Qext Design Optimization for 1497MHz CEBAF New Injector Cryomodule Based on JLab Technotes TN-95019 and TN-96-022

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Input parameters:

beam average current: $I_0 := 0.00040$ (A) (for discussed beam current)

cavity RF frequency: $f_0 := 1497 \cdot 10^6$ (Hz)

cavity cell number per cavity $N := 7$

cavity intrincial quality factor: $Q_0 := 8 \cdot 10^9$

injection electron energy $E_i := 750 \cdot 10^3$ (eV)

electron rest energy $E_0 := 511 \cdot 10^3$ (eV)

injection electron relative velocity: $\beta := \sqrt{1 - \left(\frac{E_0}{E_0 + E_i}\right)^2}$ $\beta = 0.914$

speed of light: $c := 299792458$ (m/s)

maximum on-axis electric field in acceleration direction in SuperFish calculation

$Esf_0 := 1.408 \cdot 10^6$ (V/m)

SuperFish calculayed Cavity's R/Q at beta=1: $RoQ := 868.9$ (Ω)

accelerating distance in one cavity: $d := N \cdot \frac{1 \cdot c}{2 \cdot f_0}$ $d = 0.701$ (m)

Transit Time Factor

$$TTF := \sqrt{\frac{RoQ \cdot 2 \cdot \pi \cdot 1495.99521 \cdot 10^6 \cdot 0.0602108}{(Esf_0 \cdot d)^2}} \qquad TTF = 0.711$$

cavity maximum on-axis Ez field: $Ez_0 := 16 \cdot 10^6$ (V/m) cavity maximum gradient: $E_{acc} := Ez_0 \cdot TTF$ (V/m) $E_{acc} = 1.137 \times 10^7$

maximum beam off-creast angle: $\Psi_b := 20$ (deg)

cavity static detuning: $\delta f := 5$ (Hz)

cavity microphonic peak detuning $\delta f_m := 15$ (Hz)

accelerating voltage in one cavity: $V_c := E_{acc} \cdot d$ $V_c = 7.969 \times 10^6$ (V)

beam loading factor: $b(E_{acc}, \Psi_b) := \dfrac{I_0 \cdot RoQ \cdot Q_0}{E_{acc} \cdot d} \cdot \cos\left(\Psi_b \cdot \dfrac{\pi}{180}\right)$ $b(E_{acc}, 0) = 348.92$

cavity intrinsic frequency bandwidth: $\Delta f_0 := \dfrac{f_0}{Q_0}$ (Hz) $\Delta f_0 = 0.187$

Optimization:

$$\beta_{opt}(E_{acc}, \Psi_b) := \sqrt{\left(b(E_{acc}, \Psi_b) + 1\right)^2 + \left(b(E_{acc}, \Psi_b) \cdot \tan\left(\Psi_b \cdot \frac{\pi}{180}\right) + \frac{2 \cdot \delta f + 2 \cdot \delta f_m}{\Delta f_0}\right)^2}$$

Optimized Qext:

$$Q_{extopt} := \frac{Q_0}{\beta_{opt}(E_{acc}, 0)} \qquad Q_{extopt} = 1.951 \times 10^7$$

Optimized beam power:

$$P_{opt} := \frac{{V_c}^2}{RoQ \cdot Q_{extopt}} \qquad P_{opt} = 3.746 \times 10^3 \ \text{(W)}$$

