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INJECTION/EXTRACTION KICKER FOR THE ALS-U PROJECT*

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Abstract

The ALS-U project consists in the upgrade of the existing Advanced Light Source at LBNL to a new ultra-low emittance lattice for production of diffraction-limited soft x-rays. In order to compensate for the reduced beam lifetime we intend to operate the machine in continuous top-off mode, where one of several bunch trains is extracted every 30-60 seconds and swapped with a fresh train from the accumulator ring, which is injected on axis without perturbing the circulating beam. In this paper we present our design for the injection/extraction kicker based on matched stripline electrodes. Such kicker has to provide the necessary deflection for simultaneously extracting a bunch train and injecting on-axis a fresh one from the accumulator ring. Rise and fall times must fit in the gap between bunch trains so that the injection/extraction process does not affect the remaining bunches. The main parameters of such a kicker are discussed with particular emphasis on the minimum gap length between trains, which also affects other machine subsystems.

INTRODUCTION

The characteristics of the ALS-U proposal are discussed in a separate paper in these proceedings [1]. The ultra-low beam transverse emittance, of the order of 50 picometers, means that in order to achieve a viable lifetime the bunch length needs to be stretched by way of a higher-harmonic RF system, which also is the object of a separate paper in these proceedings [2]. A common characteristic of such systems is their sensitivity to gaps in the fill pattern, which introduce transient beam loading and limit their performance, as illustrated for example in [3]. Therefore limiting length of the gaps necessary to accommodate the kicker rise and fall time is an important requirement in the design of the injection/extraction system. Our design objective is to realize a kicker that can fit into 10 ns long gaps and have a 50 ns long flat-top. Such parameters would be compatible with both the main RF system currently being discussed for the ALS-U: A 500 MHz one, with eleven trains of 25 bunches and a 100 MHz system, with 66 equally spaced bunches which would be swapped out six at a time. The choice of pulse length is dictated by both the pulser technology and by the conflicting necessities of keeping the current in the accumulator ring low (which favors short trains) and the interval between injections as long as possible for a given decrease in stored current (which favors long trains). Swapping out one eleventh of the circulating current every 30 seconds looks like a good compromise. For reasons explained in [1] the injection is to be performed on axis and the lattice allows using a straight where it is possible to install about 2 meters of striplines. The position of the 0.6 mm thin septum magnets SIN (Fig. 1) brings the required total deflection to about 3.5 mrad for a 5-sigma clearance.

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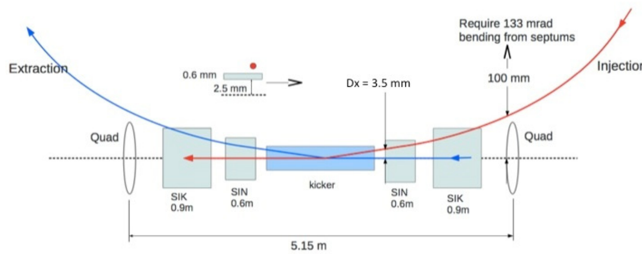

Figure 1: Layout of the ALS-U lattice in the injection/-extraction straight.

Table 1 summarizes the relevant machine parameters and kicker requirements. The sub 1% ripple is a baseline requirement, which can probably be relaxed since what counts is the net integrated kick received. Once the kicker design is finalized we will calculate the kick the first trailing bunch will receive due to residual fields in the kicker and based on that derive the maximum ripple that still gives a negligible deflection.

Table 1: System Main Parameters

Parameter	Value
Beam Energy (E_b)	2 GeV
Bend Angle (Θ)	3.5 mrad
Total Kicker Length (L_{tot})	2 m
Gap Between Trains (τ_G)	10 ns
Rise/Fall Time (τ_R)	<10 ns
Pulse Length	50 ns
Kick Repetition Period (T_{rep})	> 30 s
Inter/Intra Pulse Ripple	< 1 %
Striplines Half-Gap ($h/2$)	3 mm
Stripline Length (L_{mod})	0.5 m
Stripline Width (w)	8 mm

In the following section we calculate analytically the stripline parameters for an ideal kicker, show a baseline design obtained by computer simulations, and evaluate the kicker's beam coupling impedance, while a separate paper [4] in these proceedings is dedicated to the pulser technology and R&D.

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ANALYTICAL CALCULATION OF THE KICKER FUNDAMENTAL PARAMETERS

Based on the specifications listed in Tab.1 we can calculate the principal kicker parameters, using the well-known formulas reported, for example in [5].

