HIGH ENERGY RF DEFLECTORS FOR THE FERMI@ELETTRA PROJECT

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Abstract

Measuring and controlling the longitudinal phase space and the time-slice emittance of the electron bunch entering at 1.2 GeV in the undulator beam-lines, are crucial to obtain high FEL performances. In the FERMI@Elettra machine, two RF deflecting cavities have been installed at the end of the linac, in order to stretch the electron bunch horizontally and vertically, respectively. The two cavities are individually powered by the same klystron and a switch system is used to choose the deflection plane. This paper reports the RF measurements carried out during the acceptance test and the RF conditioning including the breakdown rate measurements.

INTRODUCTION

FERMI is a Free Electron Laser facility located at Elettra - Sincrotrone Trieste, and based on the High Gain Harmonic Generation scheme. It has been presently operating to produce high-quality photon pulses in the EUV and soft-X-ray region [1] [2]. It is composed by a RF photo injector, a S-band linear accelerator and by two FEL beam lines, FEL 1 and FEL 2. The geometric wakefields in the accelerating structures upstream of the RF deflector induce a beam break-up (BBU) instability in both transverse planes [3], as a result, the bunch tail could be laterally displaced with respect to the head in the plane of action of the wake field and the bunch assumes a typical "banana-shape" [4]. If the bunch distortion is in the horizontal plane, then the vertical deflection will show it in the x-y plane of the screen. In such a way the BBU instability in the main Linac can be checked and compensated locally by means of trajectory management. In order to manage wakefield effects on the both transverse planes then the electron bunch is independently stretched on the vertical and horizontal planes, respectively. Furthermore, these diagnostic tools are essential in order to completely characterize and optimize the electron beam in term of slice energy spread and emittance. This paper shows the characteristics and the specifications of the two high energy RF deflectors (HERFD) designed for FERMI@Elettra. Subsequently the RF measurements and the high power tests are reported.

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THE RF DEFLECTORS

The RF deflectors are traveling wave disk loaded structures in which an electromagnetic field provides a constant transversal force to the electron bunch in order to measure its time-slice parameters [5] [6]. The RF deflectors design is constrained by a number of factors, including the frequency of the available microwave sources (European S-band, 2.998 GHz), the available space in the high-energy region of the linear accelerator, the available RF power of 15 MW at the input of the structures. The required deflecting voltage to obtain the desired time-slice resolution of 10 fs rms is 20 MV [7]. We therefore have chosen a compact, low-impedance deflector with a high deflecting voltage. We compared the performance of several options to satisfy our RF and space constraints [8] and finally two constant impedance backward RF deflectors, working with the HEM11-2π/3 mode, have been designed and installed at the end of the linear accelerator (Fig. 1). The proposed solution meets the requirement on the deflecting voltage, according to:

$$V_t[MV] \approx 2.4[MV/m/\sqrt{MW}]l[m]\sqrt{P_{in}[MW]} \quad (1)$$

where l is the deflection length of $2.466m$ and P_{in} the peak input power.

The dipole deflecting mode has two degenerating polarizations and in order to avoid the excitation of the mode with polarity rotated at $90°$, two longitudinal rods of diameter $3mm$ crossing the cells off-axis at $50mm$ have been inserted. Basically the working frequency of the deflecting mode with polarity at $0°$ is essentially unperturbed while the frequency shift of the $90°$ polarization is about $120MHz$ [9].

RF COLD TEST RESULTS

This section reports on the results of the RF measurements performed at room temperature before and after brazing of the both deflecting structures that have been carried out at PMB-Alcen manufacturing company [10]. After tuning each cell in the traveling-wave mode and matching the couplers to the whole structures the $2\pi/3$ mode working frequency of the structures was estimated by phase measurements along the cells axis as a function of frequency, performed by using a rod acting as a short circuit [11] [12] . Such as movable metal rod allows to mea-

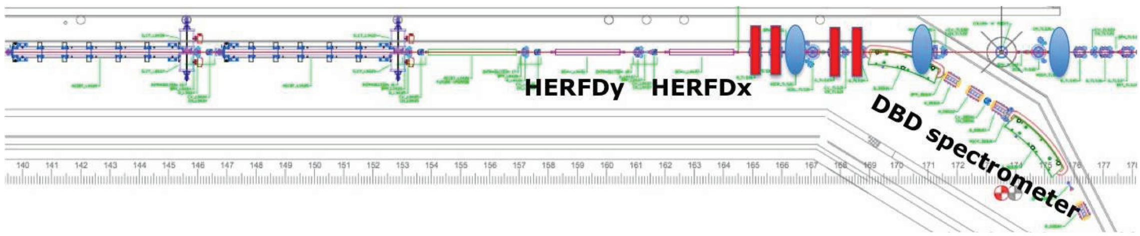

Figure 1: Layout of the end of linac, with the two RF deflectors, HERFDy and HERFDx.