FPC coupling beta: $\beta_c := \frac{Q_0}{Q_{extopt}}$ $\beta_c = 410.046$

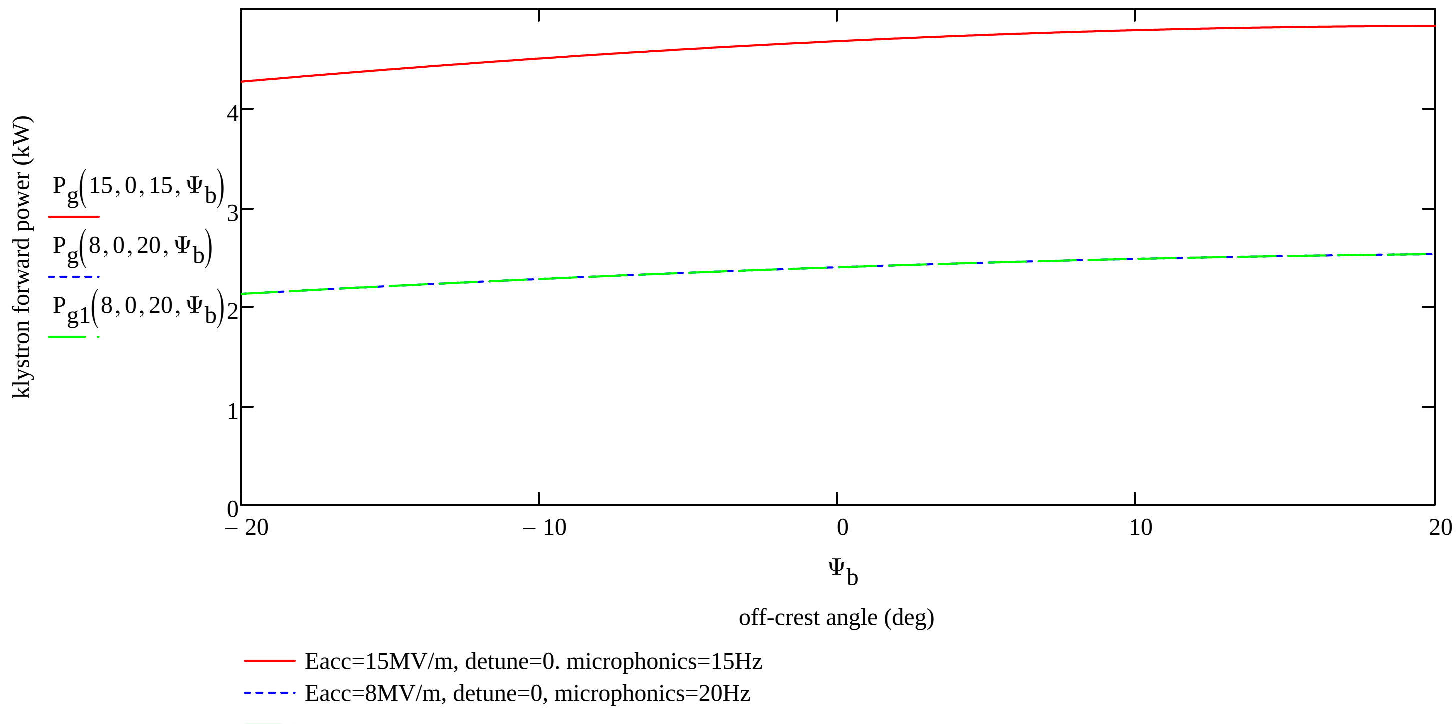
klystron power requirement from TN-95-019:

$$P_g(E_{acc}, \delta f, \delta f_m, \Psi_b) := \frac{(E_{acc} \cdot 10^6 \cdot d)^2}{RoQ \cdot Q_0} \cdot \frac{0.001}{4 \cdot \beta_c} \cdot \left[\left(1 + \beta_c + \frac{b(E_{acc}, \Psi_b)}{10^6}\right)^2 + \left(\frac{2 \cdot \delta f + 2 \cdot \delta f_m}{\Delta f_0} + \frac{b(E_{acc}, \Psi_b)}{10^6} \cdot \tan\left(\Psi_b \cdot \frac{\pi}{180}\right)\right)^2 \right] \quad \text{(kW)}$$

