RECENT IMPROVEMENTS IN DRIVE BEAM STABILITY IN CTF3

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Abstract

The proposed Compact Linear Collider (CLIC) uses a high intensity, low energy drive beam producing the RF power to accelerate the low intensity main beam with 100 MeV/m gradient. This scheme puts stringent requirements on drive beam stability in terms of phase, energy and current. Finding and understanding the sources of jitter plays a key role in their mitigation. In this paper, we report on the recent studies in the CLIC Test Facility (CTF3). New jitter and drift sources were identified and adequate beam-based feed-backs were implemented and commissioned. Finally, we present the resulting improvement of drive beam stability.

INTRODUCTION

CTF3 was built to demonstrate the feasibility of the CLIC technology based on the two-beam acceleration concept. This technology imposes strict requirements on drive beam stability, especially in terms of current, energy and phase [1, 2]. The layout of CTF3 is shown in Figure 1.

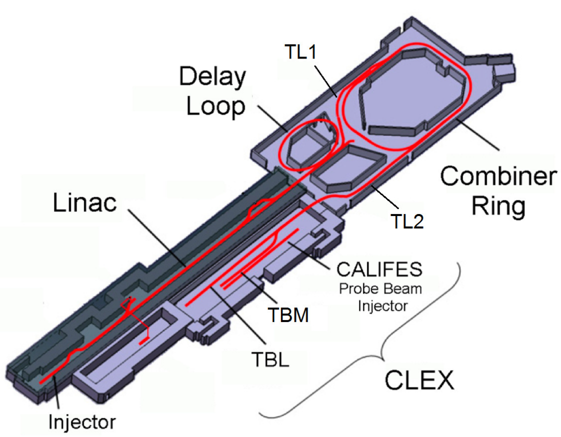

Figure 1: Layout of CTF3

MITIGATION OF DRIFTS

In order to be able to stabilize the beam in a chosen working point any change of the working point itself must be first identified. An online watchdog application has been developed for this purpose. It monitors currents of power supplies driving the magnets, all RF and beam signals and many other high-level inputs. The acquired data are then processed and filtered to highlight the largest differences of current state of the machine with respect to agreed reference values. Figure 2 shows three continuously updated fixed displays. They present sorted lists of χ^2s for machine settings, beam-related measurements and various signals grouped by their type and location. The latter is especially helpful to quickly find out in which part of the machine a problem has occurred, since any upstream drift usually provokes all the downstream beam signals to diverge. For practical reasons the locations with no beam presence are omitted. If any further investigation is needed, a dedicated program for data analysis developed for such purpose can be used.

Correlations between signals are searched and studied offline. This permits to identify the sources of either jitter or drift. Once a device is identified, it is first examined, and if it can not be passively stabilized then an appropriate feedback is implemented.

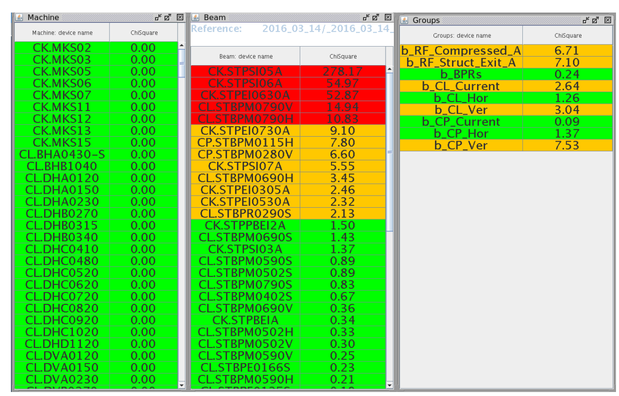

Figure 2: Screen-shot of the watchdog application: left - machine settings, middle - beam and RF measurements and right - devices grouped by location.