Table 1: RF measurements for the vertical (V.) and horizontal (H.) deflector at room temperature. Working temperatures for the vertical and horizontal deflectors are $39.5°C$ and $31.2°C$, respectively.

	Specifications	**V. Measured values**		**H. Measured values**	
		Before brazing	After brazing	Before brazing	After brazing
Frequency [MHz]	2998.01	2997.94	2998.09	2997.56	2997.63
SWR	1.0 ÷ 1.1	1.005	1.02	1.007	1.016
Attenuation [Np/m]	0.137	0.208	0.145	0.173	0.158
Filling time [ns]	500	525	521	524	525
Quality factor	13200	9600	13500	11400	12700
$\Delta\varphi$ [°]	120 $\pm$ 1.5	120.22 $\pm$ 0.46	119.85 $\pm$ 0.69	119.93 $\pm$ 0.26	119.82 $\pm$ 0.70

sure the phase advance by shorting each individual cell, step by step. The frequency for which the phase dispersion was less than $\pm 1.5°$ over the full length of the structure was considered as the working frequency. Results of the phase advance measurements are showed in Fig. 2. Table 1 lists the RF parameters of the vertical and horizontal deflectors, respectively, measured before and after brazing, at the environmental temperature of $20.2°C$. The quality factor increases after the brazing process, due to the soldering material that improved the electric contact between the cells. It is worthwhile to note that working temperatures for the vertical and horizontal deflectors are $39.5°C$ and $31.2°C$, respectively.

HIGH POWER RF TEST

Both deflectors were tested at full available RF power in the FERMI linac using the RF distribution system shown in Fig. 3. In order to share the same klystron for both deflectors an RF switch is used to just feed one deflector at full RF power at each time. A second RF switch for each deflector is foreseen in order to completely attenuate deflecting fields in the structures when the second arm of the TH2132A klystron will be even used to feed another accelerating structures foreseen at the linac-end. For both deflectors the RF conditioning process has been performed with a pulse repetition rate of 10 Hz, by gradually increasing the RF power and pulse width. This operation started with an RF power lower than $1MW$ and with an RF pulse width of $100ns$. When the power rises up for the first time then waveguides and RF structures, due to the RF heating, release some impurities that cause some spikes in the vacuum levels. However, the vacuum system was able to remove the impurities so that the vacuum levels were always under $1e-6$ mbar. It is worthwhile to note that for the horizontal

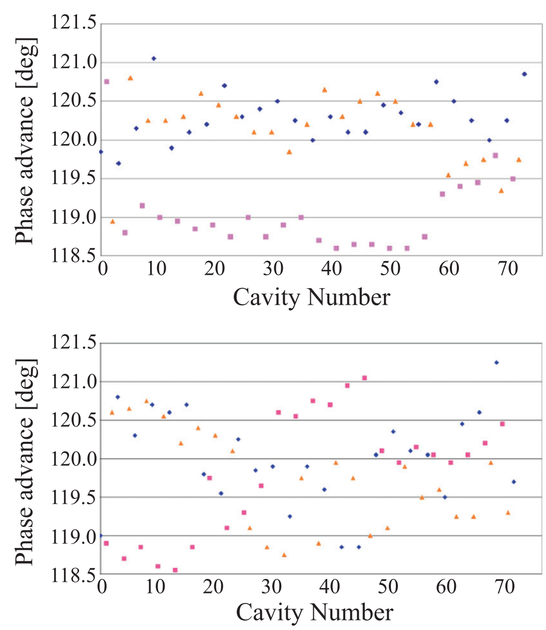

Figure 2: Results of the phase advance measurements using a movable metallic rod for the horizontal (up) and vertical (bottom) deflectors, obtaining $\Delta\varphi$ = 119.82 $\pm$ 0.70 deg (RMS) and $\Delta\varphi$ = 119.85 $\pm$ 0.69 deg (RMS), respectively.

deflector we reached the RF power of $12MW$ with the RF pulse width of $700ns$ in the first eight hours of operation. Both deflectors were considered as fully conditioned when it was possible to feed them with a RF power of $15MW$ at $2500ns$ and with the levels of the vacuum pressure below the threshold of $3e-8$ mbar. This result was reached for both deflectors after approximately 24 hours of operation. Looking at the reflected power from the deflector input was

