DIPOLE STABILIZING RODS SYSTEM FOR A FOUR-VANE RFQ: MODELING AND MEASUREMENT ON THE TRASCO RFQ ALUMINUM MODEL AT LNL

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Abstract

The Dipole Stabilizing Rods (DSR's) are devices used in order to reduce a priori the effect of perturbation on the operating mode of a four-vane RFQ caused by neighbouring dipole modes by increasing the frequency spacing between the TE_{210} mode and dipole modes, without, in principle, affecting the quadrupole TE_{210} mode. They have proven to be particularly useful in the case of coupled RFQ's whose overall length is significantly greater than the operating wavelength. In this article we present a circuit model of such DSR's, that, used in combination with a transmission line model of a four vane RFQ, has allowed us to predict the dimensioning of the DSR's in the case of the aluminium model of TRASCO RFQ. The DSR parameters and, in general, the accuracy of the model have been also confirmed by HFSS simulations and by RF measurements on the above-mentioned model.

INTRODUCTION

The effect of a perturbation (e.g. due to mechanical errors and/or misalignments) on the nominal geometry in a four-vane RFQ provokes a mixing of the operating TE_{210} mode with neighbouring quadrupole TE_{21n} and TE_{11n} dipole modes. If the overall length L of the RFQ is significantly greater than the wavelength, the neighbouring modes can be very close to the operational one, thus enhancing the effect of perturbations. This is an issue for high intensity machine, as the case of TRASCO-SPES RFQ in construction at LNL [1], where high field uniformity is required in order to minimize beam losses. TRASCO-SPES RFQ operates at 352.2 MHz and is L=7.13 m = 8.4 λ long. The segmentation of the RFQ[2] adopted in TRASCO-SPES RFQ by means of coupling cells (two in this case, located at L/3 and 2L/3 positions) can reduce the effect of TE_{21n} perturbative terms. Therefore, a chain of N coupled RFQ's can be represented for the TE_{21} (quadrupole) and TE_{11} (dipole) modes by a system of N coupled transmission lines terminated by resonant loads, called end-cells tuned at the quadrupole frequency (Fig. 1)[3,4].

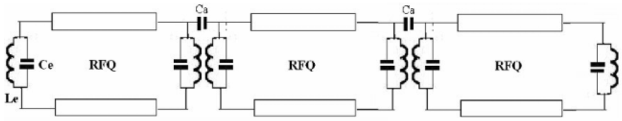

Figure. 1: The equivalent transmission line for N=3 coupled RFQ's.

It has to be pointed out that the segmentation of the RFQ's is not effective with the dipole perturbations. Moreover, the insertion of end cells raises the f_{110} frequency, shifting it closer to the operational one [4]. Therefore dedicated stabilizing systems for dipole modes are needed. The usage of DSR's to be inserted in correspondence of the end-cells and coupling cells is a solution typically used for high power RFQ's [5,6,7].

THE PRINCIPLE OF DIPOLE STABILIZATION

Dipole Stabilizing Rods are conductive bars departing from the end and coupling plates and protruding into each RFQ quadrant. If they are located at a height h_b on the axis of a RFQ transverse section in which electric and magnetic energy densities balance at the f_{210} frequency, they almost do not affect the TE_{210} mode. Moreover they couple their coaxial modes ("bar mode") with the dipole modes (Fig. 2), thus shifting the dipole band. In fact in the quadrants 1 and 3 an electric field from the bar to the electrodes appear and a magnetic field wraps around the bars.

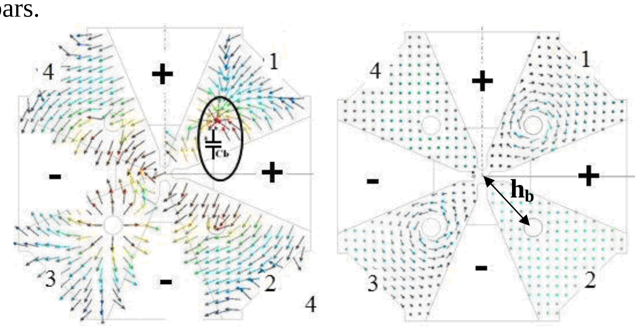

Figure 2: The coaxial bar mode coupling effect on the dipole mode: E field (left) and H field (right).

