

## REVIEW OF THE DRIVE BEAM STABILIZATION IN THE CLIC TEST FACILITY CTF3

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### Abstract

CTF3 is a Test Facility focusing on beam-based studies of the key concepts of the Compact Linear Collider CLIC. Over the past several years many aspects of the CLIC two-beam acceleration scheme were studied in CTF3, including the crucial issue of drive beam stability. The main sources of drifts and instabilities have been identified and mitigated, helping to improve the machine performance and showing significant progress towards the experimental demonstration of the very stringent requirements on current, energy and phase stability needed in CLIC. In this paper, the more effective techniques and feed-backs are summarized. The latest measurements on beam stability are reported and their relevance to CLIC is discussed.

### INTRODUCTION

The aim of the CLIC study is to provide a design for an  $e^+e^-$  linear collider in the TeV-scale [1,2]. The feasibility demonstration is partially carried out at the CLIC Test Facility CTF3. In particular, it demonstrates the generation of the “drive beam” and its use in the two-beam acceleration. The CLIC two-beam acceleration scheme imposes tight tolerances on the drive beam stability, in terms of energy, current and phase [3]. In this article we describe the different categories of feedbacks developed in CTF3 to improve the beam stability: RF-feedbacks and Beam Based Feedbacks.

### DRIVE BEAM LINE

The drive beam generation is sketched in Fig. 1. A thermionic gun is the source of the drive electron beam with the intensity of 4.5 A, emitted from the heated filament during 1.5  $\mu$ s. The bunching system permits to group electrons into bunches by 3 GHz RF and 1.5 GHz RF with a phase coding. The beam pre-accelerated up to

20 MV passes through the cleaning chicane, where 10% of low and high energy particles are eliminated. The beam of 4.0 A with a low energy spread is injected into the linac. It is accelerated in the fully loaded mode at the average gradient of 7 MV/m up to 125 MeV. Then the beam goes through a stretching chicane, where the bunch length can be increased. After that, the beam goes around the delay loop and combiner ring, where the intensity can be increased by the factor four or eight. The generated high-intensity up to 31 A, high-energy, X-band frequency of 12 GHz beam is transported to the test lines, where the beam is most required to be stable.

The quality, efficiency and stability properties of the beam have been extensively studied for a long period of time. The best short term stability has been measured only when the machine was perfectly tuned. The long term stability needed for the day-to-day operation is primarily determined by the capability of preserving the RF and injector setups.

### RF STABILIZATION

The RF stability plays the essential role in the CTF drive beam generation. RF deviations in the injector transfer into beam phase deviations and they increase the bunch length and beam losses. RF deviations in the linac significantly influence the beam energy and emittance.

In order to reach the required RF power of over 30MW, the RF pulse from the klystrons is fed into an RF pulse compression system that provides a power gain of about two in klystron peak power (Fig. 2). It is worth noting that the pulse compression system is not foreseen to be used in CLIC. However, the pulse compression system adds an extra layer of complexity that has to be controlled in CTF3.

The high-power RF at the input of accelerating structures is controlled by the low level RF phase program and the tuning of RF pulse compressors. Due to the long distance between RF actuators and accelerating

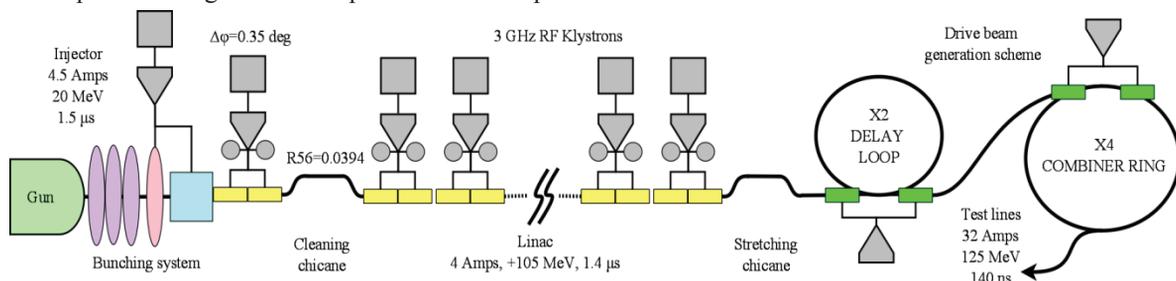


Figure 1: CTF3 drive beam layout.

