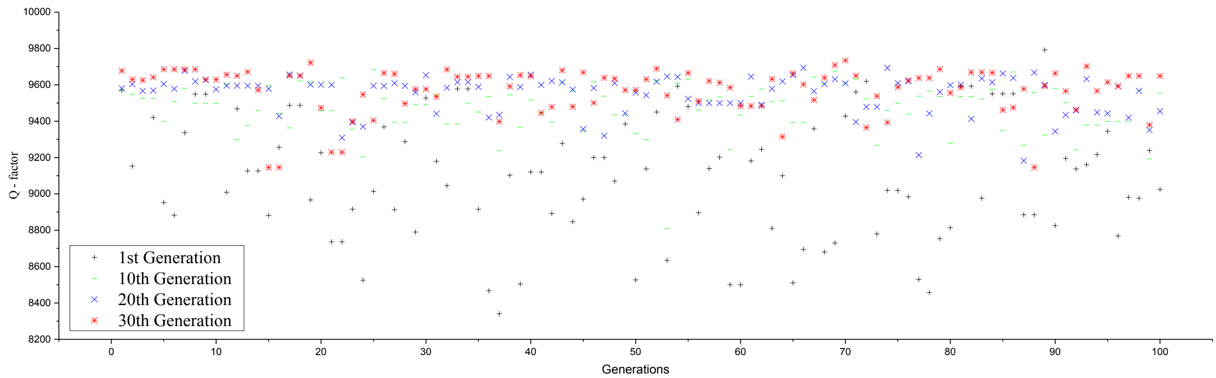

Figure 2: Fitness (Q-factor) Distribution as Evolution Goes by.

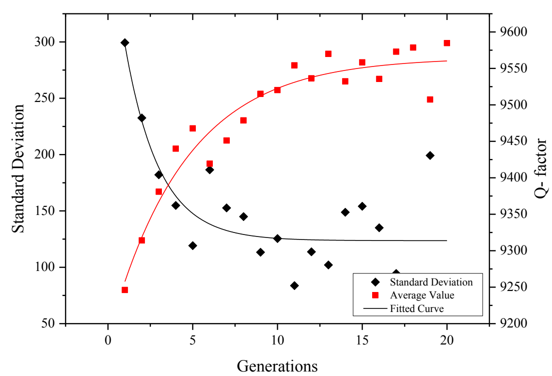

Figure 3: Average Value and Standard Deviation of the Q-factor.

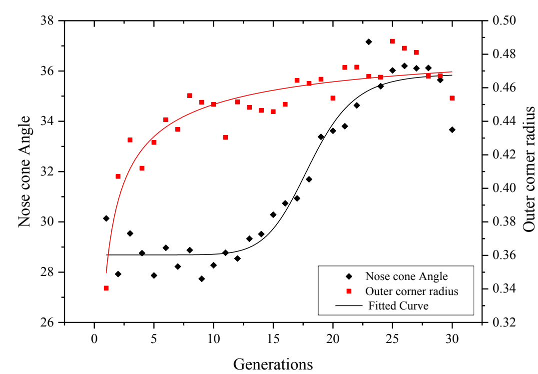

Figure 4: Parameter Values Variation: Nose-cone Angle and Outer Corner Radius.

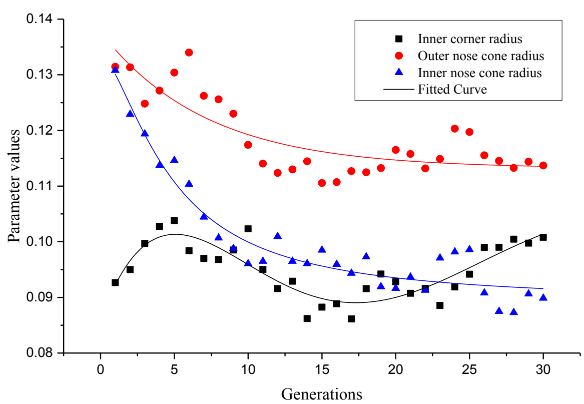

Figure 5: Parameter Values Variation: Inner Corner Radius, Outer Nose-cone Radius and Inner Nose-cone Radius.

