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RF TUNING OF THE IPHI RFQ

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Abstract

The construction of IPHI (High Power Proton Accelerator) is in its final step of installation. The RFQ will accelerate beam up to 100 mA with energy up to 3 MeV. The RFQ, made of six modules, one meter each, is of the four-vane type. The RFQ is divided in 2-meter long segments with capacitive coupling. It is also equipped with 96 fixed tuners and four waveguide RF ports located in the fourth module. This paper describes the procedure used to tune the accelerating field and power couplers of the RFQ.

INTRODUCTION

Tuning process has been developed with a cold model of IPHI RFQ [1,2] and used for the tuning of LINAC4 RFQ [3]. Electrical parameters of end-circuits and coupling-circuits must ensure that the desired voltage profile may be obtained at the end of slug tuning process. Tuning operations are detailed in Table 1.

END CELL TUNING

Dipole rods modify dipole eigen-frequencies only, while quadrupole devices modify both dipole and quadrupole eigen-frequencies: tuning starts with quadrupole devices (using excitations set method [2]), and proceeds with dipole rods (using spectrum analysis). The excitations set method needs the structure under analysis to be stable, and dipole rods pre-tuning is required. Note that dipole spectrum and quadrupole devices tuning are carefully checked every time a new configuration of segments SG1, SG2, SG3 is assembled.

Values of Q-related coefficients are reported in Table 2. General accuracy is a few 10^{-2} V/m/V. Coupling capacitances (Cc in pF) are found to be smaller than expected. Coupling cell have been designed with RF calculations and are not (easily) tunable. Sensitivity to quadrupole-like perturbations will be about two time higher than expected (while remaining 1.4 time smaller than for an un-segmented structure).

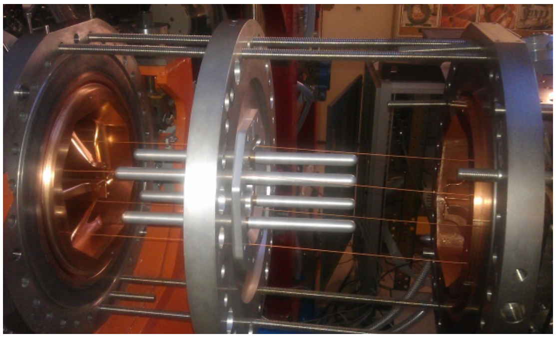

Figure 1: Tunable coupling plate.

Table 1: Tuning Operations

configuration	operations	method
SG1	dipole rods pre-tuning	spectrum analysis
SG1	end #1 plate tuning	excitations set
SG2	dipole rods pre-tuning	spectrum analysis
SG1-SG2	dipole rods pre-tuning	spectrum analysis
SG1-SG2	coupling plate #1 tuning	excitations set
SG3	dipole rods pre-tuning	spectrum analysis
SG3	end #2 plate tuning	excitations set
SG2-SG3	dipole rods pre-tuning	spectrum analysis
SG2-SG3	coupling plate #2 tuning	excitations set
SG3	dipole rods tuning	spectrum analysis
SG2	dipole rods tuning	spectrum analysis
SG2-SG3	dipole rods tuning	spectrum analysis
SG2-SG3	end #2, coupling #2 check	excitations set
SG1	dipole rods tuning	spectrum analysis
SG1-SG2	dipole rods tuning	spectrum analysis
SG1-SG2	end #1, coupling #1 check	excitations set
SG1-SG2-SG3	dipole rods tuning	spectrum analysis
SG1-SG2-SG3	local modes check	spectrum analysis
SG1-SG2-SG3	Slugs tuning	tuning loop
SG1-SG2-SG3	RF coupling tuning	s11 and bead-pull
SG1-SG2-SG3	final slug tuning	tuning loop

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The tuning of the two end cells and the 2 coupling plates is made by using aluminum end-plates with adjustable rods and/or thickness (Fig. 1), thus allowing the fabrication of the final copper end-plates (Fig. 2).

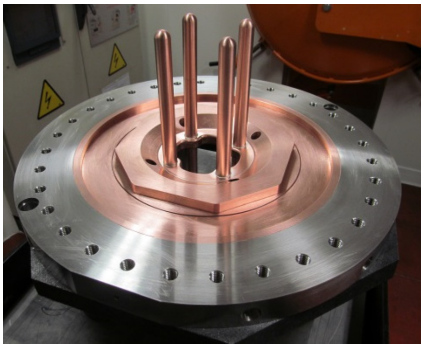

Figure 2: Final Coupling plate.

