IR FEL Linac - RF Status and Issues

A meeting was held on September 20, 1996, to discuss issues, parameters, and results of the modeling effort by Dr. Lia Merminga to achieve "First Light" and Energy Recovery for the IRFEL RF system. The following is a summary of the decisions reached as a result of this meeting. More details of the meeting follow the summary.

Summary

1. Use the new 225 kW Cathode Power Supply so the klystrons can be operated at 8 kW. The additional RF power more than doubles the maximum tolerable microphonic modulation, however the optimum value of Q_L is also reduced by a factor of 2.
2. The decision on whether to use waveguide tuners to achieve the optimum values for Q_L will be made after the first IRFEL cryomodule is assembled and measured.
3. No changes in the RF firmware are necessary at this time. Since the firmware is downloadable, it can be quickly changed later if necessary.
4. Simulations and tests on the ITS will contribute in determining the optimum start-up scenario for "First Light" on the IRFEL.
5. Plans will be written to test the mechanical reliability, hysteresis, and frequency response of the magnetostrictive tuners.

Cavity/RF Control System Parameters

Optimum settings of the IRFEL linac cavity parameters (loaded Q, coupling coefficients and static detuning) have been determined for “First Light” and Energy Recovery, assuming 4 kW (unsaturated) klystron power and a gradient of 8 MV/m. The possibility of accelerating 1.1mA beam current using 8 kW klystrons during “First Light” mode has also been investigated. Tables 1 and 2 summarize the results. Since the FEL wiggler is downstream of the linac cavities and the electron beam will be dumped after exiting the laser’s wiggler for the “First Light” mode of operation, the state of the laser does not affect the linac cavities. The opposite is true for the Energy Recovery mode of operation, since the electron beam will be recirculated back to the entrance of the linac after it exits the laser’s wiggler.

FEL	I_b (μA)	P_g (kW)	Ψ_b (deg)	δf_o (Hz)	δf_m (Hz)	β_{opt}	$Q_{L,opt}$
ON or OFF	625	4	12.5	-12	224	834	6×10^6
ON or OFF	1100	8	12.5	-21.4	488	1754	2.85×10^6

Table 1: RF system parameters optimized for "First Light" operation.

FEL	I_b (μA)	P_g (kW)	Ψ_b (deg)	δf_o (Hz)	δf_m (Hz)	β_{opt}	$Q_{L,opt}$
ON	218	4	101.25	-19.2	366	1224	4.08×10^6
OFF	340	4	100.55	-30	370	1235	4.04×10^6

Table 2: RF system parameters optimized for Energy Recovery operation.

$\boxed{\delta f_o}$ denotes the static detuning and $\boxed{\delta f_m}$ denotes the maximum peak-to-peak tolerable level of microphonics for the given power. $\boxed{\Psi_b}$ is the beam phase with respect to crest of the RF wave. Notice that for "First Light" the use of 8 kW klystrons more than doubles the maximum tolerable amount of microphonics, however the optimum loaded Q (Q_L) becomes approximately 3×10^6. Also notice that the optimum Q_L is slightly different between "First Light" and Energy Recovery modes of operation. We note that the optimum Q_L for the Injector cavities is 2×10^6 (See TN-96-022).

The decision on whether to use waveguide tuners to achieve the optimum values for Q_L will be deferred until the first set of IRFEL cavities are assembled and Q_L measured.

Are there any changes required in the RF system firmware for the IRFEL?

Here we discuss only changes required at the low level RF feedback loops and do not discuss, for example, additional interlocks that may be required from running 50 kW instead of 5 kW klystrons in the Injector.

Matching of the longitudinal phase space for bunching going into the wiggler implies that the beam is accelerated off crest by 12.5° in the linac cavities. Typically, when beam runs off crest, cavities are detuned off resonance in order to minimize the required generator power. TJNAF's RF control system has been used so far for on crest and on resonance operation; therefore, it is justified to ask whether there are any changes in firmware required to ensure reliable operation of the RF control system under the new operating conditions.

