INVESTIGATION ON MODE SEPARATION METHODS AND ACCURACY OF FIELD MEASUREMENT IN RFQ STRUCTURES WITH 3-D ELECTROMAGNETIC SIMULATION*

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Abstract

In radio frequency quadrupole (RFQ) structures, the fundamental quadrupole mode is used for focusing and acceleration of ion particles. The fields are maintained to have negligible interference with other unwanted modes of the structure using mode suppressors especially in vane type RFQs that require dipole mode separation. The field distribution on the beam axis is usually measured and referenced using multiple loop-type magnetic probe antennas on the wall along the structure. Since the structures are equipped with many slug tuners on the outer wall for correction of fields, the tuner-probe interference can be a concern. In order to investigate the mode separation properties of the commonly used mode suppressors and the accuracies in field distribution with respect to localized perturbation due to the tuners, a systematic 3D simulation was carried out using a full-scale model of the SNS RFQ.

INTRODUCTION

The radio frequency quadrupole (RFQ) has been used for acceleration, focusing, and bunching of low-beta heavy ions in many ion accelerator systems [1]. RFQs have been built in 4-vane or 4-rod type [2]. One of the major concerns in 4-vane RFQ design is to separate dipole mode from the fundamental quadrupole mode which is used for particle acceleration and focusing. Two commonly used schemes for the mode separation are pi-mode stabilizer loop (PISL) [3], and end-wall stabilizer (EWS) [4] with coupling plate. The PISL scheme uses straight shorting rods in both horizontal and vertical direction in transversal plane. The EWS scheme uses straight rods mounted on end walls and coupling plates in longitudinal direction if the structure becomes too long.

For testing and tuning of RFQs, multiple loop-type magnetic pickup probes are equipped on the cavity wall of RFQs to measure field profile. The field can be tuned by perturbation method using slug tuners for any mechanical imperfection based on the field probe measurement [5]. This measurement and retuning procedure works fine for small amount of tuner movement. However, if a big movement of tuner is needed on specific location to compensate perturbation, the tuner-induced field perturbation on the wall around the tuner could affect the accuracy of the field probe measurements.

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In this paper, we will discuss comparison of two types of RFQs equipped with PISL and EWS, and tuner perturbation effects on the field measurements. CST Microwave Studio (MWS) model of Spallation Neutron Source (SNS) RFQ which was originally developed by Lawrence Berkeley National Laboratory (LBNL) for a section [6] is extended to a complete four section structure for the analysis of electromagnetic (EM) field characteristics of the full structure.

MODE STABILIZATION

To observe mode separation characteristics with full RFQ length, we extended the LBNL model to full four section structure (3.72m) which is shown in Fig.1.

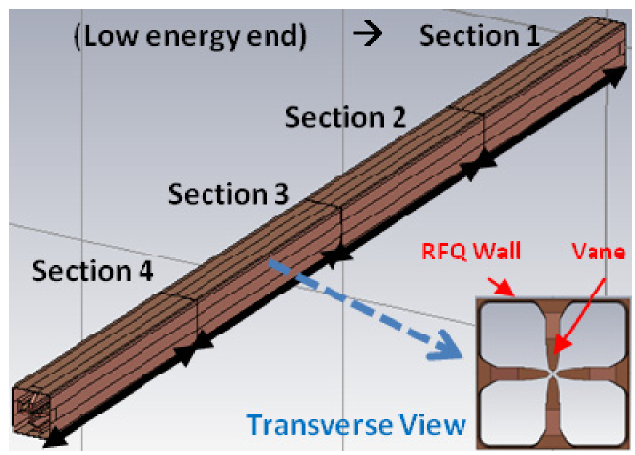


Figure 1: RFQ simulation model with CST MWS.

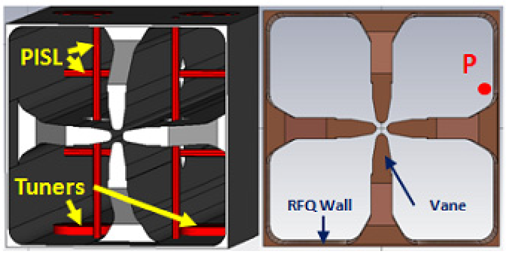
The resonance frequency of the fundamental quadrupole (Q0) mode, which is used for particle acceleration and focusing, is 414.5 MHz before fine tuning for the four section model. The frequencies of the nearest dipole and quadrupole harmonic are not sufficiently separated from the Q0 mode (Table 1).