Table 2: Tuned Values of Q-Related Coefficients

		required	aluminum plates	copper plates
end1	s_{QQ}	0	$-5.46\ 10^{-3}$	$-3.04\ 10^{-2}$
cc1	$s_{\Sigma\Sigma}$	$+7.91\ 10^{-2}$	$+7.33\ 10^{-2}$	$+9.45\ 10^{-2}$
	$s_{\Delta\Sigma}$	0	$+9.29\ 10^{-3}$	$-9.59\ 10^{-2}$
	C_c	1.10	0.706	0.53
cc2	$s_{\Sigma\Sigma}$	$+1.304\ 10^{-1}$	$+1.07\ 10^{-1}$	$+1.20\ 10^{-1}$
	$s_{\Delta\Sigma}$	0	$+1.82\ 10^{-2}$	$+2.39\ 10^{-3}$
	C_c	1.10	0.934	0.95
end2	s_{QQ}	$+2.11\ 10^{-2}$	$+4.48\ 10^{-2}$	$+2.85\ 10^{-2}$

Table 3: Extreme Tuner Positions (mm), Accelerating Mode Frequency (MHz) and Voltage Peak Relative Errors (%) vs. Tuning Step

step	tuner positions	Q_{0+0+0}	Q-component	S-component	T-component
0	0.00 0.00	350.406	–25.29 +90.06	–17.61 +15.66	–8.76 +14.52
1	–3.54 +13.04	351.412	–27.98 +15.18	–6.61 +4.35	–3.80 +6.90
2	–2.30 +10.39	351.893	–6.00 +3.97	–1.27 +0.89	–1.06 +1.73
3	–2.43 +10.85	352.041	–2.82 +0.78	–3.53 – 0.11	–0.66 +2.28
4	–3.00 +11.08	352.094	–1.23 +0.97	–0.90 +2.95	–1.73 +0.55
5	–2.91 +10.77	352.090	–0.81 +0.56	–0.08 +0.24	–0.78 +0.42

SLUGS PRE-TUNING

Once end-circuits have been tuned and copper end-plates inserted, positions of the 96 slugs and 4 dummy RF blocks are adjusted in order to achieve specified accelerating mode frequency and voltage profile via the iterated procedure described in [3]. The closed-loop control-command tuning algorithm is iterated as many times as necessary to this purpose. Voltage errors smaller than 1% and 10 kHz frequency error are reached after 5 tuning iterations (see Table 3, Fig. 3 and Fig. 4) . Note that detuning due to air index of refraction (about 100 kHz) is anticipated here, upon setting tuning frequency at 352.1 MHz.

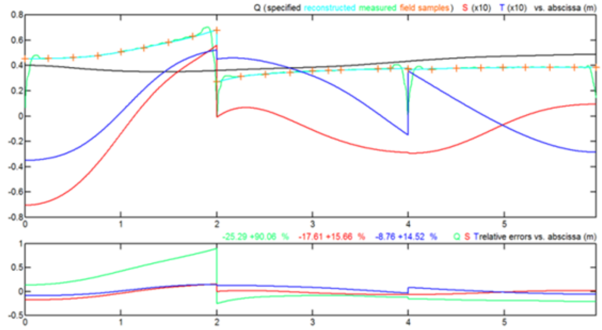

Figure 3: Voltage and voltage error at tuning step 0.

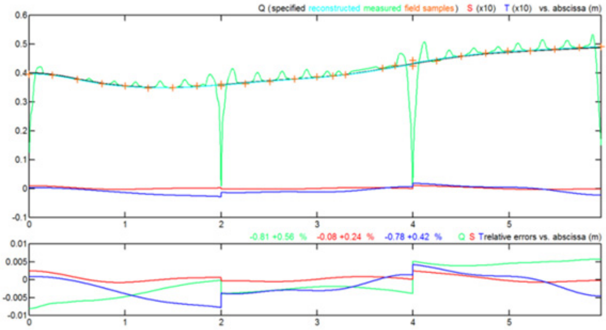

Figure 4: Voltage and voltage error at tuning step 5.

RF COUPLING TUNING

RF power is fed to the RFQ by 4 iris couplers located in the fourth module of the RFQ. The feeder line consists of a half-height W2300 waveguide, followed by a ridged quarter wavelength transformer ("ridge 2") and a ridged waveguide with smaller aperture ("ridge 1") (Fig. 5).

Figure 5: Dummy RF coupling.

The iris itself is a slit terminated by two circular openings (Fig. 6). Diameter d_c of these openings and position h_c of iris plate inside RFQ must be adjusted at each RF port to achieve both critical coupling of beam-loaded cavity and minimum voltage profile perturbation. Required cavity coupling coefficient β (without beam) is easily determined for given beam power P_B and internally dissipated power P_{Cu}. P_B is 300 kW and P_{Cu} has been estimated to 1166 kW (for nominal inter-vane voltage), leading to theoretical $\beta = 0.314$ (at each RF port).