First of all, the maximum stripline length is dictated by the rise/fall time considerations mentioned in the previous section. In addition to the pulser's own rise time one has also to take into account the propagation time of the pulse along the stripline and the bunch length (τ_b, which we will consider equal to $6\sigma_z/c$). Therefore we can write that the maximum length of a stripline module, in order for the kick not to affect preceding and trailing bunch trains is given by

$$L_{\text{mod}} \le \frac{\tau_G - \tau_R - \tau_b}{2} c \tag{1}$$

The bunch length, even after stretching, is a fraction of a nanosecond; if the pulser rise time can be kept shorter than 6 ns, then we can use 0.5 m long striplines and it is possible to fit four such devices in the injection/extraction straight.

The striplines in each module have to be excited with equal and opposite voltage $\pm V_0$, which can be calculated from the total integrated deflecting voltage $V_\perp$ necessary to achieve the desired deflection angle:

$$V_\perp = \int_0^{L_{tot}} (E_y + cB_x)dz = \Theta E_b / q_e \tag{2}$$

where we have assumed an ultrarelativistic bunch travelling along the z axis and q_e is the electron charge. For an ideal kicker, with a uniform deflecting field between its stripline electrodes and no fringe fields, we can rewrite Eq.(2) as

$$V_\perp = \int_0^{L_{tot}} 2E_y dz = 2E_y \cdot L_{tot} = 2\frac{2V_0}{h} L_{tot} \tag{3}$$

where h is the distance between electrodes. From Eqs.(2) and (3) we can calculated the voltage for a single stripline by

$$V_0 = \frac{\Theta E_b h}{4L_{tot}} = 5.25\ \text{kV} \tag{4}$$

It is worth noticing that the required pulser voltage does not depend on the number of kicker modules used, once their total length is fixed.

Shunt Impedance

Kicker power handling specifications and its bandwidth depend on its shunt impedance Z_s (Fig. 2) for which we can write:

$$Z_s(\omega) = \frac{(V_\perp / N_{\text{mod}})^2}{2P_{\text{mod}}} = 2Z_0 \left(\frac{L_{\text{mod}}\, g_\perp}{h/2}\right)^2 \left(\frac{\sin(\omega L_{\text{mod}}/c)}{\omega L_{\text{mod}}/c}\right)^2 \tag{5}$$

where N_{mod} is the number of stripline modules, P_{mod} is the power dissipated in each one and $Z_0 = 50\ \Omega$ the stripline characteristic impedance. $g_\perp$ is the transverse coverage factor, which can be approximated by

$$g_\perp \approx \tanh\left(\frac{\pi w}{2h}\right) = 0.97 \tag{6}$$

the stripline characteristic impedance.

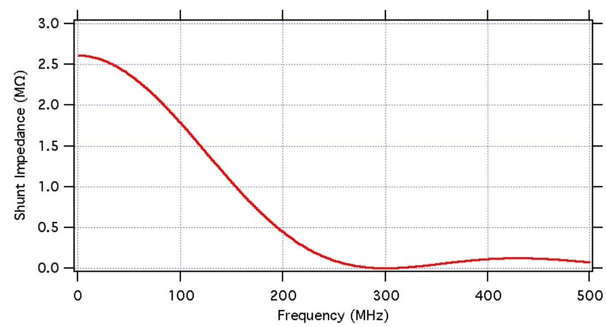

Figure 2: Stripline kicker module shunt impedance.

From Eq.(5) we can estimate the power dissipated in each module to be ~590 kW, which corresponds to a stripline voltage of 5.4 kV, in line with the value obtained in Eq.(4). The difference is due to $g_\perp$ being less than 1.

Since the power dissipated on each stripline is also equal to $V_0^2 / 2Z_0$, we can also derive a transfer function between pulser voltage and integrated deflecting voltage:

$$V_\perp(\omega) = \frac{1}{g_\perp} \sqrt{\frac{2Z_s(\omega)}{Z_0}} V_0(\omega) \tag{7}$$

and combining with Eq.(5) we obtain

$$V_\perp(\omega) = \frac{L_{\text{mod}}}{h/2} \frac{\sin(\omega L_{\text{mod}}/c)}{\omega L_{\text{mod}}/c} V_0(\omega) \tag{8}$$

The frequency dependent term in the coefficient of V_0 is reduced by 3 dB for $\omega \approx 2\pi \cdot 133\ \text{MHz}$, which can be interpreted as the stripline kicker bandwidth. This would support risetimes as short as ~2.6 ns, using the customary relationship risetime ≈ $0.35/\text{BW}_{-3\text{dB}}$.

