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ALVAREZ DTL CAVITY DESIGN FOR THE UNILAC UPGRADE

X. Du[1], A. Seibel[1,2], S. Mickat[1], L. Groening[1]
[1]GSI, Darmstadt, Germany; [2]Goethe-University, Frankfurt, Germany

Abstract

The 108.4 MHz drift tube linac (DTL) accelerator for GSI's UNLAC upgrade project is in its initial design stage using CST-MWS code. Optimization criteria for cavity design are effective shunt impedance (ZTT), transit-time factor, and electrical breakdown limit. In geometrical optimization we have aimed at increase of the energy gain in each RF gap of the DTL cells by maximizing ZTT per peak surface field with special designed tube profile. Multi-pacting probability is evaluated for one gap of typical single cell. For the beta profile design, a code based on VBA macros of CST is developed to perform cell by cell design with pre-optimized 3D tube structures. With this code several beta profile designs are presented and compared for the balance of power consumption, ZTT, tank length, and breakdown possibility of the complete cavity. The stability of the field has been taken into account and for this the crossed stem arrangement is assessed.

This paper gives a short introduction of the method, presents some important results. Possible countermeasures are discussed.

INTRODUCTION

At the existing DTL of the UNILAC five Alvarez cavities accelerate ions with an A/q of up to 8.5 from 1.4 MeV/u to 11.4 MeV/u over a total cavity length of 60 m [1]. The cavities operate at 108.4 MHz and at an rf-duty cycles of up to 30%[1].

The UNILAC upgrade intends to replace the existing Alvarez DTL with a newly designed DTL with same total length and output energy but with re-optimized shunt impedance and increased field stability. The existing Alvarez cavity tank I consists of 62 cells with tank diameter of 2 m, tube outer diameter of 200 mm, and tank length of 12 m. The designs and optimization of the new Alvarez cavities are based on the general parameters of the existing cavities.

DRIFT TUBE SHAPE DESIGN

The drift tube shape is designed to maximize the effective shunt impedance and to keep the peak electric surface field as low as possible [2]. A simplified single cell model is used for simulations with CST-microwave studio and static EM studio. The tube shape with a constant-radius corner and flat face with an angle is used at the beginning. The auto optimization tool in CST changes all parameters of the tube to obtain the best results. The parameters involved in the optimization are bore radius, drift tube face angle, drift tube corner radius, drift tube inner nose radius, drift tube outer nose radius, and drift tube flat length. But the field distribution on this tube always has a dominant maximum at certain area of the corner.

The new designed drift tube is built by a spline curve with a changing local curvature that is adjusted according to the desired surface field distribution.

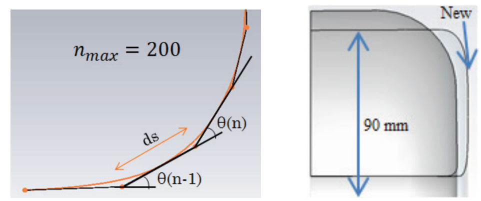

Figure 1: Spline for new tube shape design.

As shown in Fig. 1, the profile of the tube is made from steps of splines. The relationship between field distribution and curve is represented by

$$\theta(n) \xrightarrow{\text{yields}} \left.\frac{\partial^2 E_{surf}}{\partial l^2}\right|_{l=n*ds} \quad (1)$$

After the simulations, the surface field E_{surf} on the tube is evaluated. The angles of θ_n is reduced if the local field distribution is to be raised or θ_n is to be increased if the field is to be lowered. The sum of angles must be 180° such that the curve connects the inner radius to the outer radius.

With this new tube shape the surface field is uniformly distributed on the surface of the drift tube as shown in Fig. 2, keeping the maximum E_{surf} the same, while the ZTT is increased by about 12%. The tube shape is the same for all cells in one cavity for the convenience of fabrication, without discount its advantage on surface field distribution.

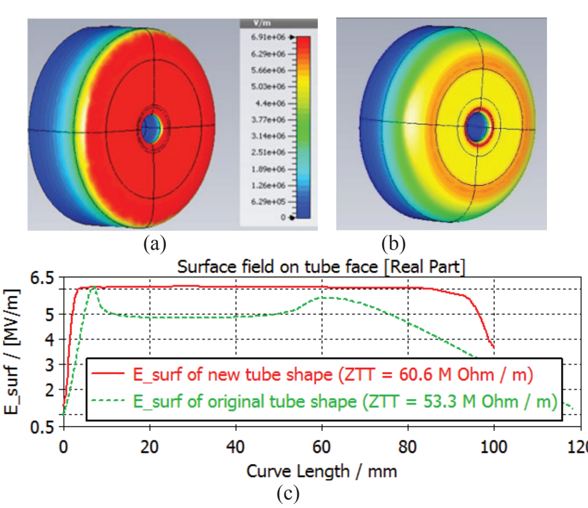

Figure 2: The surface field distribution (c) on the new tube shape (a) and on the original tube shape (b).

