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A. Castilla
Old Dominion University

Jean R. Delayen
Old Dominion University, jdelayen@odu.edu

Christian Carli (Ed.)

Mick Draper (Ed.)

Yves-Marie Ducimetiere (Ed.)

See next page for additional authors

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Authors

A. Castilla, Jean R. Delayen, Christian Carli (Ed.), Mick Draper (Ed.), Yves-Marie Ducimetiere (Ed.), Amy McCausey (Ed.), Raphael Müller, John Poole (Ed.), John Poole (Ed.), and Volker R.W. Schaa (Ed.)

MULTIPOLE AND FIELD UNIFORMITY TAILORING OF A 750 MHz RF DIPOLE [*]

A. Castilla[1,2,3†], J. R. Delayen[1,2].
[1]Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[3]Universidad de Guanajuato (DCI-UG), Departamento de Fisica, Leon, Gto. 37150, Mexico

Abstract

In recent years great interest has been shown in developing rf structures for beam separation, correction of geometrical degradation on luminosity, and diagnostic applications in both lepton and hadron machines. The rf dipole being a very promising one among all of them. The rf dipole has been tested and proven to have attractive properties that include high shunt impedance, low and balance surface fields, absence of lower order modes and far-spaced higher order modes that simplify their damping scheme. As well as to be a compact and versatile design in a considerable range of frequencies, its fairly simple geometry dependency is suitable both for fabrication and surface treatment. The rf dipole geometry can also be optimized for lowering multipacting risk and multipole tailoring to meet machine specific field uniformity tolerances. In the present work a survey of field uniformities, and multipole contents for a set of 750 MHz rf dipole designs is presented as both a qualitative and quantitative analysis of the inherent flexibility of the structure and its limitations.

INTRODUCTION

Recently, several studies regarding the rf dipole design have been presented, including analysis on the multipole components for some applications [1, 2]. However, the present work is intended to provide a point of comparison on *to what extent* the parameters in the rf dipole geometry can be manipulated to tailor specific multipole components on the electromagnetic field in order to achieve the parameters required in different application. We take as a case of study the 750 MHz rf dipole, originally designed as a crab cavity corrector for the Medium Energy Electron-Ion Collider (MEIC) at Jefferson Lab [3], for which the multipole components and uniformity of the fields are crucial factors in the beam emittance conservation, this being the main motivation for the present analysis. Nevertheless this does not exclude its possible applications to linear accelerators as luminosity corrector, beam separator or assisting in longitudinal diagnostics, among others.

The 750 MHz rf dipole crab cavity design operates in the lowest mode and has been built and tested in the vertical testing area both at Niowave, Inc. and Jefferson Lab [4], a computer render of the geometry is presented in Fig. 1 and its properties are enlisted in Table 1.

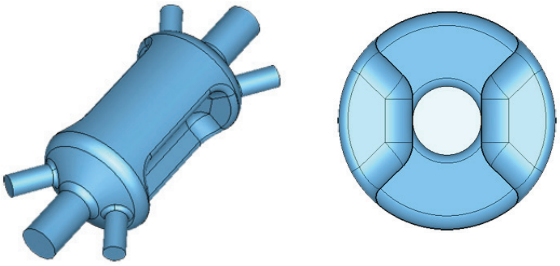

Figure 1: 750 MHz rf dipole design with flat parallel loading elements (left) and its cross section (right).

Table 1: Properties of 750 MHz Crab Cavity Rf Dipole Structure

Parameter	750 MHz	Units
$\lambda/2$ of π mode	200.0	mm
Cavity length	341.2	mm
Cavity radius	93.7	mm
Bars width	63.0	mm
Bars length	200.0	mm
Bars angle	45	deg
Aperture diameter -d	60.0	mm
Deflecting voltage -V_T^*	0.20	MV
Peak electric field -E_P^*	4.45	MV/m
Peak magnetic field -B_P^*	9.31	mT
B_P^*/E_P^*	2.09	$\frac{\text{mT}}{\text{MV/m}}$
Energy content -U^*	0.068	J
Geometrical factor	131.4	Ω
$[R/Q]_T$	124.2	Ω
$R_T R_S$	1.65	$\times 10^4 \Omega^2$

At E_T^*= 1 MV/m

PARAMETERIZATION

The rf dipole does not have a longitudinal electric field on axis, and the deflecting/crabbing kick is mainLy given by the tranverse electric field, which is concentrated in the parallel loading elements region. Therefore the field uniformity and its multipole components can be modified by introducing an outwards curvature to the flat parallel bars to reduce transversal variations of the fields. For the present study we