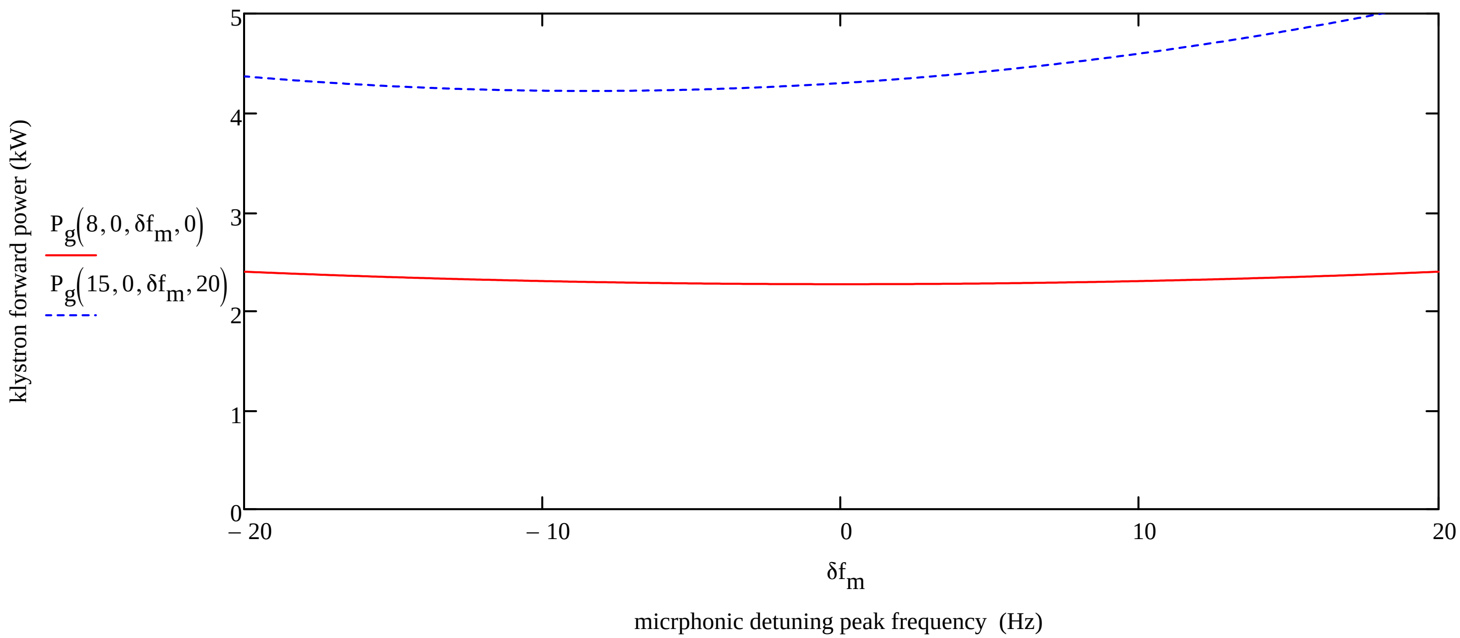
cross-check with another formula from JLab Technote 96-022

$$P_{g1}(E_{acc}, \delta f, \delta f_m, \Psi_b) := \frac{(E_{acc} \cdot 10^6 \cdot d)^2}{RoQ \cdot Q_0} \cdot \frac{0.001}{4 \cdot \beta_c} \cdot \left[\left(1 + \beta_c + \frac{I_0 \cdot RoQ \cdot Q_0}{E_{acc} \cdot 10^6 \cdot d} \cdot \cos\left(\Psi_b \cdot \frac{\pi}{180}\right)\right)^2 + \left(\frac{2 \cdot \delta f + 2 \cdot \delta f_m}{\Delta f_0} + \frac{I_0 \cdot RoQ \cdot Q_0}{E_{acc} \cdot 10^6 \cdot d} \cdot \sin\left(\Psi_b \cdot \frac{\pi}{180}\right)\right)^2 \right] \quad \text{(kW)}$$

$\Psi_b := -20, -19.9 .. 20$ (deg) $P_g(14, 0, 20, 0) = 4.458$



$\delta f_m := -20, -19.9 .. 20$ (Hz)



Eacc=8MV/m, detune=0, on-crest

Eacc=15MV/m, detune=0, off-crest angle=20 deg