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As recently conditioned DTLs have demonstrated excellent voltage holding capability at much higher field levels, with more dissipated surface field, a more aggressive design seems feasible for the new Alvarez design.

The inner tube radius is fixed to 15 mm according to beam size, and the lower limit of the outer tube radius is given by the size of magnet. The tube outer radius is also important for shunt impedance and frequency of the cavity. Larger outer radius will provide more area to contribute more electric field to the gap center, but stored energy and Power loss also increase, and larger surface area is exposed to the highest voltages.

Figure 3 shows ZTT of cells with different cell lengths and outer tube radii and the best radius for the first tank with 200 mm average cell length is about 90 mm. For the other tanks smaller tube radii are indicated instead. Accounting for the size of magnets inside the tube and for easier fabrication, the outer radius is fixed to 90 mm for all cell length.

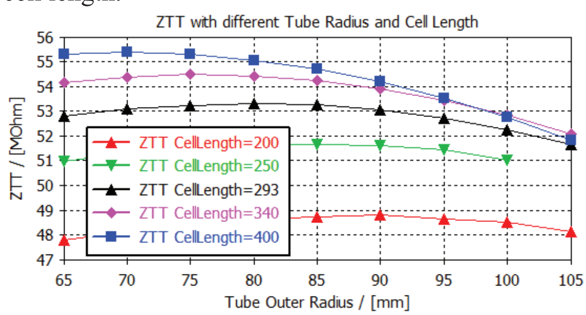

Figure 3: ZTT of cells with different cell lengths and outer tube radii.

BETA PROFILE DESIGN

Some initial parameters need to be defined prior to the beta profile design. The total length for all tanks is limited to 60 m and the DTL final output energy is 11.4 MeV/u as for the existing cavities. Accordingly, the average field should be about 2 MV/m. The tank radius is chosen as constant for simpler fabrication and it is adjusted to get the design frequency of 108.4 MHz.

The new tube shape provides more space for balancing surface field and shunt impedance as shown in Fig. 4. With limited surface field strength the gap could be narrowed to increase ZTT.

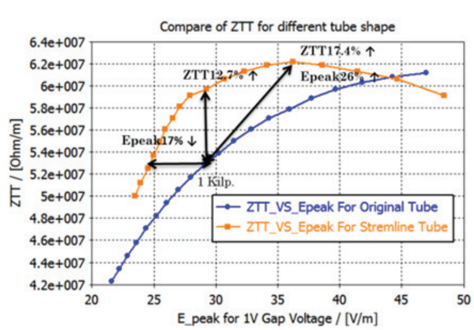

Figure 4: ZTT per maximum surface field for different drift tube shapes and gap lengths.

The tube sequence design is based on the optimized 3D tube model, predefined input energy, and maximum E_{surf}. The effective voltage is calculated from a single cell 3D model simulation, which provides the information of power loss, the transient time factor (TTF), maximum allowed E_{surf}, and the shunt impedance. The cell length is defined by the output energy of the former cell. The gap length is defined by the limit of maximum E_{surf} and the operational local frequency. The Visual Basic code of CST-MWS is used to perform continuous cell by cell design. Several versions for DTL tank1 with different maximum E_{surf} and ZTT are weighted with respect to other considerations such as length of the tunnel and availability of rf power.

Several beta profile designs with different initial parameters are compared to evaluate their feasibility, pros, and cons. We prefer a constant average electric field (E_0) with 1.0 Kilpatrick limit for maximum E_{surf}. The parameters for the recent complete beta profile design for tank1 are listed in Table 1.

Table 1: Parameters for Beta Profile Design of Tank1

Parameter	Value	Parameter	Value
Cell number	61	Average field	2.04 MV/m
Tube outer R	90 mm	S-phase	-30
Tube inner R	15 mm	E surface	.95~1 Kilp.
Cavity Length	12.2 m	ZTT	37~45MOhm/m
Tank R	964 mm	Input Energy	1.39 MeV/u
TTF	0.84~0.88	Output Energy	3.56 MeV/u
Gap voltage	310~496 KV	Total Power	1.5 MW

With the same tank length and output energy as the existing cavity, the ZTT is improved overall as shown in Fig. 5.

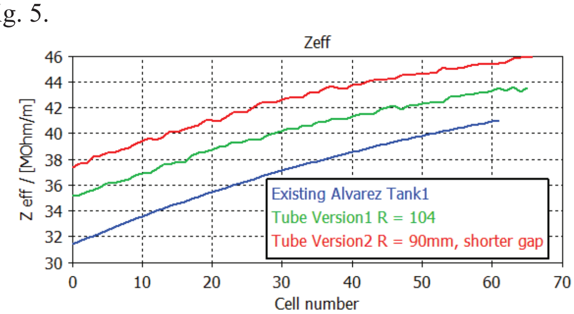

Figure 5: ZTT along the cells for different designs of tank1.

