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START OF OPERATION OF A STANDING WAVE DEFLECTING CAVITY WITH MINIMIZED LEVEL OF ABERRATIONS

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Abstract

A family of deflecting structures with improved RF efficiency and minimized level of aberrations in the deflecting field distribution was presented at RuPAC 2016 [1]. The first cavity proposed in that paper has been designed for the diagnostics of the longitudinal distribution of the unique bunches generated at the REGAE facility. A short deflecting cavity was constructed, tuned and is now installed in the REGAE beam line. The cavity has been tested at the operational level of RF power. We describe main distinctive features of the cavity and report first results on beam operation.

INTRODUCTION

Periodical Deflecting Structures (DS's) were introduced for the deflection and separation of charged particle in the 1950s and 1960s. Here the bunch crosses the DS synchronously with the deflecting field Ed on the phase $\phi = 0°$, so that all particles gain a similar increment in the transverse momentum p_t.

Today DS's find new applications for the purpose of diagnostics of the longitudinal distribution, emittance exchange and luminosity improvements in colliders by introducing a correlated transverse momentum, i.e. a streak. For these applications the DS operates in another mode - the central particle of the bunch crosses the DS at the phase $\phi = 90°$, so that the transverse field E_d is zero for the bunch center, but downstream and upstream particles achieve opposite increments in p_t. In these applications a DS should produce a minimal distortion of the original distribution of the particles in the 6D phase space.

PHYSICAL BASE

Transverse emittance growth during the passage of a DS is related to coupling and to aberrations, i.e. nonlinear additives in the distribution of the deflecting field E_d, which appear due to a non-relativistic energy of the particles, additions from higher multipole modes, and higher spatial harmonics in the distribution of the dipole field E_d. The analysis of the deflecting field distribution was performed in [2,3]. The main attention should be drawn to the higher spatial harmonics in the E_d distribution. To estimate the level of higher spatial harmonics and as a criterion for the optimization of the DS shape the parameters $\delta\psi_j(z)$ and Ψ_j on the DS axis have been introduced:

$$\delta\psi_d(z) = \psi_d(z) + \frac{\Theta_0 z}{d}, \quad \Psi_d = max(|\delta\psi_d(z)|). \quad (1)$$

The physical sense of the parameters is the deviation and the maximal deviation of the phase of the equivalent traveling wave E_d distribution from the synchronous harmonics. Here Θ_0 is the operating phase advance, d is the DS period length and $\psi_d(z)$ is the phase distribution for the equivalent traveling wave E_d.

By minimizing Ψ_d we keep the bunch close to the DS axis, where the nonlinear field of the higher spatial harmonics is minimal. Simultaneously the level of higher spatial harmonics in E_d will be reduced.

For conventional iris loaded DS's [4] the minimization of Ψ_d represents an additional limitation and can be achieved only at the expense of a reduction in the effective shunt impedance Z_e. To combine a high RF efficiency and a high field quality a decoupled DS was proposed [5]. Later on the decoupled DS was investigated and optimized more thoroughly, showing very high rates in RF efficiency together with high field quality [1].

CAVITY DESIGN PARAMETERS

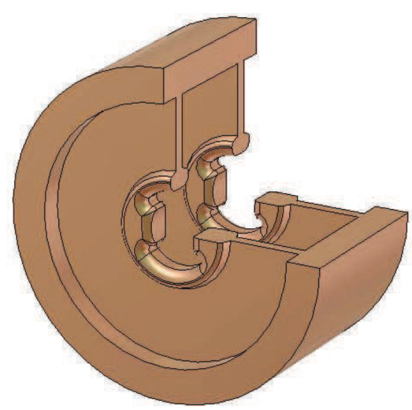

Figure 1: Geometry of the a decoupled structure which was selected for the deflecting cavity in the REGAE facility.

For implementation of a deflecting cavity for diagnostics of the longitudinal particle distribution at REGAE (Relativistic Electron Gun for Atomic Exploration) [6], a decoupled DS's option was selected as a compromise of RF parameters, low beam energy and other extreme beam parameters, and appreciation of construction effort and available space. The geometry of the selected decoupled DS is shown in Fig. 1. Operating in the standing wave mode, the short

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cavity has three regular cells and two half cells at the ends. The procedure for the optimization of the end half cells is described, for example, in [5]. Fig. 2 shows the distributions of the effective deflecting fields along the cavity axis for $\phi = 0°$ (blue curve) and $\phi = 90°$ (red curve). The main