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[†] acastill@jlab.org

parametrized this curved deformation of the parallel bars using an ellipse as is depicted in Fig. 2

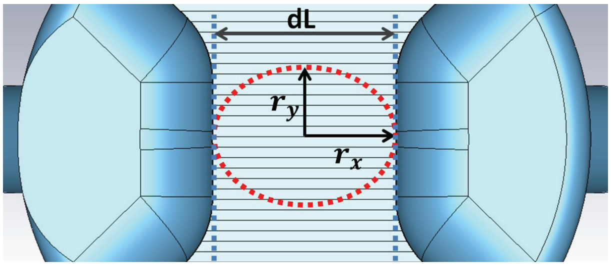


Figure 2: Close up of the parallel loading elements and the varying parameters used to tailor the multipole components for the 750 MHz rf dipole.

Keeping the parameter r_x constant and equal to the beam aperture, we varied the gap between the bars (dL), as well as the minor radius of the elliptical deformation (r_y), for comparative proposes we analyze 12 models of the 750 MHz rf dipole design, and their correspondent parameters are enlisted in Table 2.

Table 2: Table with the Parameters of the Correpondent Models Studied in This Paper

Model #	R_x [mm]	R_y [mm]	dL [mm]
1	30.0	30.0	59.8
2	30.0	29.0	59.8
3	30.0	28.0	59.8
4	30.0	27.0	59.8
5	30.0	26.0	59.8
6	30.0	25.0	59.8
7	30.0	20.0	59.8
8	30.0	30.0	58.0
9	30.0	20.0	58.0
10	30.0	30.0	57.0
11	30.0	20.0	57.0
12	30.0	30.0	56.0
13	30.0	20.0	56.0

MULTIPOLE FIELD ANALYSIS

The deflecting and crabbing applications for which the rf dipole is designed, require a strong dipolar component to operate, being the sextupole component the main concern to avoid emittance degradations of the beam in linear and circular colliders. Thus, proper tailoring of the higher multipole components is key to achieve beam stability conditions for high luminosity machines. In this section we present the main multipole strength components for the set of 750 MHz design models described in the Table. 2, and further select from them two cases of study as a comparison for their dipolar and sextupolar components of the field, and the field uniformities across the beam aperture.

Multipole Tailoring Survey

Using a Fourier series expansion of the longitudinal field $E_z(r,\phi,z)$, we calculated the multipole components as:

$$E_z^{(n)}(z) = \frac{1}{r^n}\int_0^{2\pi} E_z(r,\phi,z)\cos(n\phi)\,\mathrm{d}\phi \qquad (1)$$

Where following the standard definition of the multipole components used for magnets, and using that for time dependent rf fields $E_{acc}^{(n)}(z) = E_z^{(n)}(z)e^{j\omega t}$, then:

$$B^{(n)}(z) = j\frac{n}{\omega}E_z^{(n)}(z)e^{j\omega t} \qquad (2)$$

$$b_n = \int_{-\infty}^{\infty} B^{(n)}(z)\,\mathrm{d}z \qquad (3)$$

A detailed description of the analytical and numerical methods used to calculate the multipole field expansions is described by S. U. De Silva in [1]. To illustrate the field multipole component tailoring capabilities of the rf dipole, we present in Fig. 3 the survey of the main multipole strengths for the set of 750 MHz crab cavity models studied in this paper.

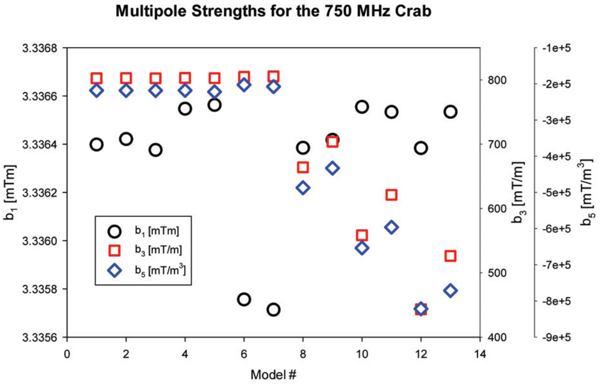


Figure 3: Survey of the first non zero multipole components: dipole (black), sextupole (red) and decapole (blue) strengths for the design models at $V_T = 1$ MV.

Even when it is hard to appreciate a clear tendency of the dipolar strength for the different models in Fig. 3, due to the scale difference on the axis, it is important to notice that the variation range for b_1 is less than 0.1%, while for b_3 is ~ 45%, and for b_5 it is about 75%, showing that it is possible to tweak higher multipole components without causing major altering in the dipolar component.

