Field Stabilization and End-Cell Tuning in a 4-vane RFQ

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Abstract

A review of the existing methods for field stabilization in 4-vane RFQs is presented and a new approach using magnetic coupling through some holes in the vanes is proposed. The possibility of properly tuning the end cells (by changing both the dimension and the position of the holes) in order to reduce the longitudinal $\vec{E}$ field on the axis in the end regions and to improve the inter-electrode voltage distribution is shown. An overall comparison of rf efficiency between the different structures is then made, showing results from computer simulations with MAFIA codes and from measurements on a 400 MHz cold model built at ITEP.

1 INTRODUCTION

The tuning of 4-vane RFQs is rather difficult owing to the very weak coupling between the neighbouring quadrants of the resonator; this coupling is further reduced when the length L of the resonator increases.

The longitudinal stability of the RFQ mode TE_{210}, i.e. its sensitivity to tuning errors, is proportional to $(L/\lambda)^2$, where λ is the rf wavelength [1]; the azimuthal stability is determined by the frequency distinction between TE_{210} mode and nearby dipole modes. The lowest mode in a 4-vane RFQ is TE_{110}; but if it is long ($L \gg \lambda$), there are a lot of higher-order modes whose frequencies can be lower or higher than the operating one; the mixing of dipole modes with TE_{210} mode affects very negatively the beam dynamics, reducing the acceptance of the accelerating structure.

This work logically continues the investigations on the 90°-apart-stem structure called '4-ladder' RFQ [2], started in 1991 in the framework of a collaboration between INFN-LNL and ITEP and carried on during 1992–93 building a 100 MHz structure at ITEP. As the idea of azimuthal field stabilization by means of holes looked rather attractive (simulations with MAFIA code [3] were confirmed by measurements on the 100 MHz cold model), we continued this work with a 400 MHz 4-vane cold model RFQ that already existed at ITEP: it was easily transformed into a 4-ladder one by cutting holes in its vanes (Fig. 1).

Moreover, recent investigations [4] showed that a 4-rod RFQ (and therefore also our 4-ladder one) has an E_z component of the electric field in the gap between end plate and electrodes, whose value depends on the tuning of the end cells: we tried to eliminate it and simultaneously achieve a good longitudinal inter-electrode voltage distribution $V_e(z)$.

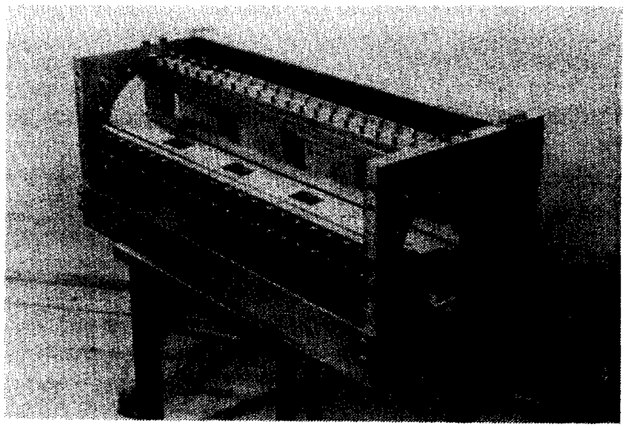

Fig. 1: The 400 MHz cold model RFQ built at ITEP.

2 FIELD STABILIZATION

Several methods of improving both azimuthal and longitudinal stability of the operating TE_{210} mode in a 4-vane RFQ have been proposed; in this paper we shall consider mainly the azimuthal stabilization.

The potential difference between opposite vanes should be zero, but if a dipole mode is mixed with the quadrupole one, then some voltage arises; the simplest way to eliminate it, is to connect opposite vanes by pairs of conductors.

This idea was first implemented by means of Vane Coupling Rings (VCRs) [5] which raise the frequency of the lowest-order dipole mode above the operating one, and exert no influence on the longitudinal stability. But they lower the frequency of the TE_{210} mode as well and cause a perturbation of $V_e(z)$, both effects due to their extra inter-electrode capacitance; moreover it is difficult to provide reliable rf contacts between VCRs and vanes, and to cool VCRs, which is very important for high duty factor RFQs.