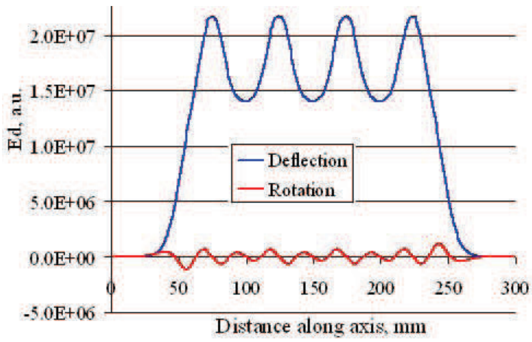

Figure 2: Effective E_d distributions along the cavity axis for $\phi = 0°$ (blue curve) and $\phi = 90°$ (red curve).

design parameters of the cavity are listed in Table 1.

The rms radius of the REGAE beam at the position of the

Table 1: Cavity Design Parameters

Parameter	Unit	Value
Operating frequency	MHz	2997.925
Energy of electrons	MeV	5
Operating phase advance	radian	π
Active cavity length	mm	≈ 210
Total cavity length	mm	270
Calculated quality factor		12550
Maximal phase deviation	radian	0.033
Separation of nearest mode	MHz	13.68
Effective shunt impedance, DS	$\frac{M\Omega}{m}$	43.2
Effective shunt impedance, cavity	MΩ	7.58
Input RF power	kW	5
Expected deflecting voltage	kV	190

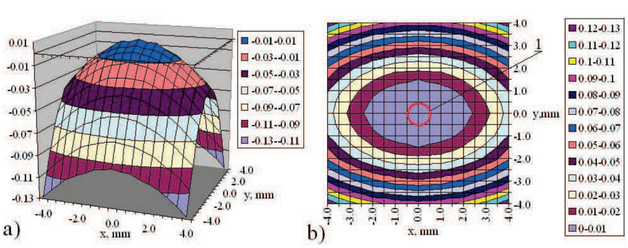

Figure 3: The surface of normalized deflecting voltage $\frac{V_{d,\ 90°}(x,y)}{V_{d,\ 0°}(0,0)} \cdot 100\%$ (a) and corresponding contour map near the cavity axis (b), 1 - rms beam size of REGAE.

deflecting cavity is expected to be $\approx$ 0.5 mm. Figure 3a depicts the surface distribution of the effective deflecting voltage at $\phi = 90°$ $V_{d,\ 90°}(x,y)$ normalized to the maximal deflecting voltage $V_{d,\ 0°}(0,0)$, $\frac{V_{d,\ 90°}(x,y)}{V_{d,\ 0°}(0,0)} \cdot 100\%$ in the region of $0 \le |x,y| \le 4$ mm near the cavity axis. From the corresponding contour maps in Fig. 3b one can estimate $V_{d,\ 90°}$ deviations as $\le \pm 0.01\%$ for the region $0 \le |x,y| \le 1.5$ mm and $\le \pm 0.03\%$ for the region $0 \le |x,y| \le 2$ mm. The total beam is expected to be in a very linear deflecting field.

CONSTRUCTION AND RF TUNING

Figure 4: Parts of the cavity after machining.

The technical design of the cavity was worked out and the cavity parts were manufactured with high precision and high quality of the surface at CANDLE SRI, Fig. 4. After high temperature brazing with silver alloys at DESY the cavity was tuned to a frequency of 2997.91 MHz assuming vacuum conditions and an operating temperature of 35 C°, [7]. Bead pull measurements showed the following values of the transverse electric field component E_x in the middle points of the irises: 100/100.08/100.04/99.86. It indicates a very narrow spread in the cell frequencies and confirms the high precision of cell dimensions.

CAVITY AT THE REGAE BEAM LINE

After vacuum test the inner cavity surface was cleaned according to the cleaning procedure [8] and mounted at the

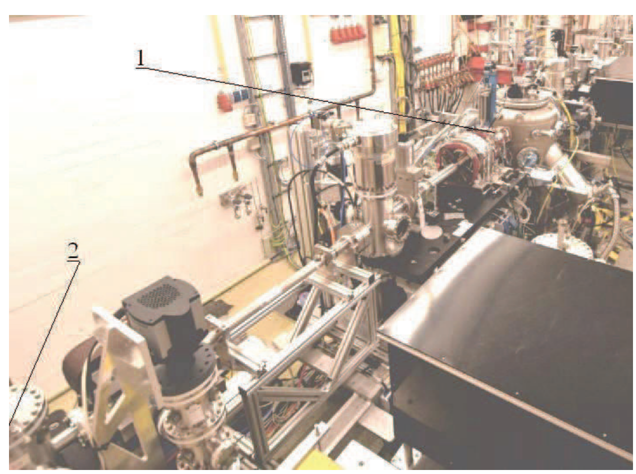

Figure 5: The REGAE beam line. 1 - the cavity, 2 - to the screen.