Specifically, the question is whether or not to introduce in the embedded code a current-dependent static detuning $\boxed{\delta f_o}$, given by

$$\boxed{\delta f_o = -\frac{I_b (r/Q) f_o}{2V_c} \sin \Psi_b} \qquad (1)$$

where $\boxed{\Psi_b}$ is the beam phase relative to crest, $\boxed{f_o}$ = 1497 MHz, V_C = 8 MV/m, I_b is the average beam current and (r/Q) = 960 Ohms/m.

During "First Light" mode the beam is accelerated 12.5° off crest in the linac cavities, resulting in an optimum detuning of -12 Hz for 625 μA beam current. Assuming no microphonics and $Q_L = 6 \times 10^6$, the difference in generator power per cavity between on resonance and -12 Hz off resonance operation is 13 W out of nearly 3 kW required power, as seen from Table 3.

In the second section of Table 3, the same comparisons are made and the results summarized for energy recovery with the FEL on and off.

First Light

FEL	$\boxed{I_b\ (\mu A)}$	$\boxed{P_g\ (W)}$	$\boxed{\Psi_b\ (\deg)}$	$\boxed{\delta f_o\ (Hz)}$	$\boxed{\delta f_m\ (Hz)}$	$\boxed{Q_{L,opt}}$
ON or OFF	625	2897	12.5	0	0	6×10^6
ON or OFF	625	2884	12.5	-12	0	6×10^6

Energy Recovery

FEL	$\boxed{I_b\ (\mu A)}$	$\boxed{P_g\ (W)}$	$\boxed{\Psi_b\ (\deg)}$	$\boxed{\delta f_o\ (Hz)}$	$\boxed{\delta f_m\ (Hz)}$	$\boxed{Q_{L,opt}}$
ON	218	1983	101.25	0	0	4.08×10^6
ON	218	1960	101.25	-19.2	0	4.08×10^6
OFF	340	1994	100.55	0	0	4.04×10^6
OFF	340	1940	100.55	-30	0	4.04×10^6

Table 3: Power Considerations

In conclusion, from power-savings considerations, there is no compelling reason to change the firmware because, even if we operate on resonance, the additional power cost is negligible.

There is however, a second issue: off resonance operation may be desirable, firstly, because it decouples phase from amplitude control and, secondly, because it increases the available control range, thereby increasing the maximum tolerable amount of microphonics. Figures 1 and 2 demonstrate these two points.

Therefore, from the point of view of quality of regulation, off resonance operation is preferable, although the system is still operable on resonance. This is because the amount of coupling introduced in the loops is small and the control range is not largely compromised as the system parameters have been optimized to deal with large amount of microphonics (See Tables 1 and 2).

We have demonstrated through simulations that a number of RF and beam start up scenarios are possible. The various scenarios are to increase the beam current with simultaneous detuning of cavities, to detune cavities at zero beam loading, or to detune cavities at full beam loading.

Therefore we propose that we determine the optimum start up scenario through a combination of further simulations and experimental tests (at ITS and the Injector). Once the optimum start up scenario has been selected, it can then be automated as a Tcl script.

Consequently, no changes in the RF firmware are necessary at this time. Any future changes can be quickly made to the downloadable RF firmware.

Additional Operational Issues

On the magnetostrictive tuners, we agreed to write plans to test the mechanical reliability, hysterisis, and frequency response of the tuners. They are to be used in the Injector cavities to demonstrate that forward power is minimized. Tuner control can be provided with a Tcl script.

It was proposed that linac cavities be phased by first setting the beam on crest of the RF wave and then move PSET by 12.5°. For finer phase corrections, the linac gang phase can be adjusted by monitoring the bunch length signal immediately upstream of the wiggler.

Linear increase of the average beam current, as opposed to maintaining the same charge per bunch and increasing the repetition frequency in factors of 2, was discussed as a preferred beam start up scenario.

