EFFECTS OF TEMPERATURE VARIATION ON THE SLC LINAC RF SYSTEM

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ABSTRACT

The rf system of the Stanford Linear Collider in California is subjected to daily temperature cycles of up to 15˚C. This can result in phase variations of 15˚ at 3 GHz over the 3 km length of the main drive line system. Subsystems show local changes of the order of 3˚ over 100 meters. When operating with flat beams and normalized emittances of $0.3*10^{-5}$ m-rad in the vertical plane, changes as small as 0.5˚ perturb the wakefield tail compensation and make continuous tuning necessary. Different approaches to stabilization of the RF phases and amplitudes are discussed.

I. INTRODUCTION

Since going to flat beam running in 1993, where the vertical emittances can be as low as $\gamma\varepsilon_y = 0.2*10^{-5}$ m-rad at the end of the Linac, all tolerances have to be revised to keep the machine stable. Here we are mainly talking about the slow drifts and day-night variations and not about the short term jitter. These changes can be observed with the history plot feature of the SLC control system, where many important parameters are monitored and their value saved every 6 minutes. About 40 parameters are changing with a daily rhythm and it is a numbers game to figure out which are the most important ones. The other important issue is the mechanism by which these changes might influence the emittance variation. The wakefield tail compensation procedure is very sensitive to any energy change. This has concentrated the studies to RF variations in phase and amplitude, which made a closer look on the tuning procedure of the SLED-cavities necessary. The different sources, the sensitivity, and the SLED tuning are discussed in detail.

II. CHANGING PARAMETERS

Around 40 parameters which are changing daily can be put into three categories: The incoming conditions of the beam, parameters in the Linac, and the outgoing conditions.

A. Incoming beam conditions

The incoming beam might change in first order in intensity, orbit, energy and phase, and in higher order in bunch length and transverse distribution, to influence changes seen in the linac.

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B. Linac sources

In the linac there are magnets, accelerating structures and BPMs, which can change the beam via feedback. The modulators, klystrons, SLED-cavities, wave guides, and the actual accelerating structures change the beam energy. Additionally there are water regulations, phase detectors, timing issues, and more.

C. Outgoing beam measurements

The outgoing beam can influence the performance of the linac via feedbacks, which hold the energy constant in the ARCs and in the scavenger extraction line. In next order there might be changes (e.g. by collimators) in the acceptance to background and energy spread which will make a linac change necessary.

All these can be responsible for changes. Magnets change of the order of 10^{-3} or less, which helps to keep the in- and out-going conditions stable. Studying the numbers has given some hints that a 1.5% energy variations might be the biggest source. This can come from RF amplitude or phase changes.

III. EMITTANCE SENSITIVITY

The flat beam emittance of $0.2*10^{-5}$ m-rad is achieved by a delicate cancellation with linac bumps [1] down from about $2.0*10^{-5}$ m-rad. These "bumps" consist of betatron oscillations over about 6 wavelength (2200° in betatron phase). A 1% beam energy change, equals a 1.5˚ RF phase

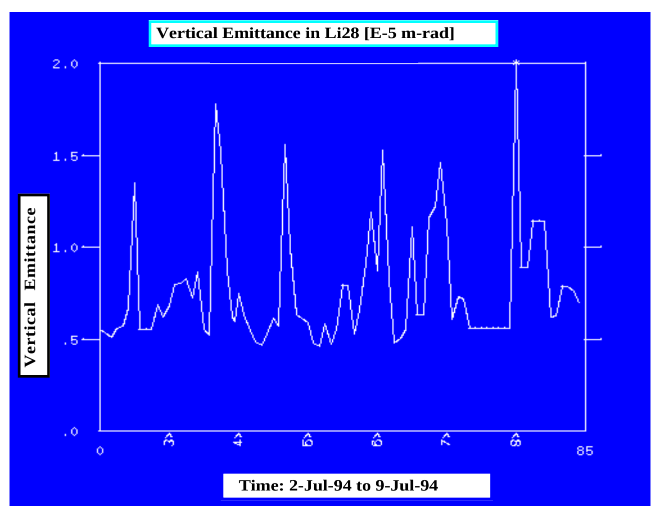

Figure 1: Day-night variations of the emittance.
At the end of the linac changes of 300 % of the minimum emittance can be observed.

change at cos 20˚ (BNS-phase), will cause a 22° change, which will be 11˚ on average. This will regenerate a beam tail, giving an emittance growth of $\Delta\varepsilon = 2.0 * \sin 11^\circ = 0.4$ in units of 10^{-5} m-rad. Fig. 1 gives an example of the earlier part of the run where no particular interest was taken to emittance growth.