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REGAE beam line, Fig. 5, right behind the target chamber. The operating frequency is controlled by the temperature of the water in the channels, adhered to the cavity body by a heat conducting paste. RF power is supplied by a solid-state

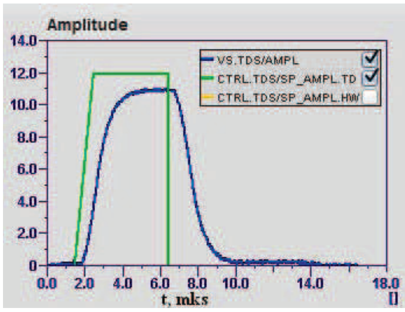

Figure 6: Envelopes of RF signals from the amplifier (green curve) and from the RF probe in the cavity (blue curve).

amplifier with a nominal RF power of 5 kW. The input RF coupler is a loop, due to small dimensions produced by 3D printing and coated with a thin film of gold. By means of rotation the driving RF loop was matched to a reflection coefficient of $S_{11} = -31.6$ dB. The loaded quality factor of Q_l, estimated from the S_{11} measurements as $Q_l = 4570$, corresponds to an unloaded quality factor $Q_0 \approx 9150$. The

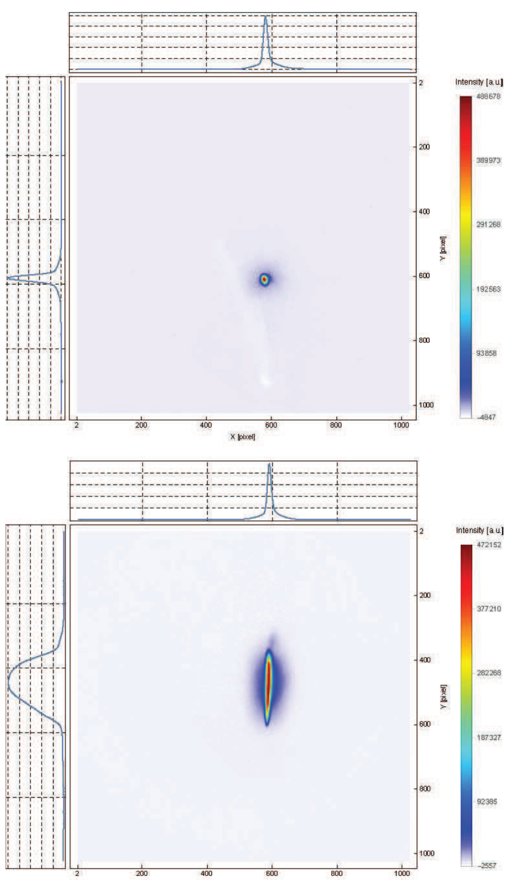

Figure 7: The REGAE beam images at the screen without (top) and with (bottom) streaking of the bunch.

transmission coefficient from the driving to the signal loop was adjusted to $S_{12} = -37.1$ dB, ensuring sufficient power for RF diagnostics. RF power up to 5.5 kW was reached in the cavity without any problem, Fig. 6. The cavity operates with a very moderate deflecting field of $E_d \approx 0.9\frac{MV}{m}$ and, correspondingly, rather low RF power. There were no indications or proofs for multipacting discharge during operation with the nominal RF power.

In Fig. 7 beam images at the screen without (top) and with (bottom) operating deflecting cavity are presented, visually showing the streaking effect of the bunch by a deflecting cavity.

SUMMARY

For the first time a deflecting cavity specially optimized for minimal transverse emittance perturbations during streaking of a bunch was designed, built, RF tested and is now in operation at REGAE. As compared to conventional deflecting structures, such a cavity provides physical benefits as a combination of a high shunt impedance and linear fields. The high shunt impedance allows powering the cavity with an amplifier, rather than with an expensive klystron. The cavity was successfully tested at the nominal RF power and first beam tests clearly show the streaking effect of the bunch by the deflecting cavity. The cavity is now in routine operation for diagnostics and will help to further optimize the parameters of electron bunches at REGAE.

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