Beam Coupling Impedance

To estimate the longitudinal impedance of a kicker module we need to calculate the characteristic impedance of a stripline in the common mode, i.e. when both stripline are at the same voltage, which is how a bunch

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passing through would excite it. To do so we have to specify the exact transverse section of striplines and vacuum chamber, which is designed so to have a characteristic impedance of 50 Ω in the differential mode (striplines at opposite voltage).

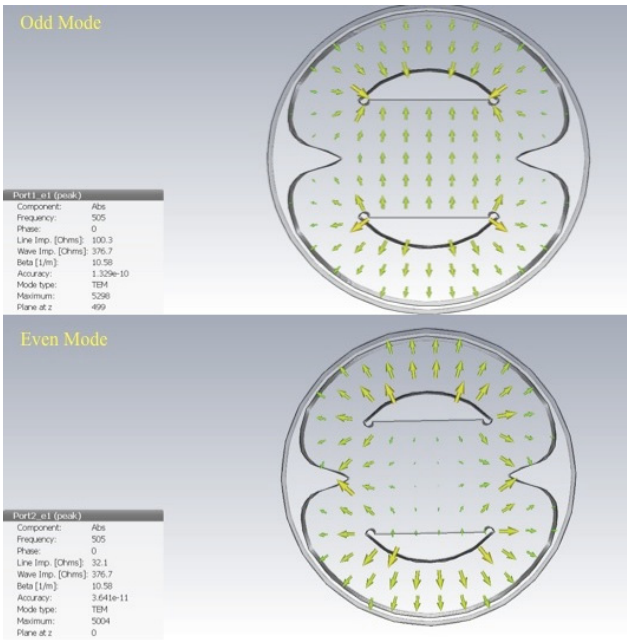

Figure 3: Transverse section of stripline kicker with electric field map for differential (top) and common mode (bottom). Characteristic impedances are Z_{odd}= 50 Ω and Z_{even}= 64 Ω.

The transverse section shown in Fig. 3 features transverse ground plates, or "fenders", which lower the common mode characteristic impedance down to 64 Ω. This is necessary to reduce the impedance mismatch between stripline and 50 Ω load and pulser and limit the amplitude of reflected signals, which would increase the coupling impedance value. The theoretical value of the longitudinal coupling impedance for a single module is given by [6]:

$$
\begin{aligned}
Z_{//}^{\mathrm{Re}}(\omega) &= Z_{even} g_{//}^2 \sin^2(\omega L_{\mathrm{mod}} / c) \\
Z_{//}^{\mathrm{Im}}(\omega) &= \frac{1}{2} Z_{even} g_{//}^2 \sin(2\omega L_{\mathrm{mod}} / c)
\end{aligned} \tag{9}
$$

and the transverse impedance is

$$
Z_{\perp} = Z_{//} \frac{g_{\perp}^2 Z_{odd}}{g_{//}^2 Z_{even}} \frac{c}{\omega (h/2)^2} \tag{10}
$$

where $g_{//}$ is the longitudinal coverage factor:

$$
g_{//} \approx \frac{2}{\pi} \tan^{-1}\left[\sinh\left(\frac{\pi w}{2h} \right) \right] = 0.84 \tag{11}
$$

From Eqs. (9) and (11) we can see that the real part of the longitudinal impedance has 45 Ω peaks at odd integer multiples of 150 MHz. We are planning to reduce this value by introducing ~3 cm long tapers which would halve it at 2 GHz and effectively make it negligible above 3 GHz.

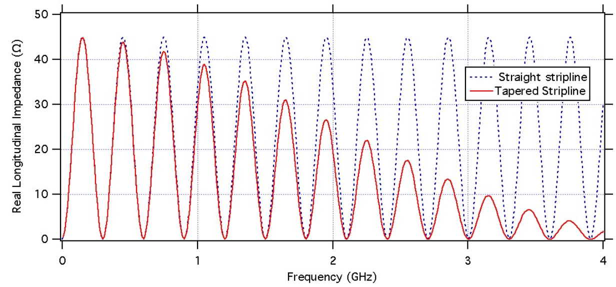

Figure 4: Real longitudinal impedance. Comparison of tapered and untapered striplines, same total length.

The total stripline length would remain the same to preserve the response time, at the price of a small reduction in the shunt impedance.

CONCLUSIONS

We have discussed the requirements for the injection/extraction kicker for the ALS-U project and presented the analytical study for a solution based on four 0.5 m long stripline kicker modules. In order to top-up the circulating beam in a user transparent fashion such a kicker requires pulsers capable of producing ~5.5 kV with a rise/fall time of the order of 6 ns.

We also discussed the techniques we intend to adopt to reduce the kicker impedance by way of fenders and longitudinal tapering.

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