Optimization Process by Using Single-objective Genetic Algorithm

For a single-objective problems, genetic algorithm is much faster and precise than a conventional parametric sweeping technique. Q-factor or shunt impedance is considered mainly during the design process which tells figures of merit of the RF cavity. The python 2.7.5 [2] has been used to realize the genetic algorithm at the automatic optimizing program because of its simple programmability.

100 individuals are generated at a single population and total 30 generations are went on during the optimization. Table 1 shows about constraints of each parameters which limits random generator.

Optimization Results

Because genetic algorithm uses stochastic method similar to the Monte Carlo method and each individuals are generated randomly, some of individuals are missing due to its un-physical values especially on the early generations. Their fitness values were treated as 0 value so they could be removed from the generation.

The advantage of the genetic algorithm is a wide diversity. When the optimization algorithm is used, there always exists possibility to be trapped at the local maxima positions. But for the genetic algorithm, there is a possibility to escape from the local maxima during the mutation process.

In the shown in Fig. 2, only 4 representative generation's individuals are plotted as generation goes by. One can find that as generation proceed, the greater part of individuals are inclined to be converged to the maximum value. You may find that some of individuals have higher fitness value even though at the early generation caused by mutation process.

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Table 2: Optimized RF Cavity Parameters

Parameters	Values
Frequency	9.3 GHz
Transit time factor	0.7881841
Q-factor	9792.30
Shunt impedance	241.350 MOhm/m
Effective shunt impedance	149.935 MOhm/m
E_{max} / E_0	2.6807

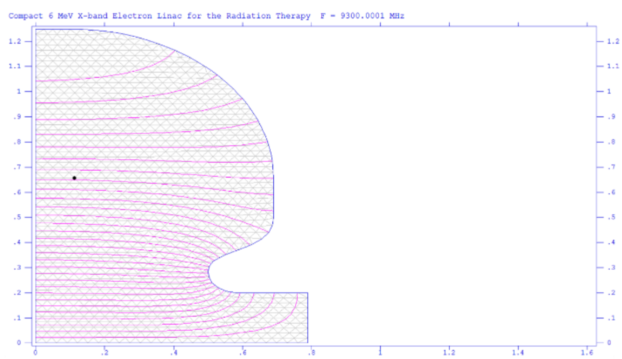

Figure 6: Half-cell of the Optimized RF cavity Single Cell.

A standard deviation of the each generation which shows degree of scattering is calculated by using following formula,

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

where S is a standard deviation of the each generation, N is total number of individuals of each generation, x_i is a value of individuals and $\bar{x}$ is average value. In Fig. 3, standard deviations are getting smaller as generation proceed which means degree of scattered individuals is getting smaller and converged on a single value. In Fig. 3, fitness values (Q-factors) are converged on a maximum value as shown at Fig. 2. From a Fig. 4, one can find that nose-cone angle should be around 36° to get a high Q-factor. To decrease a power dissipation from the RF cavity, an RF cavity designer normally used to round edges of the outer shell where surface magnetic field and current flow is maximum at TM101 operating mode. Rounding edge is of help to decrease power dissipation but it is appeared that the highest rounding edge doesn't mean always the lowest power dissipation from Fig. 4 and 5. From genetic algorithm optimization results, we could find a proper values to decrease power dissipation efficiently at each position.

A Fig. 6 shows an electric field distribution of the optimized RF cavity single cell and Table. 2 shows about the properties of the optimized RF cavity.

FUTURE WORK

To increase an accelerating efficiency of the RF cavity, transit time factor of the RF cavity which is mainly related to the gap distance should be increased. Normally nose-cone is introduced to shorten the gap distance for a high TTF. But this nose-cone causes decrease of shunt impedance and Q-factor which related to the power efficiency of the RF cavity. Due to those good values TTF and shunt impedance are conflicted each other during the optimization process one need another optimization technique.

Multi-objective genetic algorithm such as NSGA-II or SPEA2 can optimize multi object simultaneously even though they conflict each other. Until now most of the applications of the multi-objective genetic algorithm were about the optimization of the beam property by changing the beam line components such as magnets [3-5] or property of the RF photoinjector [6][7]. At the next work, multi object genetic algorithm will be used to find a proper design which satisfy high TTF and high Q-factor.

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