Table 1: Mode Separation without Stabilizer

Frequency	Mode	Description
413.0	Dipole	
414.5 (Q0)	Quadrupole	Accelerating/focusing Field
416.0	Quadrupole	
422.7	Dipole	

Pi-mode Stabilizing Loop (PISL)

PISL scheme (Figure 2) supports good mode separation of the accelerating field from dipole fields. Robust field stabilization is available with PISL by coupling of each RFQ quadrant. However, manufacturing costs increase with PISL due to structure complexity. The dimensions of the RFQ need to be adjusted to have right operation frequency since PISL moves the Q0 frequency [3].



(a) (b)

Figure 2: Transversal view of an RFQ with PISL : (a) PISL and Tuner location, (b) Field Probe Position.

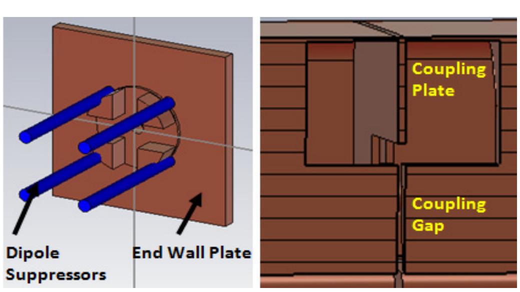
More than 30MHz separation is available between Q0 and dipole modes with PISL scheme designed by LBNL. This mode separation is more than enough to prevent mode mixing by dipole fields. The Q0 frequency is moved to the lowest cut-off mode (Table 2).

Table 2: Mode Separation with PISL

Frequency	Mode	Description
403.9 (Q0)	Quadrupole	Accelerating/focusing Field
405.8	Quadrupole	
437.3	Dipole	

End-Wall Stabilizer with Coupled Structure

For field stabilization of long RFQ's, segmented RFQ [4] design scheme is widely used with coupling plate and end-wall dipole stabilizer rods (Figure 3). The quadrupole harmonic mode can be separated from the Q0 mode by coupling plate if the structure is very long. Dipole mode frequencies can be controlled with stabilizer rods mounted on end-wall plates. Dipole modes separation from the Q0 frequency is smaller than PISL RFQ. This RFQ has advantages of easy manufacturing, and maintaining Q0 frequency.



(a) (b)

Figure 3: End-Wall Stabilizer and Coupling Plate: (a) End-Wall Stabilizer, (b) Coupling Plate.

Modelling with one coupling plate at the middle of longitudinal structure, the Q0 frequency has 6.3MHz separation from adjacent dipoles (Table 3). Another hybrid mode appears by importing coupling plate. The Q0 frequency is not affected much from the designed frequency.

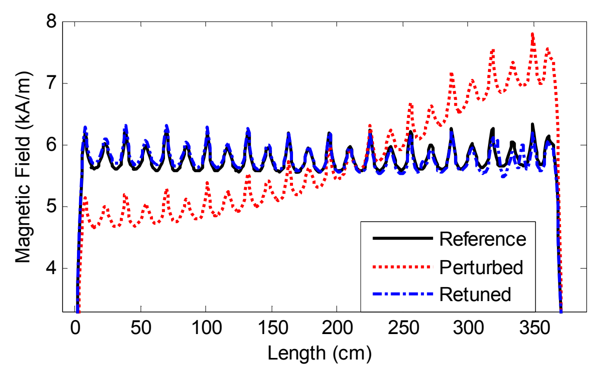
Table 3: Mode Separation with End-Wall Stabilizer

Frequency	Mode	Description
409.5	Dipole	
410.7	Hybrid	Hybrid Mode at Plate
415.8 (Q0)	Quadrupole	Accelerating/focusing Field
419.8	Quadrupole	
422.2	Dipole	

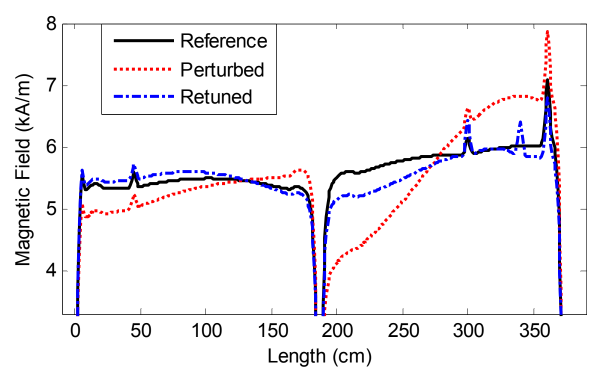
FIELD PERTURBATION BY TUNERS AND MEASUREMENT ACCURACY

Previous LBNL MWS model includes cylindrical slug tuners for tuning purpose which can be seen in Fig. 2 (a). To demonstrate a retuning process, slug tuners are imported into both PISL and EWS RFQs, and added a small vane perturbation on RFQ section 4. This single vane perturbation induces non-uniform field profile and retuning process is carried out to obtain flat field again with the tuners. Field probes located on point P in Fig 2 (b) measure magnetic field to check RFQ field profile.