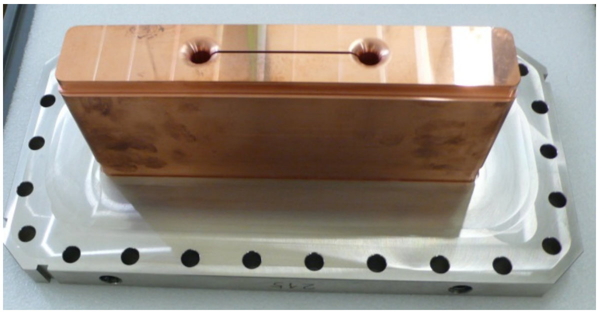

Figure 6: Ridge 1 with iris.

SLUGS FINAL TUNING

Once iris couplers have been inserted, the position of the 96 slugs is re-adjusted. Tuner positions are in the interval [-1.67, 12.5] mm, within specified range. Voltage errors smaller than 1% and frequency error smaller than 5 kHz are reached after 7 tuning iterations (Fig. 7).

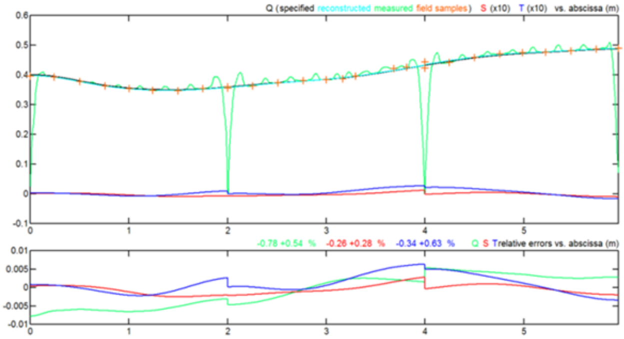

Figure 7: Voltage and voltage error at final tuning step.

TUNING CHECK WITH COPPER SLUGS

Positions of adjustable tuners have been accurately measured. Steel shims have been machined accordingly; fixed-length copper slugs are inserted in RFQ and positioned using the shims. Beadpull measurements have been realized after vacuum test to check the final voltage profile (Fig. 8). Larger variations for the voltage profile are found close to coupling-plate #1, again suggesting that voltage errors likely result from a modification of this coupling-circuit, not from a variation of tuner properties.

RF COUPLING CHECK

Every RF ports are measured with all definitive RFQ parts and with RFQ under vacuum. The RFQ is connected to four feeder lines, with vacuum windows, half-height to full-height waveguide transitions and is fitted with a waveguide-to-coaxial transition (Fig. 9). Partial coupling coefficients for each RF port are $\beta_1 = 0.2679$ $\beta_2 = 0.2795$ $\beta_3 = 0.3123$ $\beta_4 = 0.2782$ compared to theoretical value of 0.314. This fact may result from geometrical differences between aluminium iris used for tuning and final copper couplers. This small discrepancy will lead to some additional reflected power.

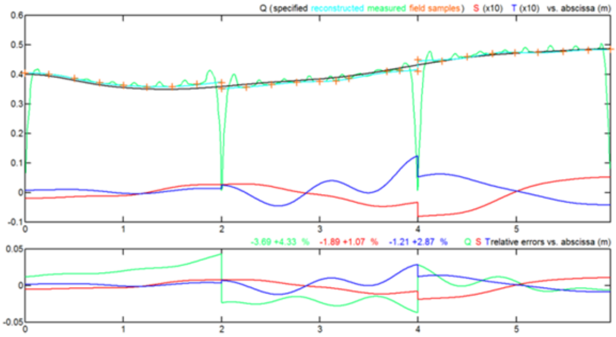

Figure 8: Final voltage profile.

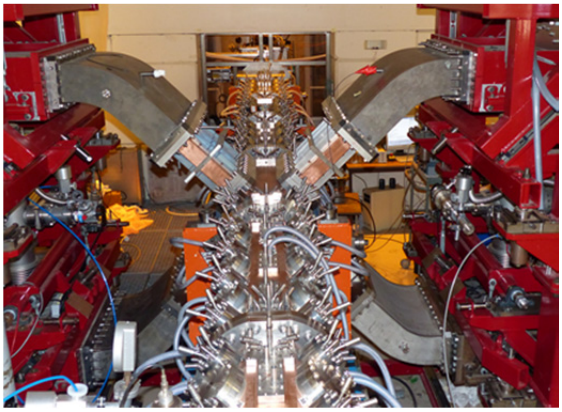

Figure 9: Completed assembled RFQ.

CONCLUSION

Main difficulties consisted in replacing tunable parts by electromagnetically equivalent final copper pieces. Small mechanical differences between these parts led to voltage errors outside the 1% requirement, additional dissipated power and difficulties to obtain optimal coupling. Voltage profiles will be measured during the RFQ operation thanks to 96 pick-ups inserted in copper tuners. RF conditioning will start within next weeks.

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