FIELD STABILITY

The designed electric field distribution might be disturbed in the real cavity due to imperfections from mechanical errors and heat distortion. This effect might be decreased by post couplers. The slope of the tilt sensitivity (TS) will be reduced if the post couplers are inserted with their optimum length [3].

Mechanical stability of the 108MHz Alvarez cavity requires 2 stems for every tube. Our simulations show that instead of post couplers, by rotating specific stems in the cavity to different angle as shown in Fig. 6, the TM modes which are close to the operational mode, will be pushed away.

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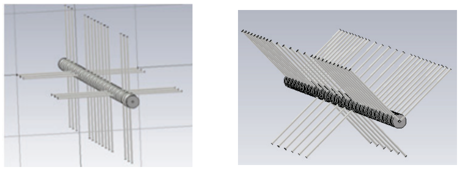

Figure 6: Stem arrangement for improved field stability.

As a consequence the sensitivity of field flatness wrt the local frequency uncertainty is reduced significantly. The improvement is shown in Fig. 7, showing that the field distributions are more resistant to a gap length error of -10 mm in the first cell for instance.

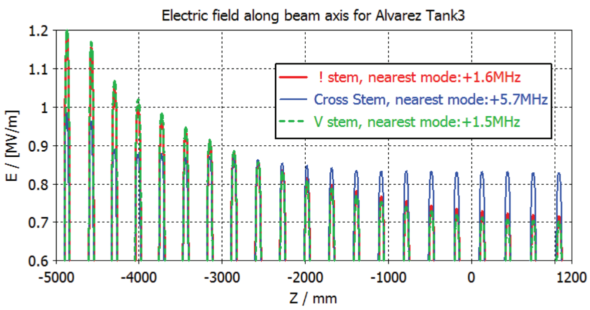

Figure 7: Electric field distribution with a perturbation at the first cell of cavity.

This feature in Alvarez cavity is feasible to apply to any DTL cavity, its theoretical basis is intended to be extended to a more universal law, such that the specific stem arrangement could be fund easily for specific Alvarez cavity.

MULTIPACTING PROBABILITY

Due to the large tube radius and the electric field between gaps it is possible that some electrons might trap in the gaps and cause multipacting (MP) [2]. MP is a resonant rf electron discharge in vacuum with electron multiplication due to secondary electron re-emission process. To rise MP, occurrence of two conditions is required:

1. electron synchronization with the rf fields.
2. electron multiplication via secondary electron re-emission.

MP problems should be studied in the cavity design stage. For a simple way to judge if the electron is synchronized with the rf field, we calculated an example cell with the parameters as 200 mm cell length and 300KV gap voltage, 38-88 mm gap length, all being close to the parameters for the new UNILAC Alvarez cavity.

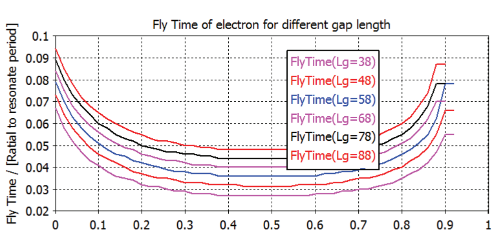

Figure 8: Electron time-of-fly with in different gap length and with different start phase.

We assume that a secondary electron generates from one tube, accelerates or decelerates by alternating electric field, and propagates to the adjacent tube.

Calculation show that the electron time-of-flight is much less than one rf period as shown in Fig. 8, it cannot synchronize with the rf field.

MODEL CAVITY

GSI just ordered a 1/3 scaled aluminium model cavity(Fig. 9) to study the fabrication of the new tube shape, basic rf properties and to estimate frequency shift and field distribution shift from mechanical errors and simulation uncertainties [4]. To this end bead pulling measurement will be performed on this model cavity. Necessary correction of the geometry will be considered according to the measurements. The stems angles of this model are adjustable, thus allowing to measure how the stem angles affect the frequency of modes and the field flatness. This model cavity will provide many measured data to cross-check with simulation.

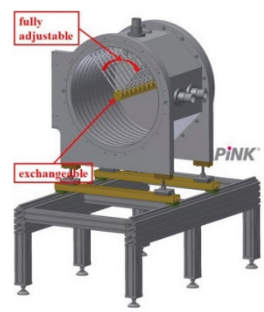

Figure 9: Electric field distribution with a perturbation at the first cell of cavity.

CONCLUSION AND OUTLOOK

The new design of Alvarez cavities will have the same total length and output energy as the existing cavities in UNILAC, but with less power consumption and improved cavity stability. Into the design enters the long term operating experience of the existing Alvarez cavities; age related cavity problems will be fully considered at the cavity design stage. We have elaborated several beta profile designs for tank 1 and tank 2. The magnet design for tank 1 is in progress; the 1/3 model cavity is expected to be delivered from the manufacturer in June 2015 and bead pull measurement and other cold tests will follow.

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