LCLS-II Technical Note

Maximum Beam Current as a Function of Cavity Gradient and Detuning with a 3.8 kW RF Source

LCLS-II TN-15-29

8/17/2015

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1 Introduction

L-band RF power for the SCRF cavities of LCLS-II will be provided by solid-state amplifiers (SSAs) for which the engineering specification calls for a maximum CW output power of 3.8 kW for the initial phase of operation. This figure is based on supporting a nominal design gradient of 16 MV/m at a maximum beam current of 100 μA (see Engineering Note LCLSII-2.4-EN-0431). It takes into account waveguide losses, the nominal cavity coupling, operational overhead and up to 10 Hz cavity detuning. Note that there will likely be additional overhead – in the most recent (7/21/15) linac design schematic, 4 GeV is reached without exceeding 15.7 MV/m in L1-L3 and the beam runs off-crest in many cavities. Also, the beam current will likely be closer to 65 μA.

In this brief note, we evaluate one aspect of flexibility in operational parameter space. In particular, we determine what limit our available RF power places on beam current as a function of the 1.3 GHz cavity gradient, which in turn can be used to compute the maximum beam energy for a given current. Results are shown for different levels of allowed detuning of the cavities (e.g., from microphonics).

2 Maximum Operating Current

Table 1 lists parameters of the 1.3 GHz accelerator cavities and the RF source relevant to the calculation.

TABLE 1: Cavity and RF Parameters

Drive frequency	f_0 =1.3 GHz
Cavity length	L = 1.038 m
Effective R/Q	R/Q = 1,010 Ω
Loaded quality factor	$Q_L = 4.12\times10^7$
RF source power	P_g = 3.8 kW
Transmission efficiency	η_{tr} = 0.918
Overhead factor	OF = 1.08
Power available to cavity	P_i = 3.26 kW

The power required by an SCRF cavity to sustain a given voltage with a given beam current riding on crest and a resonance detuning amplitude δf (i.e. $f_c = f_0 + \delta f$) is given by the following equation.

$$P_i = \frac{V_c^2}{4\frac{R}{Q}Q_L}\left[\left(1+\frac{I_b}{V_c}\frac{R}{Q}Q_L\right)^2 + \left(2Q_L\frac{\delta f}{f_0}\right)^2\right] \tag{1}$$

Inverting this for the maximum current that can be accelerated at a given cavity voltage with fixed power and a fixed external coupling yields

$$I_{b,\max} == \frac{V_c}{\frac{R}{Q}Q_L}\left[2Q_L\sqrt{\frac{R/Q}{Q_L}\frac{P_i}{V_c^2}-\left(\frac{\delta f}{f_0}\right)^2}-1\right]. \tag{2}$$

This beam current limit is plotted in Fig. 1 *vs.* the cavity gradient (= V_c/L) for different detuning values assuming the cavity input power equals the RF source power derated by the transmission loss and operational overhead. By design, a detuning of 10 Hz limits the current to 100 μA at 16 MV/m. At 15.7 MV/m, the current can be as high as 110 μA, and a 65 μA beam can be accelerated as high as 17.1 MV/m. Current and gradient do not scale inversely because, with fixed over-coupling (Q_L), only a fraction of the power goes into the cavity.

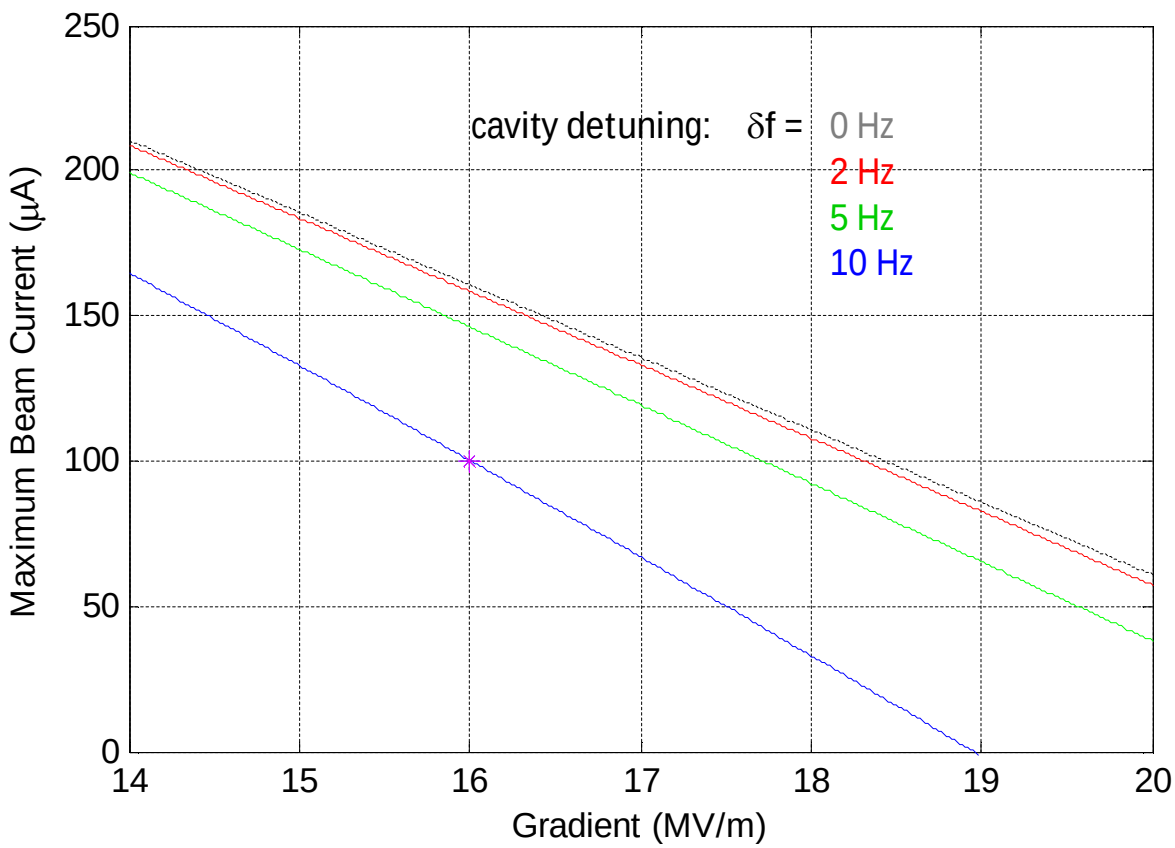

Figure 1. On-crest beam current limit as a function of acceleration gradient for a 3.8 kW RF source and cavity detunings of 10 Hz (blue), 5 Hz (green) and 2 Hz (red). The dashed black is the asymptote for perfect tuning, and the asterisk indicates the parameters for which the source power was specified.