Therefore one can think of modelling the bar as a parallel inductance L_b and parallel capacitance C_b depending on bar length l_{bar} added in the end and coupling cell sides the equivalent transmission line for TE_{11} modes (Figure 3).

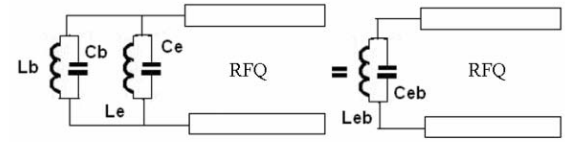

Figure 3: The equivalent circuit for TE11n modes of the RFQ in correspondence of the undercuts when bar are inserted

Now, if l_{bar} is such that the equivalent admittance $Y_{eq}(\omega, l_{bar}) = j\omega(C_e + C_b) + 1/(j\omega(L_e + L_b))$ vanishes at the 2D dipole frequency, not only the TE_{110} frequency becomes equal to the 2D value, but the dipole free region width around the quadrupole mode is maximized. Therefore the optimization of DSR's could be accomplished by simply tuning the TE_{110} frequency to its original 2D value. Due to the TEM nature of the bar mode inside the quadrants, an unambiguous voltage V_b between the bar and the electrode can be calculated. Moreover, the capacitance per unit length can be evaluated in this part, where almost all the electric energy is concentrated, according to the relationship

$$C_b = (4w_{eb} / |V_b|^2)(l_{bar} - l_{end-cell}) = c_b (l_{bar} - l_{end-cell})$$

w_{eb} being the electric energy per unit length.

On the other hand, the knowledge of the frequency of the bar mode allows to evaluate the inductance L_b. It is worth noticing that due to the field configuration in the End Cells, there is an excess of inductance with respect to the uniform coaxial line, and then an optimal bar length less than $\lambda/4$ is to be expected.

RESULTS OF SIMULATIONS ON THE ALUMINUM MODEL

The dimensioning and design of DSR's has been also verified with HFSS simulations on the aluminum model of the RFQ, installed at LNL, Its overall length is L=3.044 and it consists of three coupled segments. For such RFQ, calculations have given the following values for the main parameters of interest.

Table 1: Main parameters for the aluminum model of the RFQ.

f_{110} (2D) [MHz]	339.289
f_{210} (2D) [MHz]	350.613
C [pF/m]	28
C_e [pF]	0.86
c_b [pF/cm]	0.42
h_b [mm]	55

The diameter of the bar has been set to 14 mm (a realistic value for room of a cooling system) and the bar length has been varied in order to find the maximum dipole free region (fig 4). In the following figure the behavior of the dipole bands as a function of the bar length l_{bar} is shown.

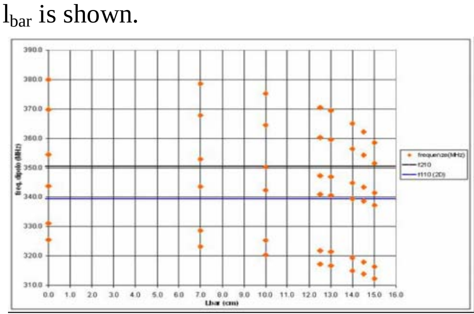

Figure 4: Dipole frequencies shift as a function of the bar length.

From this figure it is possible to notice that the length $l_{bar}^* = 14$ cm both creates a symmetrical dipole free region of about ± 6 MHz, the f_{110} frequency is e equal to its 2D value within 0.1%. The results have obtained both with HFSS simulations [8] and with the transmission line model (Figure 5) and the agreement is within 1%.

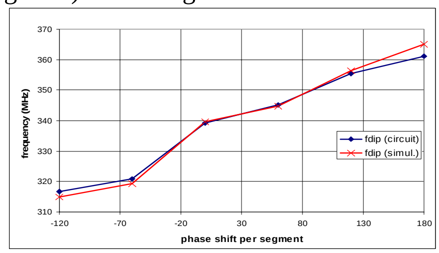

Figure 5: calculated and simulated dispersion curve for dipole modes with DSR's.

EXPERIMENTAL RESULTS

The experimental apparatus consists of the aluminum model of the RFQ, the Vector Network Analyzer (VNA) and the setup for the bead pulling measurements [9,10].