BEAM-BASED FEEDBACKS

The CTF3 feedback systems are designed in such a way that their safe operation is ensured. Each feedback does not act unless all the control parameters are within the thresholds defined at the time of commissioning and calibration of the system. Typically, a check is done on the first BPM downstream from the measurement location of the quantity which is being stabilized. Feedbacks follow changes of the beam pulse length and automatically adapt reference ranges. The same feedbacks are used to restore the beam conditions during restart. Nevertheless, reaching the reference working point may be impossible when the output power of one of the two injector klystrons changes dramat-

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ically (higher than 1 MW). Attempt to compesate this by adjusting RF phases or gun current may result in significant beam losses. In order to ensure safe operation, a check of injector klystron power was therefore implemented into several feedbacks.

BEAM CURRENT STABILIZATION

In the past years the beam current stability was satisfactory. A feedback system was in place (demonstrating a relative stability of $5 \cdot 10^{-4}$) [3], but was generally not used in operation. Still tests of beam intensity stabilization system were performed . In the middle of the year 2015 the beam current got significantly less stable and affected machine operation. A new feedback system had then to be implemented since the size of drifts was too large for the existing system. The beam current is measured after the injector where the beam becomes fully relativistic and the first high accuracy Beam Position Monitor (BPM) is installed. The feed-back loop is closed on the gun intensity knob, that regulates the grid voltage in the CTF3 thermionic gun.

BEAM PHASE STABILIZATION

The beam phase is predominantly defined by the injector, after which electrons become ultra-relativistic. CTF3 injector can operate in two different modes:

- 3 GHz Beam - only the 3 GHz bunching system and the accelerating cavities are used. They are powered by two klystrons. This mode is typically used during machine start-up and for the experiments that do not require final drive beam intensities above 16 A (e.g. phase feed-forward experiment [4], optics checks and corrections).
- 1.5 GHz Beam - the three additional 1.5 GHz subharmonic bunchers (SHBs) are powered. This is required to operate the delay loop and to achieve the full drive recombination.

Injector Feedback

The Beam Phase Reference monitors (BPR) installed in CTF3 measure the beam phase, but their signal is also proportional to the beam current squared and inversely proportional to the bunch length. Two such devices are installed in the injector, one in the middle of the injector and a second one at its end. Sensitivity analysis showed that the injector feedback work more efficiently if the phases of the klystrons are locked on the phase signal of the upstream BPR and the bunch length signal of the downstream one. This feedback is used for both injector modes. Initially its performance was limited by a noisy beam phase measurement and by $0.36°$ minimum phase step. Both issues were addressed and eventually fixed during the winter shutdown 2015/2016.

TWT Phase Feedback

For the 1.5 GHz mode an additional feedback was developed in order to stabilize the phases of the traveling wave tubes (TWTs) that power the SHBs. The system stabilizes the RF power at the exit of SHB cavity in presence of the beam (i.e., beam loading measurement) and the beam phase measured by the upstream BPR. An automatic calibration procedure has been implemented because the proportionality ratios are as well subject to drifts.

BEAM ENERGY STABILIZATION

After implementation of the RF power stabilization system [5], the beam energy stability was improved. Nevertheless, it was found that some beam energy variations remained and caused beam intensity fluctuations through losses. The energy variations are mainly due to slow changes of sensitivity in RF phase and power measurements (e.g. temperature effects), on which the phase loops and the RF power stabilization feed-back rely on, respectively. Second, it must be remembered that any beam current variation affects the acceleration in the fully loaded structures of CTF3.

Loading Feedback

Even though the CTF3 linac is operated in fully loaded mode, for most of the cavities the remaining power at the output port, the loading, is measurable. This strongly depends on the phase between the electron bunches and the accelerating field.

In a first stage, the loading "feedback" was just keeping the remaining power below a given limit or minimizing it as a function of klystron phase. Afterwards a more advanced concept has been developed. The remaining power along the beam pulse (not just the average) is measured and it is stabilized on a reference "trace" while adjusting the appropriate klystron phase. The reference trace is the average of several traces acquired for a short period after the feedback is turned on. The construction of the penalty function is not trivial because simple difference or χ^2, even in the simplest case, is neither linear nor monotonous as the working point is close to full beam loading. The feedback minimizes a linear combination of χ^2 from the reference measurement (trace along the beam pulse) and the slope of the remaining power along the pulse. By setting a klystron specific free parameter it becomes monotonous function of klystron phase deviation. Loading feedbacks are implemented and commissioned for all the klystrons in Linac and are relatively slow as they operate on scales of minutes rather than seconds. The energy variation is measured as beam position in the first dispersive BPM, with a horizontal dispersion of 60 cm. The relative beam energy variation with and without the beam-based feedbacks is shown in Figure 3.