Tuner-induced Perturbation on Magnetic Field



(a)

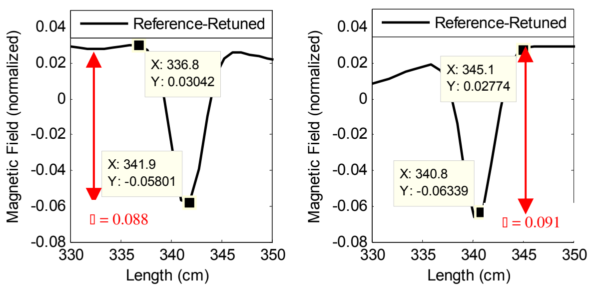


(b)

Figure 4: Magnetic field profile after tuning process (a) PISL RFQ Structure (b) End-Wall RFQ Structure.

Figure 4 shows magnetic field profile with retuning process. The reference field stands for the initial field with no perturbation. These reference fields are scaled by the design peak surface field of 1.37 Kilpatrick. In an RFQ with coupling plate, field variation caused by perturbation occurs mainly on a specific coupling section where perturbation exists. Strong coupling of each quadrant in PISL RFQ contributes fields to be recovered as close as reference profile after retuning process.

Several big bumps on magnetic field are relevant to tuner-induced perturbation. In this example, two bumps on magnetic field which longitudinal location is in 290~350 cm, are generated by tuner perturbation. These bumps could be easily observed in EWS RFQ because of flat magnetic field profile.



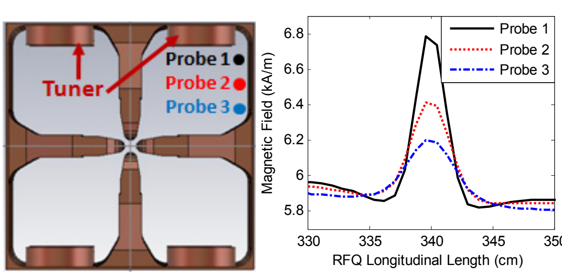
(a) (b)

Figure 5: Relative field differences (normalized) (a) PISL RFQ Structure (b) End-Wall RFQ Structure.

Figure 5 shows relative field differences between reference and retuned field, which are normalized by the reference field. A rough measure of a bump size normalized to reference field is 0.088 for PISL RFQ, and 0.091 for CPEW RFQ with the same tuner movement of 7mm. For a given tuner perturbation, the size of field bumps is almost same in both RFQs.

Optimal Position of Field Probes

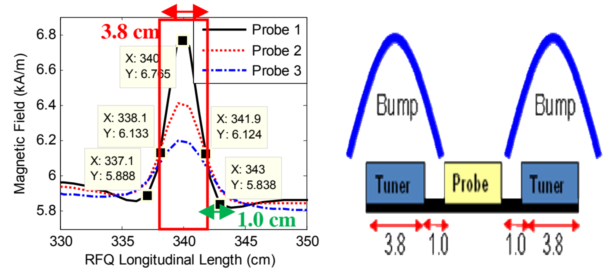
Optimal locations of magnetic field probes need to be determined to minimize possible field perturbations in the retuning process and guarantee accurate measurement of RFQs. This problem is an equivalent to find optimal points on transversal plane, and on longitudinal line of an RFQ.



(a) (b)

Figure 6: Field bumps by transversal probe location (a) Probe Location (b) Field Results.

Figure 6 (b) shows a comparison of a size of field bumps by different probe locations which are depicted in Figure 6 (a). The size of field bumps is strongly dependent of the distance between slug tuner and probe antenna. Therefore, it is recommended to mount probes sufficiently far away from slug tuners to minimize bump amplitude.



(a) (b)

Figure 7: Field bumps by longitudinal probe location (a) Field Results (b) Suggestion for Probe Position.

Width of field bumps is important to determine probe position on longitudinal axis. A fixed diameter of 3.8 cm is used for the design of slug tuners in our simulation model. Fields under slug tuners are the most sensitive to tuner movement. Furthermore, transition regions in which magnetic fields have higher values than average can be considered to find a minimum space requirement between tuners and field probes. In this example, the length of transition region is 1.0 cm (Figure 7 (b)). With the help of 3D RFQ simulation, this parameter can be easily expected before building a cold model of an RFQ.

CONCLUSIONS

RF properties of two common schemes used for RFQ mode stabilization, PISL and EWS are compared with 3D EM simulation. Magnetic Field perturbation which could be caused by tuning process with slug tuner movement is analyzed with these models. The size of field perturbation by tuner is almost same in both RFQ models. The 3D simulation study can contribute to find optimal position of field probes and minimize tuner perturbation effect which could affect measurement accuracy of RFQ field.

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