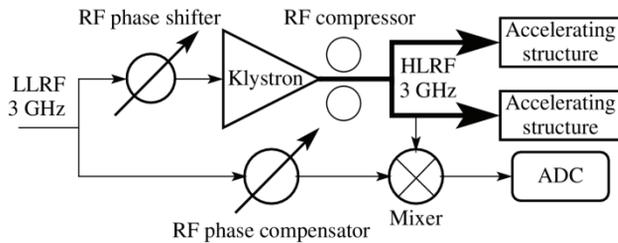


Figure 2: RF flow diagram.

structures there is no possibility to apply any in-pulse beam feedback correction. Therefore RF deviations can be compensated only by pulse-to-pulse feedback systems and by systems eliminating sources of deviations.

### RF Pulse Compression

The pulse compression cavities (so called LIPS- and BOC cavities) need to be precisely tuned, and their resonant frequencies must be stabilized to  $\pm 1.5$  kHz to achieve the required total  $\pm 1\%$  amplitude and  $\pm 5^\circ$  phase variations. This corresponds to  $\pm 0.03^\circ\text{C}$  of the maximum permitted temperature deviation. Each compressor cavity is connected to an individual cooling circuit, where the mean water temperature is stabilized to this level [4].

In order to keep the compressor temperature stable and therefore to stabilize compressed RF phase and amplitude, the temperature stabilization feedback takes into account the inlet and outlet water temperatures, the ambient temperature and the dissipated RF power in the compressor. The water mean temperature control is used as the actuator for slow corrections. The stabilization system reduces RF power variations from 10% down to 1.5% and it almost completely eliminates RF phase variations of  $\pm 2.5^\circ$ .

The most tangible source of the residual RF compression variations was recently found and cured. The temperature of heated water for RF compressors fluctuated up to  $\pm 0.1^\circ\text{C}$  in time as a result of distortions in the 3-phase mains voltage powering heater resistors. The finding was confirmed with RF, water temperature and mains voltage measurements. The measured variations were also significantly correlated with the operation of the Anti-proton Decelerator machine at CERN. The machine cycle of about 100 sec was clearly pronounced in all measurements. In order to cope with such external influences a high resolution measurement of the mains voltage was integrated into the water temperature control system, which reacts appropriately on voltage changes up to  $\pm 10\%$  with the total delay of less than 1 sec. The new configuration eliminates the low-frequency pattern of the voltage variation.

### RF Phase Loop

The main source of the RF phase fluctuations after RF pulse compressors is the temperature change of long waveguides and phase shifters. Phase offset deviations of over  $10^\circ$  were observed along a hot day. A low-level RF phase loop is used to compensate phase offsets in a pulse-

to-pulse feedback mode. The RF phase at the input of the accelerating structure is measured with respect to the reference of the klystron low-level RF with a resolution of below  $0.01^\circ$ . The digital phase shifter, which is installed between the low-level RF reference and the klystron, allows controlling the phase offset with the smallest step of about  $0.35^\circ$ . A sophisticated algorithm controlling the loops shows the expected ability to reduce the phase offset to long-term pulse-to-pulse variations down to  $\pm 1.1^\circ$  and standard deviations down to  $0.4\text{--}0.7^\circ$  at 3 GHz. The current low level phase control limitations do not allow generating the 12 GHz drive beam with a beam phase jitter below than  $1.5^\circ$ . It is expected that the beam phase jitter will be significantly reduced by the beam phase feed-forward system, which is under development.

### RF Amplitude Stabilization

In spite of the above stabilization systems the RF-amplitude after the pulse compression has been observed to vary in the order of a percent. The observed RF variations remain correlated with small residual water temperature perturbations.

The RF pulse compression is steered by the way the phase changes along the RF pulse. Through adjusting the phase program of the klystron it is possible to regulate the amplitude of the RF. The feedback operates by comparing the RF-amplitude to a set point and based on the difference inferring a correction to the phase program. It has been shown that the increased RF-amplitude stability is significantly improving the energy stability of the beam [5].

