MODE STABILIZATION STUDY OF 352.2 MHz FOUR-VANE TYPE RFQ

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Abstract

The 352.2 MHz, 3 MeV Radio Frequency Quadrupole (RFQ) is one of the main components of the front-end H^- injector of proposed Indian Spallation Neutron Source (ISNS) at RRCAT, Indore. Since the quadrants of the four-vane type RFQ are weakly coupled, any perturbation can excite dipole modes, which may deflect the beam and result in loss and emittance growth of the beam. In addition to this, the frequency of higher quadrupole and dipole modes decreases with the increase in the length of RFQ. Hence, these higher modes tend to mix with the operating one and make the RFQ unstable. The separation of higher dipole and quadrupole modes with the operating mode is studied and the techniques to stabilize the operating quadrupole mode against these unwanted modes are described briefly in this paper.

INTRODUCTION

Among the various techniques to overcome the mode mixing in four-vane type RFQ of several wavelengths long (~4λ in our case), one solution to stabilize the operating mode TE_{210} against the neighboring TE_{21n} modes is the segmentation of the RFQ by means of resonant coupling as proposed by L. M. Young [1]. This technique is, however, not effective for the dipole TE_{11n} modes perturbations, which are deflecting modes and may result in loss and emittance growth of the beam. For the stabilization of RFQ against the dipole modes, the dipole stabilization rods are widely used along with the resonant coupling scheme.

Studies of the mode separation with the length of RFQ and the resonant coupling technique with dipole stabilization rods to stabilize the RFQ are performed and described in the following sections.

MODE SEPARATION STUDY

Analytical Treatment

From the dispersion relation of TE_{pqn} family of modes for the four-vane type RFQ cavity, the resonant frequency of n^{th} order mode, f_n, can be calculated by

$$f_n = \sqrt{{f_0}^2 + \left(\frac{nc}{2L}\right)^2} \quad \ldots(1)$$

where f_n is the frequency corresponding to TE_{pqn} mode , f_0 is the frequency of fundamental TE_{pq0} mode, L is the total length of RFQ and n is an integer (0, 1, 2,…). With this relation, the frequencies of higher quadrupole modes and dipole modes are calculated for 3.47 m long cavity where the values of fundamental quadrupole mode TE_{210} frequency (352.2 MHz) and fundamental dipole mode TE_{110} frequency (342.01 MHz) calculated from SUPERFISH are used.

It is observed that the neighboring quadrupole mode TE_{211} is only 2.7 MHz higher in frequency than operating mode TE_{210}. On the other hand, the TE_{111} dipole mode is 7.46 MHz lower and the next TE_{112} dipole mode is only 0.59 MHz higher in frequency than operating TE_{210} mode.

Effect of Vane-End Cut-Backs

To see the effect of end cut-backs, a full 3D unmodulated RFQ model is prepared in CST studio and due to symmetric structure only a quadrant needs to be simulated. Since the cut-backs are designed to satisfy the open-end condition of TE_{210} quadrupole mode, the separation of higher quadrupole modes remains unchanged with cut-backs, but this is not the case with the dipole modes. The dipole mode frequencies are found to increas with the end cut-backs, as a result of which the separation of neighboring TE_{111} and TE_{112} dipole modes with the operating TE_{210} mode is modified to -3.8 MHz and +5.2 MHz respectively.

RESONANT COUPLING

For this 3.7 m long RFQ, the nearest quadrupole mode TE_{211} is only 2.7 MHz higher in frequency from operating mode of RFQ. To increase the separation between these quadrupole modes, this RFQ can be divided into two segments of equal length and then joined by means of resonant coupling as proposed by L. M. Young. Each segment can be considered a complete RFQ with vane cut-backs at both the ends and these segments can be joined with a coupling plate having a large center hole through which the vane tips extend to almost touch each other such that the gap can provide the capacitive coupling between the two segments [1-3].

A coupling cell to join the two segments is designed with the help of CST MWS. The cut-plane view of the coupling cell is shown in Figure 1.

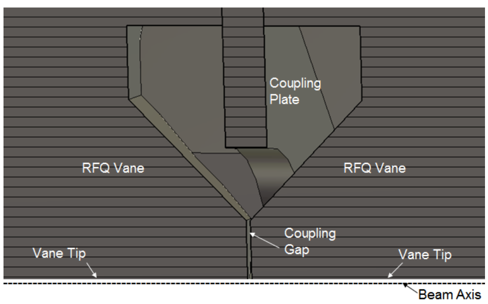

Figure 1: Cut-plane view of coupling cell.

