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TRANSVERSE RF DEFLECTING STRUCTURES FOR THE MAX IV LINAC

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Abstract

The MAX IV LINAC operates both as a full-energy injector for two electron storage rings, and as a driver for a Short Pulse Facility (SPF). Recently a conceptual design report for a Soft X-ray Laser (SXL) beamline at the end of the existing LINAC was started. For SPF and SXL operation, it is important to characterize beam parameters such as bunch profile, slice energy spread and slice emittance. For these measurements, two 3 m long transverse deflecting RF structures with a matching section are being developed. The structures are operating at S-band and have variable polarizations. When fed via a SLED pulse compressor, the two structures can generate a total integrated deflecting voltage higher than 100 MV which is sufficient for measurements with temporal resolutions down to 1 fs. This paper describes the initial RF design of the deflecting structures.

INTRODUCTION

When the MAX IV LINAC [1] will be upgraded to a driver for a SXL [2], it becomes increasingly important to measure beam parameters such as bunch profile, slice energy spread and slice emittance. A transverse deflecting system is being designed, and the plan is to install it in a branch line at the end of the LINAC. The deflecting system must be able to characterize bunches as short as 10 fs and with energies up to 3 GeV. In order to measure both the horizontal and vertical slice emittance, it should be possible to change the streaking plane. Similar travelling-wave deflecting structures with variable polarizations are already being developed at CERN/DESY/PSI [3]. The design of the optical matching section is also ongoing, and it is estimated that a total deflecting voltage of $V_\perp = 100$ MV from the RF structures is required for a temporal resolution of 1 fs at 3 GeV.

INITIAL DESIGN REQUIREMENTS

The RF design requirements for the deflecting system are listed below.

- **I S-band structures** - It will be considerable cheaper to use S-band technology since we can use standard MAX IV S-band components that are used in the main LINAC. Many of the RF components for the deflecting system can therefore be used as hot-spare parts for the rest of the LINAC since the system is not critical for regular MAX IV operation. C and X-band structures can provide higher deflecting gradients, but it is only possible to construct a deflecting system with the required performance at the given budget at MAX IV when selecting S-band technology.
- **II Standard MAX IV 37 MW RF station and SLED unit** - A standard MAX IV RF station based on a Scandinova K2 modulator and a Toshiba klystron will be used. The maximum pulsed RF power is 37 MW, and a standard MAX IV SLED pulse compression unit can boost the peak power further.
- **III Variable polarization** - It should be possible to switch the streaking plane in the structures between horizontal and vertical.
- **IV Two 3 m long structures** - The maximum total length of the structures is 6 m. By using two structures, each with a length of 3 m, the input power to each coupler cell is reduced.
- **V Constant-impedance structures** - This would simplify the manufacturing compared to constant-gradient structures since all the regular cells are identical.
- **VI $V_\perp \approx$ 100 MV** - A total integrated voltage of approximately $V_\perp = 100$ MV is required to obtain the desired temporal resolution in the measurements.

RF DESIGN

RF Set-up

The two deflecting structures are fed by a single klystron via a SLED system, as seen in Fig. 1. The maximum pulsed rms power from the klystron is 37 MW. The LLRF system should not only be able to create pulses with a $0-180°$ phase shift for the SLED system, but also phase modulate the RF pulse in many smaller steps which reduces the risk of arching at higher power levels [4] [5]. As explained below, each structure is fed via two waveguides, and the polarization is altered by adjusting the phases in these waveguides. The waveguide phase shifters have not yet been designed, but a design similar to those presented in [6] is considered. Directional couplers and vacuum pumps are places at suitable locations along the waveguides.