## BEAM BASED FEEDBACKS

Even with the stabilized RF (Fig. 3), observations have shown that the beam drifts in time. One of the current CTF3 goals is to establish a highly stable combined beam. The energy and intensity are required to be stable at the same time:  $\left| \frac{\Delta I_L}{I_L} \right| < 0.075\%$  and  $\left| \frac{\Delta E}{E} \right| < 0.1\%$ . In order to mitigate instabilities, feedbacks operating directly on beam measurements have been developed. A better understanding of the optics has increased the dynamic

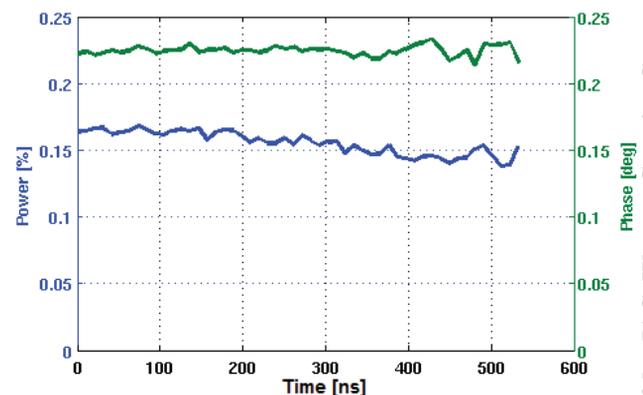


Figure 3: Residual pulse-to-pulse RF jitter along the pulse at the input of one accelerating structure.

aperture and hence, also contributed to the improved beam stability.

### Beam Intensity Stabilization

The beam intensity stability is one of the target parameters, which slowly varied by over 0.2% before a beam current stabilization feedback was implemented. In the chosen mode of operation the feedback copes with small energy and intensity variations and it keeps the intensity stable at the end of the linac, but it cannot completely compensate energy distortions [6].

The actuator of the intensity compensation is the grid voltage control in the thermionic gun. The gun control allows modifying the beam intensity in the order of  $10^{-5}$  Amps, which is sufficiently small. The beam intensity is measured by Beam Position Monitors (BPM) with a resolution of only 5.8 mA. The integration over the pulse length up to 1.4  $\mu$ s and averaging over several consecutive BPMs improve the resolution and reduce the noise down to 0.3 mA, which is below 0.01%. The minimum step of RF phase shifters in the injector bounds not only the beam phase error, but also the beam intensity stability to  $\left|\frac{\Delta I_e}{I_e}\right| \geq 0.015\%$ . A self-calibration process of the feedback controller computes an accurate calibration of feedback parameters for an optimum performance.

The beam intensity jitter has been reduced down to 0.045%. The intensity stabilization in the linac successfully transfers intensity variations from the linac into the injector within a small and preserved range of gun adjustments in the day-to-day operation. Thereby it keeps the intensity stable at the end of the linac and it already notably reduces energy deviations.

### Beam Energy Stabilization

In order to mitigate the residual beam energy variation a feedback was designed. It measures the energy using a dispersive pickup and changes the power of the last klystron in the linac accordingly. The RF-amplitude is adjusted by changing the phase program of the klystron. In order not to be so sensitive to noise the feedback average over four pulses before it applies a correction. A comparison when the feedback was on and it was off is shown in Fig. 4. The use of the energy feedback reduced the standard deviation of the energy by about 40% over a time period of 15 minutes.

### Beam Phase Stabilization

The injector in CTF3 determines the phase of the beam. The phase stability is of importance for the experiments in CTF3 and for the overall performance of the machine.

A feedback has been designed and implemented to stabilize the phase using measurements from two beam phase monitors. It operates by adjusting the phase of the two first klystrons to keep the injector stable. The first measurements showed that the feedback reduces drifts of the beam phase by about 40%.

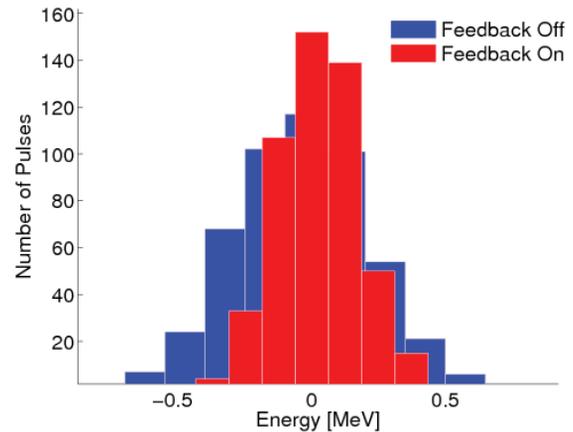


Figure 4: The relative energy deviation from the reference point, in red: feedback on, and blue: feedback off.

## CONCLUSIONS

The developed drive beam stabilization systems are continuously and simultaneously applying corrections at different parts of the machine. The result of collective corrections is represented by beam stability measurements at the end of the linac and they show a significant improvement of the preservation of beam qualities. These systems are laid as the basis for daily operations of the beam-based tests and beam optic studies. A further improvement of the injector RF and beam optics optimizations is going on.

## ACKNOWLEDGMENT

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