IV. SLED TUNING

The SLED system provides nearly a doubling of the rf field strength [2]. The energy is stored in two high Q cavities, which are sensitive to temperature changes. Many steps have been done to keep it stable: water cooling with temperature stabilization of about 0.1-0.2˚C, and additional isolation. Studying the pulse form during the charging and decharging of the SLED cavities has led to some ideas why the system is not tuned to its optimal level.

A. Basic SLED

The outputs of two SLED cavities are combined in a 3-dB coupler. The output of this coupler is the SLED output pulse whose amplitude and phase varies with time. If the klystron phase does not vary during the charging of the cavities, the amplitude dips to zero and the phase changes by 180° at about 2 µs after the rf turn-on. The phase remains constant and equals the klystron phase after it has been flipped 180°.

B. SLED tuning details

The tuning angle is defined as

$$\Psi = \arctan\left(2Q_L \frac{f - f_r}{f}\right),$$

where f, f_r are respectively the operating and resonant frequencies, and Q_L is the loaded quality factor.

If the klystron phase does vary during the charging, as is the case at SLC, the amplitude doesn't reach zero when the cavities are tuned, but the difference in phase of the SLED output before and after the 180° klystron phase flip is still a minimum. If the two cavities are tuned to different frequencies, the amplitude can reach zero, but would lead to an incorrect tuning procedure.

An observed phase change from before to after the klystron phase flip gave an indication, that the SLED cavities were not tuned correctly. The reason for this could have been that the cavities were tuned at another temperature, but retuning it with the same procedure gave the same result. It had to do with something else. Since the rf is not switched on by the subbooster, but rather by the voltage of the modulator, the phase of the klystron changes by a huge amount during this turn-on which fills the SLED cavities with a wrong phase. Therefore a 180˚ switch is not the optimum or the SLED cavities have to be slightly mistuned.

The cavities can be correctly tuned to resonance by minimizing the phase difference between the before and after the 180° klystron phase flip. This would also result in the highest peak field, since the two vectors (one from the klystron, one from the cavities) are aligned. Fig. 2 shows a typical rf pulse form in amplitude and phase generated by simulations for different tuning angles. The simulations assumed a phase change at the klystron of 100° from –5 to –4 µs for the modulator, the normal 180° switch, and tuning angles Ψ of ±20° besides the tuned case.

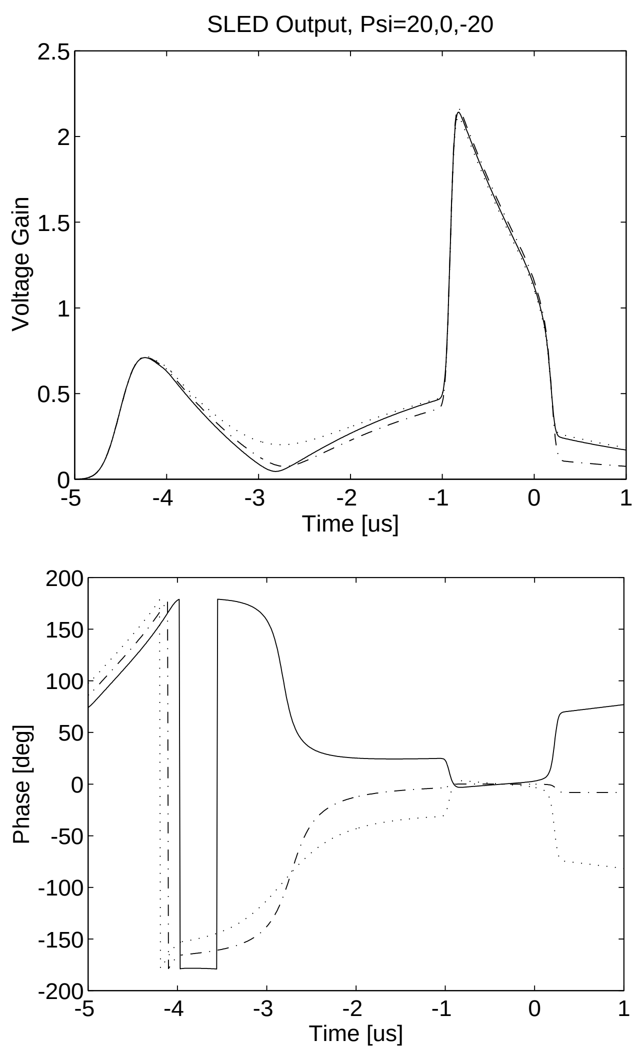

Figure 2: SLED pulse form in amplitude and phase. *The amplitude rises slowly with the rising modulator voltage. Therefore the minimum amplitude doesn't touch zero before the peak at the 180˚ phase change. The tuning angles correspond to about a ±0.5 ℃ temperature change.*