Energy Flattening Feedback

The residual beam energy variation along the pulse measured at dispersive pickup is usually few times larger than pulse-to-pulse variation. In order to reduce it, energy flattening feedback has been implemented. It modulates the energy gained in the accelerating structures powered by the

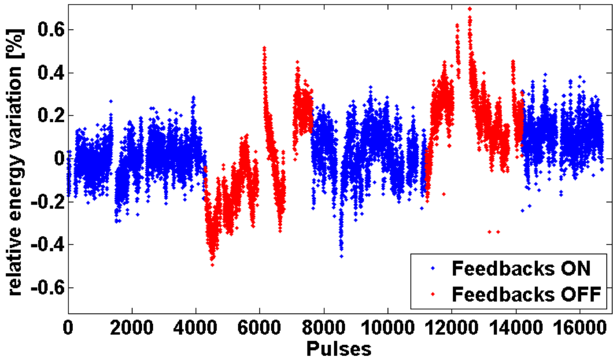

Figure 3: Relative pulse-to-pulse energy variation measured in dispersive pickup with beam-based feedbacks turned on (blue) and off (red).

last linac klystron by programming its waveform generator. The flattening improves the variation along the pulse, nevertheless it has not been fully commissioned for online operation yet.

PRESENT BEAM STABILITY

Presently achieved beam stability is quoted in this section and compared to CTF3 goals. The achieved phase and energy stability over periods of several minutes and several hours is shown in Table 1. Natural energy stability (mean along the pulse) has been improved from 0.22% to 0.12% by improving the gun pulser during the winter shutdown in 2015/2016. Natural phase stability may vary a lot, but usually is about 0.4° at 3 GHz. The current stability from the gun to the dump with a beam multiplication factor 4 is shown in Figure 4. Each blue line stands for a relative current stability over an hour of beam time with beam-based feedbacks running, the red lines stand for the same quantity without beam-based feedbacks. The green dashed line reflects the CTF3 current stability goal.

Table 1: Present Beam Phase and Energy Stability

Time scale	Phase [°]	Energy [%]
several minutes	0.15	0.05
several hours	0.24	0.08
CTF3 goal	0.2	0.1

CONCLUSIONS AND OUTLOOK

The CTF3 Drive Beam Stability has been significantly improved in the past years. This was obtained thanks to the new feedbacks presented here, but also because of improved quality and control of the optics [6, 7]. Sources of jitter and drifts were identified and adequate beam-based feedbacks were implemented and commissioned for online operation. Some of the CLIC requirements have been reached, the rest is being approached. Additionally, the

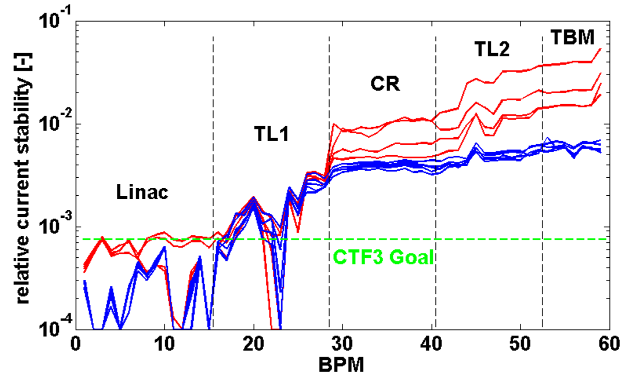

Figure 4: Several sets of relative beam current stability measurement (combination factor 4) along the machine. Each line refer to stability over a period of one hour. In blue; beam-based feedbacks operating, in red: feedbacks turned off.

beam stability is crucial for efficient running of the experiments and beam setup.

ACKNOWLEDGEMENTS

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