Deflecting Voltage

If one would feed the structure via a SLED system, the fields (electric or magnetic), $E_L(t)$, delivered to the coupler cell in the time interval $t_1 < t < t_2$ is given by (1), where E_0 is the field without a SLED system. t_1 is the time when the $0° - 180°$ phase shift occurs, and t_2 is when the RF pulse ends. The power delivered to the coupler cell is given by

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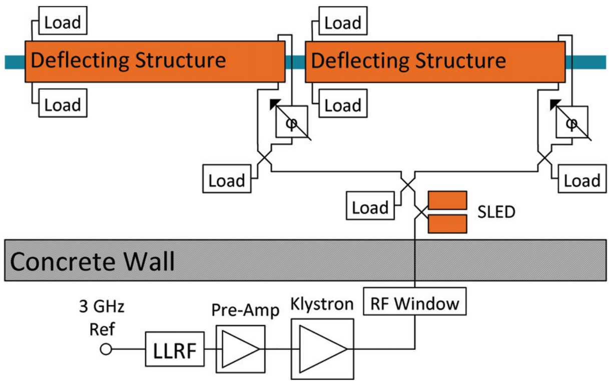

Figure 1: The RF set-up.

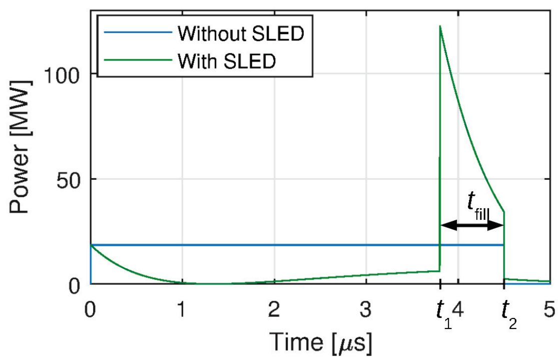

Figure 2: The maximum rms power delivered to one structure.

$P_L(t) = P_0(E_L(t)/E_0)^2$, where P_0 is the pulsed rms power that the klystron would delivered to each structure without the SLED system ($P_0 = 37/2$ MW in Fig. 1).The parameter α_S defined in [7] and the SLED rise/fill time T_S are 1.71 and 1.52 μs, respectively. Figure 2 shows $P_L(t)$ with the timing parameters that all the installed MAX IV SLED systems have been conditioned for.

$$E_L(t) = E_0(1-\alpha_S) + \alpha_S E_0(2 - e^{-\frac{t_1}{T_S}})e^{-\frac{t-t_1}{T_S}} \qquad (1)$$

Cell Design

Seven basic disk-loaded cell configurations with the dimensions shown in Fig. 3 have been studied in COMSOL Multiphysics [9]. The cell configurations have different phase advances, $\Psi = 2\pi L f_c/c_0$, and iris thickness, t. v_g was swept the for each configuration while the resonance frequency of the operation mode was kept constant at $f_c = 2.9985$ GHz by adjusting a and b. Figure 4 shows the maximum $V_\perp$ for the cell configurations obtained as $2 \cdot V_\perp(P_0 = 18.5 \text{ MW})$ in (3). The SLED charge time was set to $t_1 = 3.8$ μs as in Fig. 2. The higher $V_\perp$ obtained with the $\pi/2$ structures is due to their higher τ_0, even though the $2\pi/3$ structures have higher $r_\perp$. Note that the performance of the $5\pi/6$ structures drops rapidly for $v_g/c_0 > 0$ 018 since a

A constant-impedance backward-travelling transverse deflecting structure ranging from $0 \leq z \leq L_{\mathrm{tot}}$ that is fed with the SLED pulse in (1) at $z = L_{\mathrm{tot}}$, has a deflecting field $G_\perp(z) = E_\perp(z) + c_0(\hat{\mathbf{z}} \times \mathbf{B}(z))_\perp$ at time $t = t_2$ that is given by (2). $E_\perp(z)$ and $\mathbf{B}(z)$ are the electric field component in the direction of the deflection and the total magnetic field vector, respectively. $r_\perp$, τ_0 and c_0 are the transverse shunt impedance (LINAC definition in units Ω/m), the total attenuation factor as defined in [8] and the speed of light, respectively. In (2), it is assumed that the filling time of the structure is $t_{\mathrm{fill}} = t_2 - t_1 = L_{\mathrm{tot}}/v_g$ (see Fig. 2) where v_g is the group velocity of the structure. It is also assumed that the electrons are ultra-relativistic and propagating in the center of the structures along the z-axis, and that the kick angle is relatively small. The total deflecting voltage for one structure, $V_\perp$, is then given by (3).