If a straight bar is used, passing through the holes in the vanes and with ends connected to the shell of neighbouring quadrants (as a straightened half-ring), then a π-mode Stabilizing Loop (PISL) is obtained [6]. The main advantage of PISLs is the possibility to install them from outside the cavity by inserting the bars through holes in its shell: this can be done after assembling the RFQ. They have practically no problems with water cooling and rf contacts, because water connections and rf contacts can be chosen outside the resonator.

Another solution for short RFQs are resonant loop couplers [7] and dipole suppressors [8] placed at the end of

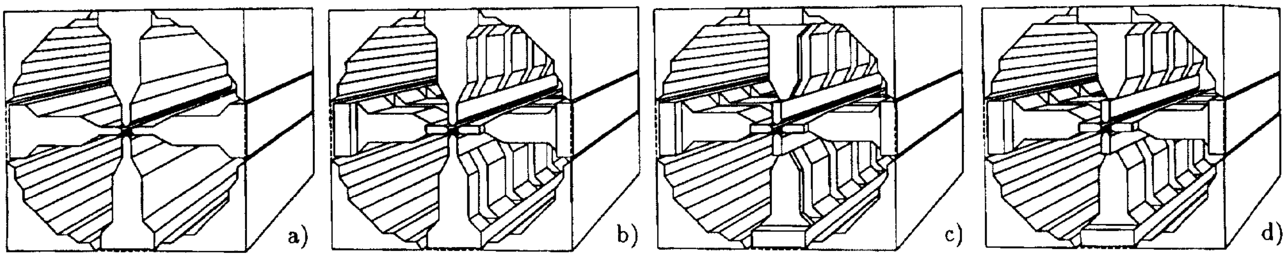

Fig. 2: MAFIA plot of the 4-vane (a), 4-ladder (b), tuned 4-ladder (c) and 'unshifted holes' (d) 400 MHz structures.

the RFQ, which affect dipole modes by splitting and shifting them above and below the operating quadrupole one. As the cutoff frequency of the TE_{11n} modes is only a few percent lower than the one of the TE_{21n} modes, and considering that the end-cell tuning for dipole and quadrupole modes is different, the lowest TE_{110} mode will be shifted to the TE_{210} mode and can even be mixed with it.

Our previous investigation on the 100 MHz 4-ladder RFQ [2] showed that a magnetic coupling between neighbouring quadrants, through some holes in the vanes, moves the quadrupole mode well below the dipole ones. We decided to check this method as a way to stabilize conventional 4-vane RFQs, using the 400 MHz cold model which had been built in ITEP a few years ago. Results of our investigations are given below.

3 RESULTS FROM SIMULATIONS AND MODEL MEASUREMENTS

The features of the 4-vane structure that was used for our investigations (Fig. 2a) are the following:

- Total length - 59.6 cm
- Vane length - 57.6 cm (no undercut)
- Gap between vanes and end plates - 1.0 cm
- Inner tank diameter - 16.0 cm
- Aperture radius - 0.3 cm (unmodulated vanes)
- Curvature radius of the vane tips - 0.3 cm
- Material of the electrodes - aluminium

The resonant frequencies, the quality factor and the longitudinal inter-electrode voltage uniformity of this structure are shown in Table 1. As already noticed in Ref. [2], MAFIA slightly over-estimates frequencies, nevertheless the agreement of the results is quite good and it allows us to trust completely in MAFIA simulations (the poor Q is due to bad contacts and material used for the vanes).

In order to stabilize the quadrupole mode, we cut holes on the vanes (Fig. 2b). The width of the holes is 4.0 cm, their height is 5.0 cm, the distance between centres of the holes is 12.8 cm; the holes on neighbouring vanes are shifted with respect to each other by 6.4 cm. The results obtained are shown in Table 2; notice again the good agreement between simulations and model measurements.

In this case $f_q < f_d$, because the quadrupole mode was lowered more than the dipole ones; moreover, the end cells are mistuned for dipole modes rather more strongly than for quadrupole mode and this leads to an increase of f_d.

