X-BAND TRAVELING WAVE RF DEFLECTOR STRUCTURES *

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Abstract

Design studies on the X-Band transverse RF deflectors operating at HEM_{11} mode have been made for two different applications. One is for beam measurement of time-sliced emittance and slice energy spread for the upgraded LCLS project, its optimization in RF efficiency and system design are carefully considered. Another is to design an ultra-fast RF kicker in order to pick up single bunches from the bunch-train of the B-factory storage ring. The challenges are to obtain very short structure filling time with high RF group velocity and good RF efficiency with reasonable transverse shunt impedance. Its RF system will be discussed.

INTRODUCTION

The RF deflectors were developed from 1960's for high energy particles separation using the interaction with a transversely deflecting mode. As a measure of the deflecting efficiency, the transverse shunt impedance $r_\perp$ is defined as:

$$r_\perp = \frac{\left(\frac{c}{\omega}\frac{\partial E_z}{\partial r}\right)^2}{\partial P / \partial z} \quad , \qquad (1)$$

where z and r is structure longitudinal and transverse axis respectively, E_z is the electrical field amplitude for the dipole mode with angular frequency ω and P is the RF power as function of z. Using the simulation codes for electromagnetic field in RF structures, the transverse shunt impedance can be calculated from:

$$r_\perp = \frac{QV_\perp{}^2}{\omega UL} = \frac{c^2 QV_z{}^2}{\omega^3 r_0^2 UL} \quad , \qquad (2)$$

where Q is quality factor, $V_\perp$ and V_z are integrated potential change in r and z direction for a particle traversing through structure along a trajectory with $r=r_0$ and length of L, U is stored energy within the structure with the length of L.

Traveling wave X-Band deflector structures have many advantages: their RF systems are simpler without the requirement of circulators for standing wave structures and their shunt impedances (proportional to the square root of frequency) are higher than structures working at lower frequencies. In addition, SLAC is well advanced in the art of high power X-Band RF source [1] including klystrons and pulse compression systems. In recent years, many new applications of RF deflectors have been developed. Here we will mainly discussion the deflector applications for measurement of bunch length as well as longitudinal phase space and super fast RF kicker for future light sources, which could not be realized by conventional charged particle deflecting devices.

DEFLECTOR FOR BEAM MEASUREMENT

If a charged particle beam is at the zero-crossing phase of the deflecting mode, the bunch is given a strong correlation between longitudinal coordinate and transverse position due to RF kick.

Recently at SLAC, a 2.4 m long S-Band deflector built in 1960's was used in LCLS beam line for commissioning. [2] The bunch length in the order of 100 fs was successfully measured and the tuning of the bunch compressor was performed based on the bunch measurement data.

In the future, in order to characterize the extremely short bunch of the LCLS project, we need to extend the time-resolved electron bunch diagnostics to the scale of 10-20 fs. We have to consider a new RF deflector with much powerful deflecting capability. The peak deflecting voltage necessary to produce a temporal bunch resolution of Δt is: [3],[4]

$$eV_\perp \approx n\frac{\lambda}{2\pi c\Delta t}\sqrt{\frac{\varepsilon_N Emc^2}{\beta_d}} \, , \qquad (3)$$

where E is the electron energy and the transverse momentum of the electron at time Δt (with respect to the zero-crossing phase of the RF) is $p_y = eV_\perp/c$, n is the kick amplitude in the unit of nominal rms beam size, λ is the RF wavelength, ε_N is the normalized rms vertical emittance, c is the speed of light, and β_d is the vertical beta function at the deflector. This is for an RF deflector, which is $\pi/2$ in betatron phase advance from a downstream screen.

As a practical estimation, in order to create an offset of roughly double rms beam size with 10 fs temporal separation, for the LCLS beam parameters with full beam energy of 13.6 GeV and vertical normalized rms emittance of 1 μm, the necessary peak vertically deflecting voltage for a X-band (11424 MHz) deflector is 33 MV.

For the accelerator structure design, we have to consider to use the available peak power from an X-Band klystron and to obtain higher RF efficiency and reliability at acceptable maximum electric field for RF breakdown and maximum magnetic field for RF pulse heating. Making effort in optimization, the designed deflector is a single section 2π/3 mode backward wave structure with length of 1.5 m. Its main parameters are listed in the Table 1.