becomes too large at higher group velocities. Also note that the losses in the waveguide system due to finite conductivity and mismatch are not included in Fig. 3. It is estimated that these losses will reduce $V_\perp$ less than 5 %. Even though the $\pi/2$ structures have higher $V_\perp$, it was decided to focus on the $2\pi/3$ geometry since a fewer number of cells are required for a 3 m long structure (90 compared to 120 for the $\pi/2$ structure). The final cell design has not yet been decided, but Table 1 shows the parameters of a preliminary design. The peak surface electric and magnetic fields for that geometry are acceptable, but in order to further decrease the former, elliptical iris walls are currently being investigated. Hence, the cell geometry will probably change in the final design.

$$G_\perp(z) = \sqrt{\frac{2r_\perp \tau_0 P_0}{L_{\mathrm{tot}}}}e^{-\tau_0}\left\{(1-\alpha_S)e^{z\frac{\tau_0}{L_{\mathrm{tot}}}} + \alpha_S(2-e^{-\frac{t_1}{T_S}})e^{z(\frac{\tau_0}{L_{\mathrm{tot}}} - \frac{1}{T_S v_g})}\right\} \qquad (2)$$

$$V_\perp = \int_0^{L_{\mathrm{tot}}} G_\perp(z)\mathrm{d}z = \sqrt{\frac{2r_\perp \tau_0 P_0}{L_{\mathrm{tot}}}}e^{-\tau_0}\left\{\frac{L_{\mathrm{tot}}(1-\alpha_S)}{\tau_0}(e^{\tau_0}-1) + \frac{\alpha_S(2-e^{-\frac{t_1}{T_S}})}{\frac{\tau_0}{L_{\mathrm{tot}}} - \frac{1}{v_g T_S}}\left(e^{(\tau_0 - \frac{L_{\mathrm{tot}}}{v_g T_S})} - 1\right)\right\} \qquad (3)$$

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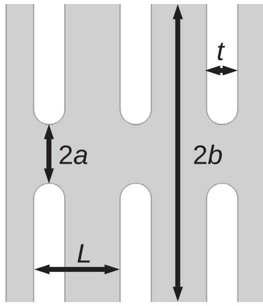


Figure 3: Dimensions of the cells.

Table 1: Preliminary Parameters of Deflecting Structure

Parameter	Value
f_{RF}	2.9985 GHz
a	11.90 mm
b	59.62 mm
L	33.33 mm
t	5 mm
L_{tot}	3 m
Ψ	$2\pi/3$
P_0	18.5 MW
v_g/c_0	0.0165
t_{fill}	607 ns
$r_\perp$	32.7 MΩ/m
τ_0	0.397
$V_\perp$	61.4 MV

Coupler Design

In order to change the polarization of the streak, the coupling cells are fed with two waveguides, as illustrated in Fig. 5. The polarization is horizontal when the waveguides are fed in common-mode, and it is vertical when the waveguides are fed in differential-mode. The deflecting fields along the structure have a purely linear polarization when the phase difference between the two waveguides is 0° or 180°, even if there is an amplitude unbalance between them. For all other phase relations, the polarization has a circular component. The magnetic-coupling slots at the waveguide ends are so-called fat-lipped [10], and the peak magnetic field in these regions is considerable lower than around the irises in the regular cells. Hence, the coupler should not be the bottle-neck when considering pulsed heating. Two stubs, located on the opposite side of the waveguides, improve the matching and the field symmetry. No matching cells between the coupling and regular cells are needed for this coupler design. Identical coupler cells, with high-power RF load attached to the waveguides, are attached to the upstream ends of the structures (see Fig. 1).

CONCLUSIONS AND FUTURE WORK

This paper describes the initial design of two 3 m long S-band transverse deflecting structures with variable polarizations. The structures will be used for characterizing different beam parameters such as the bunch profile, slice energy spread and slice emittance at the end of the MAX IV LINAC. There are still more RF and mechanical design to do before the production can start. The waveguide phase shifters and LLRF system will be designed and constructed. Shorter prototypes to verify the design will also be constructed in the MAX IV workshop before the production of the final structures begin. The plan is to have the complete transverse deflecting system in operation in 2019.