Figure 6: The experimental setup (left) and the stabilizing rods mounted on the coupling plate (right)

The stabilizing rods are fixed to the end and coupling plates by means of proper screws. The VNA is the 8753ES model of the Agilent Corporation.

The first measurement has been performed without inserting the bars, and the quadrupole and dipole mode spectra measurements have given the dispersion curve of Fig .5. In particular the quadrupole frequency f_{210} is equal to 350.375 MHz (with tuners flush).

Upon insertion of the bars the new dispersion curve obtained for quadrupole and dipole modes is the following (Fig. 6), in which it can be noticed that, as predicted by theoretical analysis and simulations, the dipole frequency arrange symmetrically around the f_{210}, that has remained unchanged within 0.03%, by giving a dipole free region of about ± 6MHz (with tuners flush).

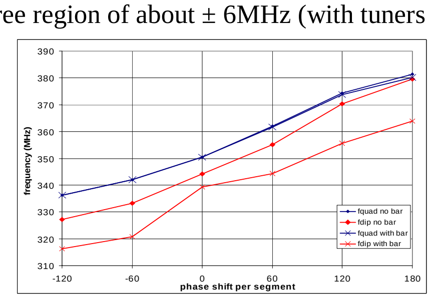

Figure 7: Measured dispersion curve for RFQ without and with bar inserted

It has to be pointed out that such measurements exhibit a very good match with the theoretical prediction given by the Transmission Line Model and HFSS simulations (below 0.1%). The only discrepancies can be found in the behavior of the TE_{11} modes predicted by the equivalent line model prior to bar insertion (in this case HFSS and measured results are some per cent higher).

The bead pulling measurements of the longitudinal evolution of the electric field for the TE_{210} mode have been performed as well, with and without dipole stabilizers. In the following figures it is possible to compare the perturbing dipole contents (TE_{11n} modes) on the operating mode in the two cases. It can be noticed that the insertion of the bars has decreased of about 50% the dipole perturbations, as expected.

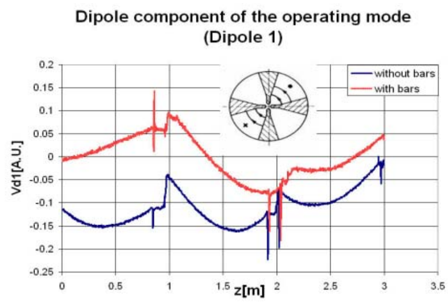

Figure 8: Perturbation of the dipole mode 1 on the operating mode before and after Dipole Stabilizer insertion

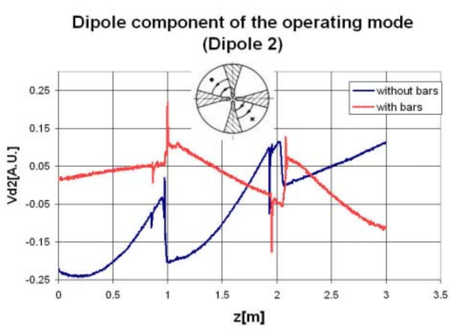

Figure 9: Perturbation of the dipole mode 2 on the operating mode before and after Dipole Stabilizer insertion

Finally, in Fig. 10 the quadrupole component in the two cases is shown. In this case the Dipole Stabilizers have only a slight effect on the TE_{210} component.

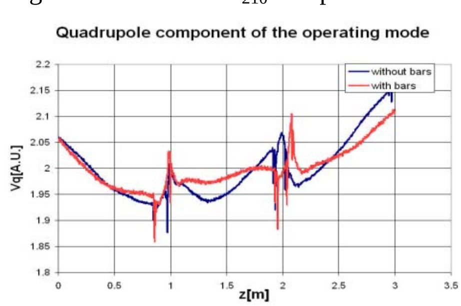

Figure 10: Behaviour of the quadrupole component.

CONCLUSIONS

The RF measurements performed on the aluminum mode of the RFQ equipped with dipole stabilizers have shown that the combined predictions of the Transmission Line model and of HFSS simulations are accurate and can be reliably used in phase of testing of such devices on the high-power TRASCO-SPES RFQ. Therefore one could be confident that the cooled DSR's that will be constructed and brazed on the coupling and end plates could be directly mounted on the cavity. Moreover, the Transmission Line Model has been updated and, so that the tuning algorithm of the RFQ that makes use of 96 slug tuners can be improved.

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