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Table 1: RF Specification of a Deflector for the LCLS Beam Measurement

Structure type	TW DLWG
Mode	2π/3 Backward wave
Aperture 2a	10.00 mm
Cavity diameter 2b	29.74m
Cell length d	8.7475 mm
Disk thickness	1.45 mm
Quality factor Q	6400
Kick factor k	$2.986\text{x}10^{16}$ V/C/m/m
Transverse shunt impedance r⊥	43.17 MΩ/m
Group velocity Vg/c	- 3.165 %
Total length L	1.5 m
Filling time T_f	158 ns
Attenuation factor τ	0.885
Input peak RF power	30 MW
Maximum electric field	129 MV/m
Maximum magnetic field	0.45 MA/m
Deflecting voltage	38.9 MV

DEFLECTOR USED AS A SUPER FAST RF KICKER

It has been proposed to convert the SLAC B-factory to be a very strong FEL light source.[5] In order to pick up single bunches from the bunch-trains, we need to have an ultra-fast RF kicker. There are 1746 bunches circulating in an orbit with 2200 meters circumference in the B-factory. The bunch spacing is two RF periods with 1.26 m in space or 4.2 ns in time. Therefore, the most challenging design issues are to obtain less than 6 ns RF filling time and more than 5 MV vertical deflecting voltage.

For higher RF efficiency, most deflectors of the disc-loaded waveguide structures were designed in the "backward wave" region of dispersion curves as shown by a dashed line circle in Figure 1,[6] where the group velocity is negative and the RF energy propagates in the opposite direction with particle beam. In order to obtain fast group velocities for fast kicker under discussion, it is necessary to design the deflector structures in the region shown by a solid line circle in Figure 1, where the group velocity is positive with value of more than 30% of the speed of light, the RF energy propagates in the same direction with particle beam. For a disc-loaded waveguide structures with aperture radius a, cell radius b, every dispersion curve in Figure 1 was calculated for certain ratio of a/b. The region with higher group velocities corresponds to the structures with larger iris apertures, they have lower shunt impedances and high RF power requirements. In order to optimize the RF design, the group velocities and transverse shunt impedances were calculated as the function of the ratio a/b, which were shown in Figure 2.

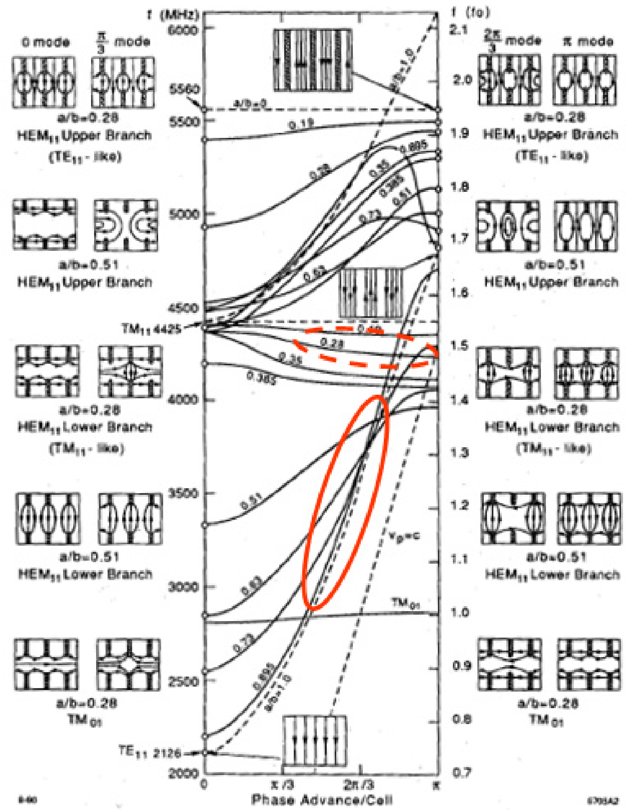

Figure 1: Dispersion diagram and E-field configurations of TM01 and HEM11 modes for some X-Band structures with various ratio of aperture radius with cell radius a/b.