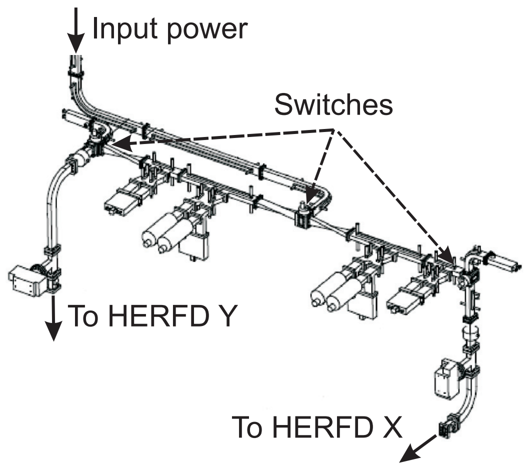

Figure 3: Waveguide switch system, used to choose the deflection plane.

possible to count the number of arcs due to extraction of electrons from the metallic surface and consequently estimate the breakdown rate (BDR). After 40 hours of conditioning we estimated BDR as a function of the pulse width at $15MW$ for the horizontal deflector. Results are shown Fig. 4. Since filling times of the both deflectors are approximately $500ns$ then the RF pulse width was fixed at $900ns$. Such as value ensures a suitable filling of the structures and furthermore the BDR is kept below $2e-5$.

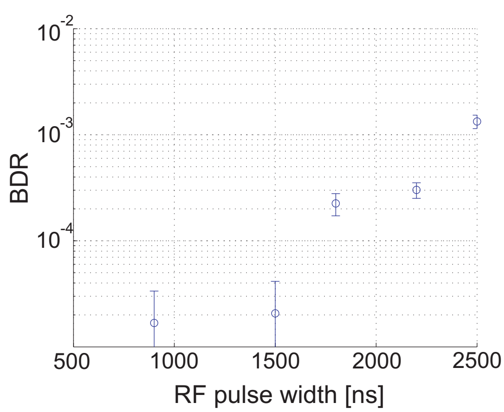

Figure 4: BDR as a function of the pulse width at $15MW$ for the horizontal deflector.

CONCLUSIONS

This paper presents the two HERFDs realized for the FERMI@Elettra project, showing the RF measurements carried out during the acceptance test and the high power test. We reached the final value of RF power of 15 MW and the pulse length of $2500ns$ in the first 24 hours of the RF conditioning operation. The breakdown rate measurements have been reported, and a suitable RF pulse length has been chosen in order to avoid perturbing the measurements with electron beam. These deflectors have been intensively used for time-slice emittance and longitudinal phase-space measurements during the beam commissioning [13].

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REFERENCES

[1] E. Allaria et al., "Highly coherent and stable pulses from the FERMI seeded free-electron laser in the extreme ultraviolet", Nature Photonics, pp. 699-704, 2012.

[2] C. J. Bocchetta et al., "FERMI@Elettra Conceptual Design Report", Sincrotrone Trieste, Italy, Tech. Rep. ST/F-TN-07/12, 2007.

[3] P. Craievich, T.Weiland and I. Zagorodnov, "The short-range wakefields in the BTW accelerating structure of the ELETTRA LINAC", NIM A, Volume 558, March 2006, Pages 58-61.

[4] P. Craievich and S. Di Mitri, "Beam Break-up Instability in the FERMI@ELETTRA Linac", EPAC, UK, June 26-30, 2006.

[5] G. A. Loew, "Design and application of RF separator structures at SLAC", PUB 135, Standford linear accelerator center, Standford University, California, August 1965.

[6] P. Emma et al., "A transverse RF deflecting structure for bunch length and phase diagnostic", Technical note TN-00-12, Standford linear accelerator center, California, August 2000.

[7] P. Craievich et. al., "A transverse RF deflecting cavity for the FERMI@ELettra project", Proceedings of DIPAC 2007, Venice, Italy, May 20-23, 2007.

[8] P. Craievich, M. Petronio, R. Vescovo, "Deflecting Mode Optimization for a High Energy Beam Diagnostic Tool", PAC09, Vancouver, Canada, May 48, 2009.

[9] M. Petronio, "Research and Applications of Radio-Frequency Deflecting Cavities", PhD Thesis, University of Trieste, 2010.

[10] PMB - Alcen, Peynier, France, `http://www.pmb-alcen.com`.

[11] E. Westbrook, "Microwave Impedance Matching of Feed Waveguide to the Disk-loaded Accelerator Structure Operating in the 2pi/3 Mode" SLAC Technical Note 63-103, SLAC, Stanford, California, Dec 1963.

[12] M. Chanudet, "Matching of the coupler cavity to travelling wave structures at any operating mode" LAL/RT 93-06, Jun 1993.

[13] G. Penco et. al., "Time-Sliced Emittance and Energy Spread Measurements at FERMI@Elettra", Proceedings of FEL 2012, Nara, Japan, August 26-31, 2012.