Comparison of Two Cases

Focussing down on two cases from the set of 750 MHz rf dipoles studied in this paper that correspond to two extremal values of b_3 and b_5, such as model 1 and 12 (see Fig. 3 and Table 2), it can observed from Fig. 4 the diference in the

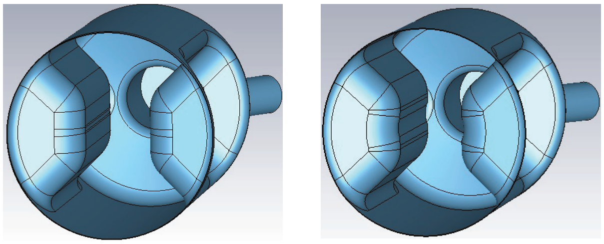
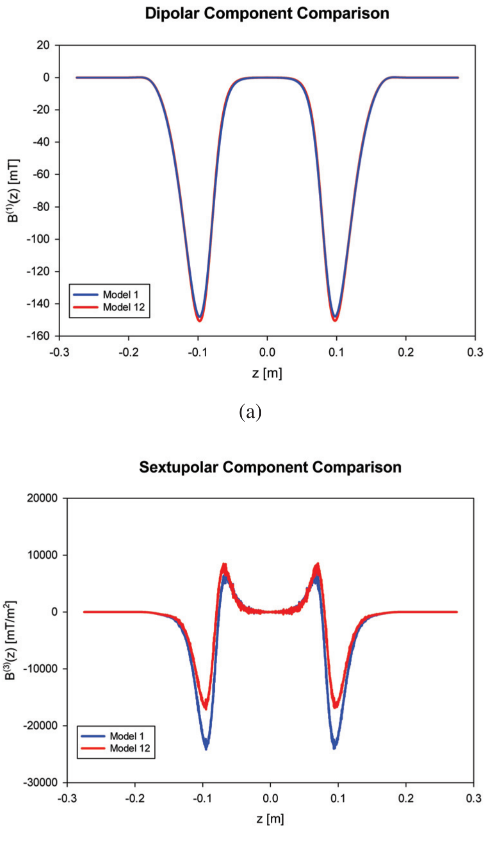


Figure 4: Cut-plane views of two different shapped loading elements, correspondent to Model 1 (left), and Model 12 (right).

curved deformation on the parallel loading elements for each case.

The comparison of the first two multipole components of the field for both models are depicted in Fig. 5, where is possible to see the reduction of the sextupolar component while the dipolar component remains the same up to a ∼ 99.9%.



(a)

(b)

Figure 5: Comparison of the multipole components: dipolar (a) and sextupolar (b), along the z- axis with a radial offset r_{off} = 1 cm for Models 1 (blue) and 12 (red).

A non uniform transverse kick across the beam aperture results in different net deflection/crabbing of particles offsetted from the beam axis, thus is very important to mantain the field uniformity in the vicinity of beam axis to avoid induced perturbation or instabilities in the beam.

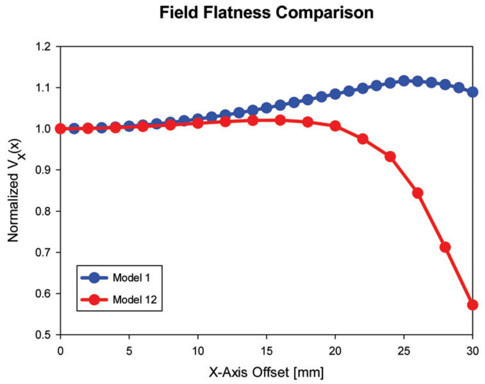


Figure 6: Comparison of the normalized transverse kick V_x across the beam aperture in the horizontal direction.

CONCLUSIONS

We analyzed the feasibility of employing elliptically parametrized curved deformations on the parallel loading elements as a tailoring method for the multipole components and transverse uniformity of the fields on the 750 MHz crab cavity as a case of study for the rf dipole geometry. The results showed the versatility of the rf dipole for applications with strong emittance and bunch instabilities control requirements. We presented as point of comparison the results of two cases from a set of 750 MHz rf dipole models examined in this paper, the main multipole strength components are listed in Table 3 next.

Table 3: Multipole Components for Two Models of the Rf Dipole Cavity Designs

	Model 1	Model 12	Units
V_T	1.0	1.0	MV
b_1	3.336	3.336	mTm
b_2	0.0	0.0	mT
b_3	8.025	4.933	$\times 10^2$ mT/m
b_4	0.0	0.0	mT/m^2
b_5	-2.1780	-8.218	$\times 10^5$ mT/m^3

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