The dimensions of vane cut-backs with coupling plate of 1.5 cm thickness and centre hole of 5 cm radius are

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optimized such that the coupling cell resonates at the operating quadrupole mode frequency.

Gap Distance Optimization

The full length RFQ model is simulated to study the effect of gap distance and the operating mode is optimized at 349 MHz due to the limitation in handling very large number of mesh points but the sufficient fine mesh is imposed at the gap. The gap is situated in the middle of the structure at a position where the synchronous particle sees the zero rf field. Due to the coupling of two segments, each mode splits into two modes (0-mode and π-mode). As a result of this, the neighboring quadrupole modes of the operating ${}^{0}TE_{210}$ mode are ${}^{\pi}TE_{210}$ on the lower side and ${}^{0}TE_{211}$ on the upper side. From the theory of compensated structures, the gap distance should be optimized such that the frequency difference of operating mode with the next lower quadrupole mode and the next upper quadrupole mode is equal for the longitudinal stability of the structure against perturbations [2]. Figure 2 shows how the neighboring quadrupole mode frequencies vary with the gap distance. The variation of gap distance does not affect the operating mode frequency but the neighboring mode frequencies increase with the gap distance. At a gap distance of 1.5 mm, the upper and lower quadrupole modes are separated by 5.5 MHz and 5.3 MHz respectively from the operating mode.

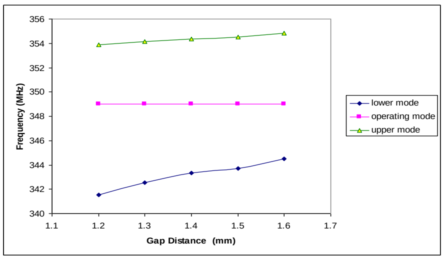

Figure 2: Neighboring quadrupole mode separation vs gap distance.

DIPOLE STABILIZATION RODS

Dipole stabilization rods (DSRs) are cylindrical rods attached with both (entrance and exit) end plates and both sides of coupling plate, inserted in each of the four quadrants to increase the frequency separation between the TE_{210} operating mode and the deflecting dipole modes [3,4]. The bar mode, introduced by the DSRs, does not couple with the quadrupole mode but the coupling of the bar mode with the dipole modes causes the dipole frequencies to shift. The main parameters of the DSRs to be optimized are the diameter, length and the location of the rods in the four quadrants.

The criterion for the choice of the diameter of the DSRs is that it should be as small as possible so that it does not perturb the operating mode frequency, as well as it should have enough space for the cooling arrangement. On the other hand, the criterion for choosing the location of the DSRs is that the rods should locate at a position on the bisector of the quadrants where the perturbation of the rods to the operating electric and magnetic fields is the same. The diameter of 11 mm and 44.55 mm height on the bisector of the quadrant are optimized for the DSRs from the 2D code SUPERFISH. SUPERFISH does not take into account the field perturbation due to the cut-backs. Hence to find the exact location of DSRs, 3D model in CST MWS with end cut-backs is used. The 3D simulation is in very close agreement with the SUPERFISH results and the location of 11 mm diameter rod is found to be 45.25 mm from the centre of RFQ on the bisector of the quadrant.

The length of the rods is optimized to make sufficiently wide and symmetric dipole free region about the operating quadrupole mode. The variation of the different mode frequencies is shown in Figure 3.

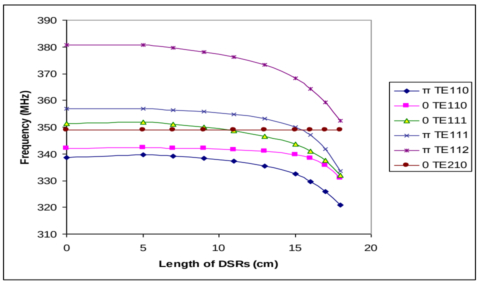

Figure 3: Variation of dipole mode frequencies with the length of DSRs.

It is observed that the dipole mode frequencies decrease appreciably with the length of DSRs leaving operating quadrupole mode frequency unchanged. At the length of 17 cm of DSRs, the lower dipole mode ${}^{\pi}TE_{111}$ and the upper dipole mode ${}^{\pi}TE_{112}$ are 7.6 MHz and 9.8 MHz apart from the operating ${}^{0}TE_{210}$ quadrupole mode which provides the sufficiently wide dipole free region of 17.4 MHz around the operating mode.

ACKNOWLEDGEMENT

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