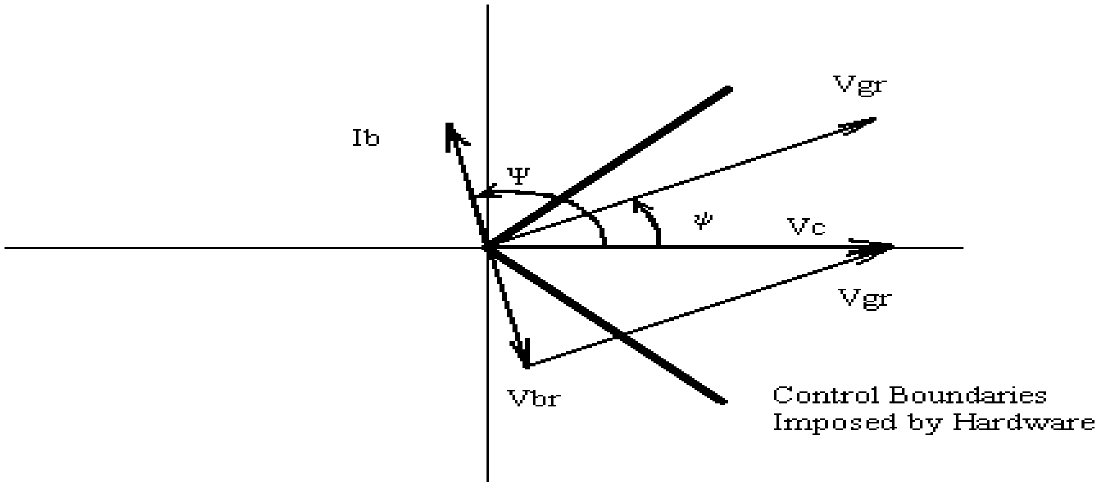

Figure 1. On Resonance Operation

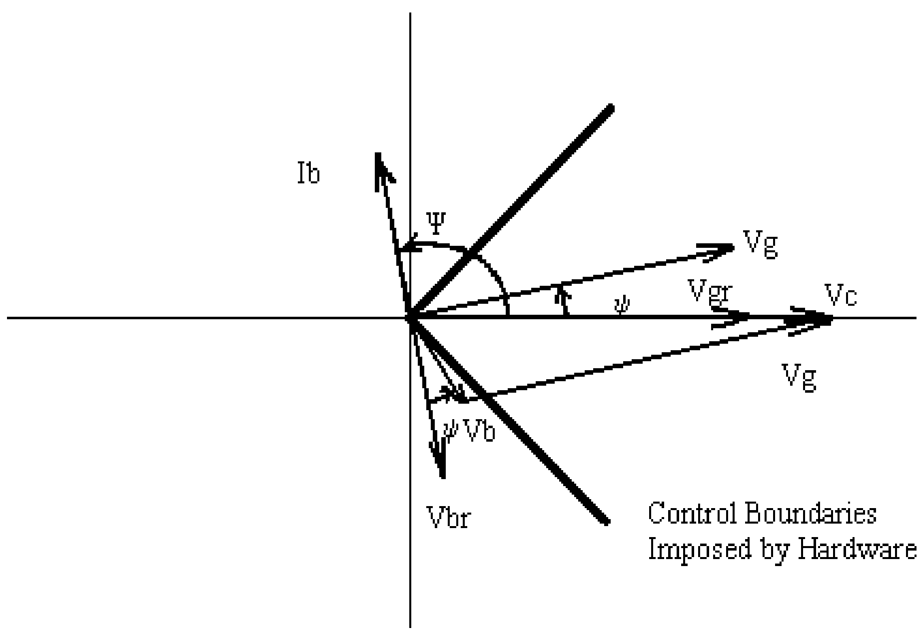

Figure 2. Off Resonance Operation

V_{br} - Beam Induced Voltage On Resonance
V_{gr} - Generator Induced Voltage On Resonance
V_c - Cavity Voltage On Resonance
I_b - Beam Current
Ψ_b - Phase of Beam
Ψ - Detuning Angle of being Off Resonance
V_b - Beam Induced Voltage Off Resonance
V_g - Generator Induced Voltage Off Resonance
------- - Control boundaries imposed by hardware