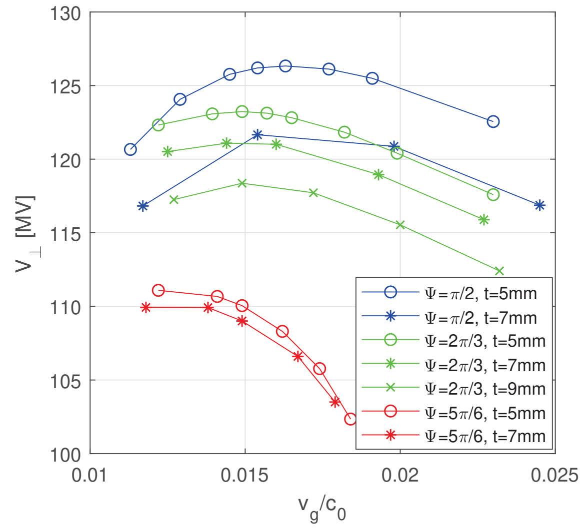
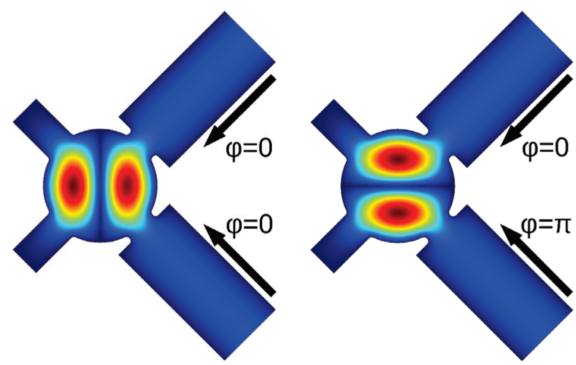


Figure 4: The total deflecting voltage for two structures with the RF set-up shown in Fig. 1.



(a) (b)

Figure 5: |**E**| in the coupler cell when deflecting the beam in the horizontal plane (a), and in the vertical plane (b). The two feeding waveguides are to the right, and the two matching stubs are to the left. φ is the relative phase of the incoming RF signal.

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REFERENCES

[1] S. Thorin *et al.*, “The MAX IV LINAC”, in *Proc. LINAC’14*, Geneva, Switzerland, Sep. 2014, paper TUIOA03, pp. 400–403.

[2] S. Werin *et al.*, “The Soft X-Ray Laser Project at MAX IV”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, paper WEPAB077, pp. 2760–2762.

[3] B. Marchetti *et al.*, “X-Band TDS Project”, in *Proc. IPAC’17*, Copenhagen, Denmark, May. 2017, paper MOPAB044, pp. 184–187.

[4] C. Serpico *et al.*, “Optimization of the SLED phase modulation parameters of the FERMI linac”, in *Proc. PAC’13*, Pasadena, CA USA, Sep. 2013, paper WEPMA01, pp. 981–983.

[5] D. Olsson *et al.*, “Increasing the Photon Energy for Photonuclear Experiments in MAX-lab by Phase Modulating the SLED Pulse”, in *Technical Report LUTEDX/(TEAT-7242)/1-11/(2016)*, 2017.

[6] A. Grudiev, “RF Design of X-band TDS with variable polarization”, presented at CLIC Workshop 2017, CERN, Geneva, Switzerland, Mar. 2017.

[7] Z. Farcas *et al.*, “SLED: A Method of Doubling SLAC’s Energy”, in *SLAC-PUB-1453*, 1974.

[8] T. Wangler, in *RF Linear Accelerators 2nd Edition*, Chapter 3, WILEY-VCH Verlag & Co, 2008.

[9] COMSOL Multiphysics, http://www.comsol.com/

[10] C. Nantista *et al.*, “Low-Field Accelerator Structure Couplers and Design Techniques”, in *SLAC-PUB-10575*, 2004.