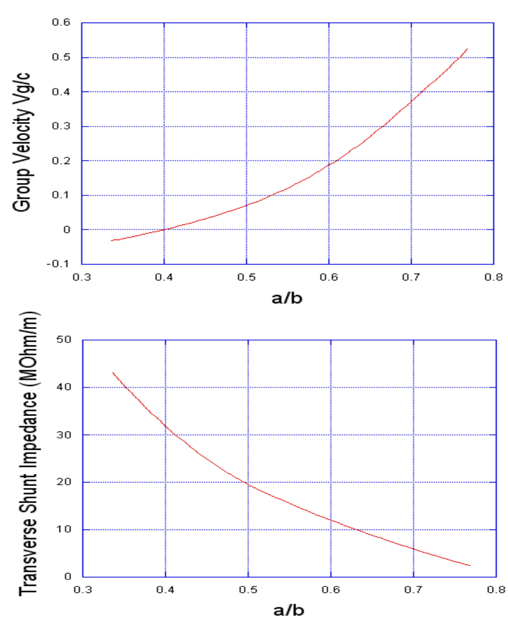

Figure 2. Group velocity (top) and transverse shunt impedance (bottom) as the function of the ratio of cell aperture radius with cell radius (a/b).

Table 2 lists all most important parameters for a 0.75 m ultra-fast X-Band 11424 MHz RF kicker with filling time 4.8 ns and the deflecting voltage is 5MV at 400 MW input power.

Table 2: RF Specification of a Deflector as a Fast Kicker for the PEP-X

Structure type	TW DLWG
Mode	2π/3 Forward wave
Aperture 2a	27.0 mm
Cavity diameter 2b	35.33 mm
Cell length d	8.7475 mm
Disk thickness	1.45 mm
Quality factor Q	9763
Kick factor k	1.052×10^{16} V/C/m/m
Transverse shunt impedance $r_\perp$	2.39 MΩ/m
Group velocity Vg/c	52.4 %
Total length L	0.75 m
Filling time T_f	4.77 ns
Attenuation factor τ	0.0176
Input peak RF power	400 MW
Maximum electric field	121 MV/m
Maximum magnetic field	0.19 MA/m
Deflecting voltage	5 MV

Figure 3 shows a schematic diagram for the SLED-II system and Figure 4 shows the waveforms of the input and output power in high power system tests. This system will provide a reliable RF source to power the fast kicker under designing.

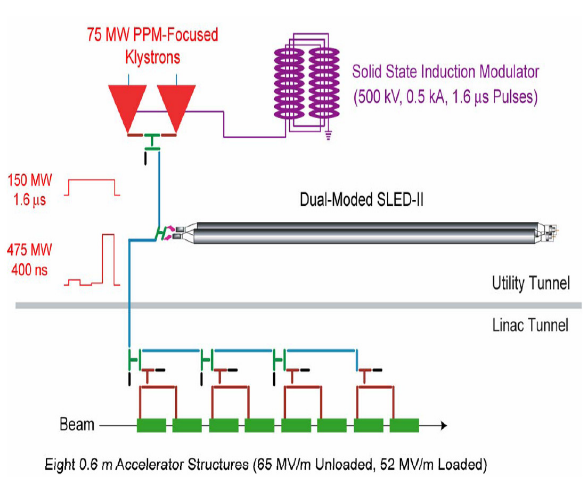

Figure 3: Schematic diagram of the SLED-II System.

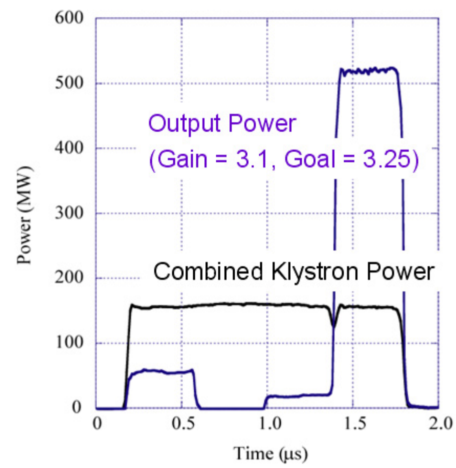

Figure 4: Waveforms of the input and output power for a SLED-II system.

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