Table 1: Parameters of the 4-vane before tuning

	Computed	Measured
TE_{210} freq. (f_q)	449.17 MHz	448.2 MHz
TE_{110} freq. (f_d)	448.28 MHz	447.1–447.5 MHz
Quality factor (Q)	7.6×10^3	4.0×10^3
V_e uniformity	33.8%	30%

Table 2: Parameters of the 4-ladder before tuning

	Computed	Measured
TE_{210} freq. (f_q)	429.45 MHz	428.58 MHz
TE_{110} freq. (f_d)	431.35 MHz	430.3–430.8 MHz
Quality factor (Q)	8.7×10^3	4.2×10^3
V_e uniformity	18.8%	18%

Table 3: Simulated parameters after tuning

	4-vane	4-ladder 'shifted'	4-ladder 'unshifted'	
TE_{210} freq.	427.83	417.65	419.24	MHz
TE_{110} freq.	425.91	418.16	420.29	MHz
Separation	-1.92	+0.51	+1.05	MHz
Q factor	8.9×10^3	9.1×10^3	9.1×10^3	
V_e uniform.	1.9%	1.1%	2.1%	

In Table 3 the results of MAFIA simulations are shown after the end-cell tuning for f_q by the undercutting of vanes: in the first column is the tuned 4-vane, in the second one the tuned 4-ladder (Fig. 2c), in the third one a structure having holes on neighbouring vanes at the same longitudinal position ('unshifted holes' version of 4-ladder - Fig. 2d). This new structure is 6.4 cm shorter than the others, but all the remaining dimensions are the same.

According to simulations, both f_q and f_d are lowered but the difference between them decreases: so the frequency separation provided by holes with the above-mentioned dimensions is not sufficient to guarantee a reliable stabilization of the quadrupole mode. Notice that the Q factor of both versions of the 4-ladder structure is not worse than the tuned 4-vane one, taking into account that f_q is slightly lower for both of them.

In Fig. 3 the V_e uniformity along the RFQ and the $\vec{E}$ field in the gap are shown for the same structures of Fig. 2. As can be seen, a flat inter-electrode voltage can be obtained for both 4-ladder structures (Figs. 3c and 3d); the E_z component on the axis of the 'shifted holes' version before tuning (Fig. 3f) decreases after tuning (Fig. 3g) and