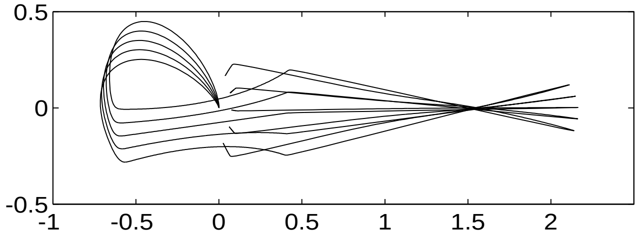

Figure 3: Vector diagram.

The voltage vector after the SLED cavity, with real (horizontal) and imaginary part (vertical), is plotted for five different tuning angles. The tip of that vector curves around for different times.

Figure 3 is a plot of the real and imaginary parts of the SLED output field vector, as time increases. The vector is a line from the origin to a point on the line. It starts at the origin, goes first up due to the klystron phase assumption, then the SLED cavities get finally filled with the right rf, it goes flat to positive values. Then the fast 180° switch takes place to above 2 times the original voltage, then it decays slowly to zero, by going exactly through a zero phase (flat) at about 1.5, where the phase is held constant in this simulation, like in the experiment.

C. Experimental detuning results

The SLED cavities are tuned by adjusting screws which deform the cavities and therefore change the tuning angle Ψ. A 90° turn corresponds to Ψ = 37° or 1 °C temperature change:

$$\Psi = \arctan(8.4 \cdot 10^{-3}\, \phi),$$

where ϕ is the mechanical angle in degrees. Figure 4 shows the rf and beam response for different screw rotations between ±90°.

D. Temperature Sensitivity [3]

If the cavities are tuned to resonance, a 0.5 °C temperature variation will cause only a 0.5 % change, while a detuning equivalent to 0.5 °C will cause already a ten times bigger change of 5 %. If all cavities are detuned an equal amount, the normal energy management by scaling of the magnets (LEM) would compensate for that change, while differences in the variation are not corrected.

V. MAIN DRIVE LINE

The Main Drive Line (MDL) runs along the linac and feeds the 30 subboosters and the klystrons with a common phase reference. The changes in length are adjusted for by measuring the changes directly by a interferometer with a pulse along the line. But any power changes due to the resistivity change of copper of 0.39 %/°C will generate a delay in the times-6 multiplier. An additional 4° phase change over the length of the linac is expected which is not corrected.

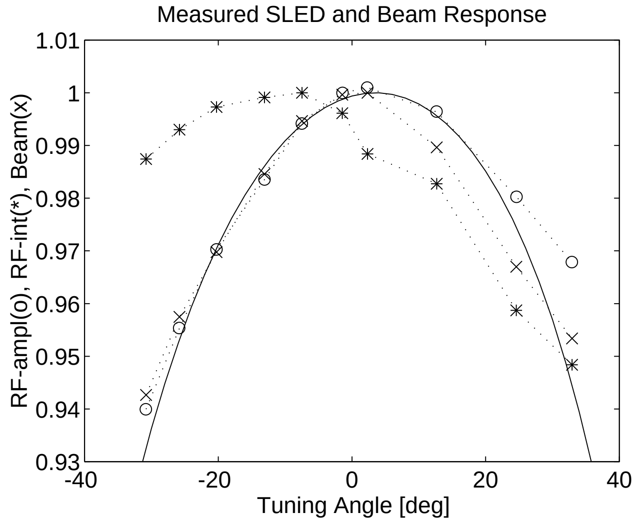

Figure 4: SLED outputs and beam energy.

The measured results from the beam energy (x) and rf amplitude (o) agree well with each other and with the simulated curve (solid). The integral over the significant pulse (*) or E_noload represents pure the real behavior.

VI. DISCUSSION

Day-night temperature variation at the SLC linac is a major limit for delivering stable low emittance beams. Luckily most of the 1994/95 run happened during the rainy season with 1/3 of the peak temperature variations. The rf is the main contributor and especially a correct SLED tuning procedure seems to be critical, which might help to get the variations down by a factor of 2 to 3. Then additional causes like the power level of the main drive line get important.

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[3] Z.D. Farkas, G.A. Loew, *Effect of SLED Temperature Changes on Effective Accelerating Field*, SLAC, CN-124 Oct. 81.