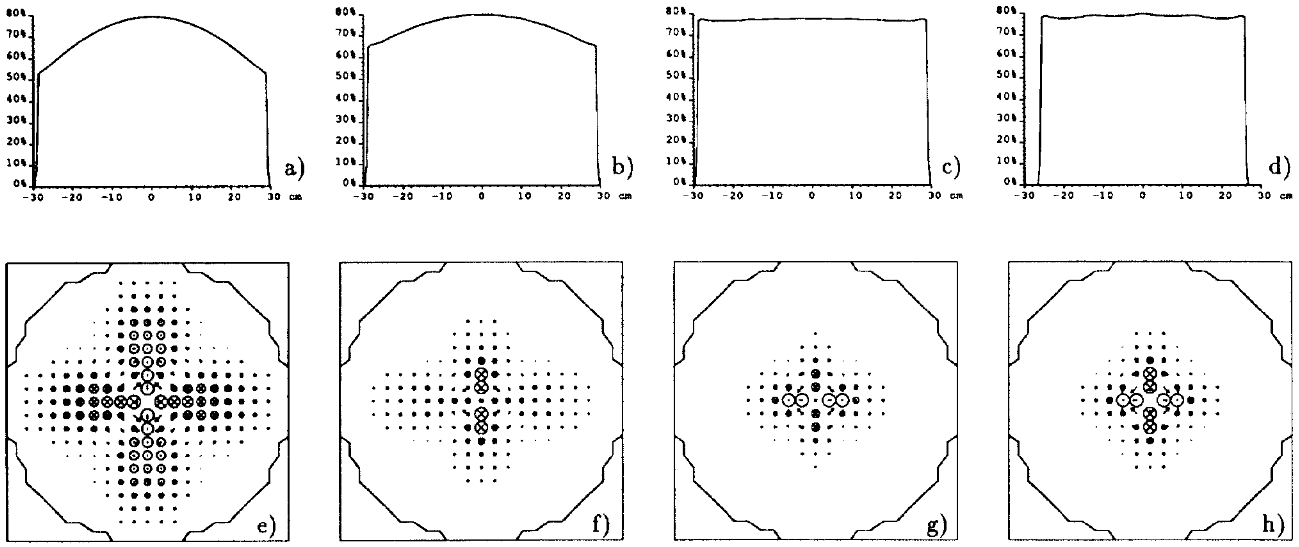

Fig. 3: MAFIA plot of normalized $V_e(z)$ and of $\vec{E}$ field in the gap for the four structures of Fig. 2.

it disappears in the 'unshifted holes' version (Fig. 3h).

In order to compare these structures from the point of view of rf efficiency and mode stability, MAFIA simulations for both of them (with shifted and unshifted holes) were made to get approximately the same f_q of the tuned 4-vane RFQ (427.83 MHz), by reducing the diameter to 13.7 cm and properly changing the size of the holes (7.6x4.3 cm for the 'shifted' version and 8.3x4.3 cm for the 'unshifted' one). The results are given in Table 4.

Table 4: Comparison at the same f_q frequency

	4-vane	4-ladder 'shifted'	4-ladder 'unshifted'	
TE_{210} freq.	427.83	427.75	427.90	MHz
TE_{110} freq.	425.91	453.59	442.53	MHz
Separation	-1.92	+25.84	+14.63	MHz
Q factor	8.9×10^3	8.1×10^3	7.9×10^3	
Spec. Z_{sh}	53.7	53.0	54.3	kΩ·m
V_e uniform.	1.9%	0.9%	4.3%	

Both versions allow one to achieve a good mode separation, still keeping a similar rf efficiency (specific shunt impedance, Z_{sh}). The frequency separation between quadrupole and dipole mode is much larger for the 'shifted holes' than for the 'unshifted holes' version, because the first provides more strong coupling between quadrants (even though the area of the holes is smaller), owing to the longitudinal currents flowing along the vanes, which create a rotating magnetic flux passing through the holes.

In our first attempt (Table 3) the distance between holes was too much and their area was not sufficient to provide a strong coupling between quadrants; that is why the mode separation for that case was so small.

Moreover, Table 4 shows that the 'shifted holes' 4-ladder has a better longitudinal inter-electrode voltage distribution in comparison with the 'unshifted holes' one.

4 CONCLUSIONS

The proposed method of azimuthal field stabilization, based on the transformation of a conventional 4-vane resonator into a 4-ladder one by means of holes in the vanes, provides a reliable separation between quadrupole mode and dipole ones and keeps a good rf efficiency.

A way to eliminate completely the electric field in the gap is to place the holes on neighbouring vanes at the same longitudinal position, though this reduces the mode separation and the inter-electrode voltage flatness.

The rf efficiency of this modified structure can even be improved in comparison with the conventional 4-vane one by optimizing both the dimensions and the position of the holes and by proper end-cell tuning. Moreover, this can be achieved without any additional element being introduced into the cavity, this means simplicity of manufacture.

5 ACKNOWLEDGMENTS

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6 REFERENCES

[1] D.D. Armstrong et al., LANL Report LA-UR 84-498 (1984).

[2] V.A. Andreev and G. Parisi, PAC'93, Washington, D.C., May 1993, p. 3124.

[3] R. Klatt et al., LINAC'86, Stanford, CA, June 1986, p. 276.

[4] V.A. Andreev, A. Lombardi, G. Parisi and M. Vretenar, PAC'93, Washington, D.C., May 1993, p. 3121.

[5] H.R. Schneider and H. Lancaster, IEEE Trans. Nucl. Sci., NS-30, No. 4, p. 3007 (1983).

[6] A. Ueno, T. Kato and Y. Yamazaki, LINAC'90, Albuquerque, NM, September 1990, p. 57.

[7] A. Schempp, LINAC'86, Stanford, CA, June 1986, p. 251.

[8] M. Vretenar, CERN/PS 87-56 (LI), 1987.