

## BEAM STABILITY AT CTF3

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### Abstract

The two-beam acceleration tested at CTF3 imposes very tight tolerances on the drive beam stability. A description of the specialized monitoring tool developed to identify the drifts and jitter in the machine is presented. It compares all the relevant signals in an on-line manner to help the operator to identify drifts and to log data for off-line analysis. The main sources for the drifts of the drive beam have been identified and their causes are described. A feedback applied to the RF was implemented to reduce the effects. It works by changing the waveform for the pulse compression to compensate for the drifts.

### INTRODUCTION

The aim of the CLIC study is to provide a design for a multi-TeV  $e^+e^-$  linear collider. The feasibility demonstration is carried out at the CLIC Test Facility, CTF3. In particular, it demonstrates the generation of the “drive beam” and its efficiency in the two-beam acceleration [1]. The CLIC two-beam acceleration scheme imposes tight tolerances on the drive beam stability. The accepted variance of the beam current is  $\frac{\sigma_I}{I} = 7.5 \cdot 10^{-4}$  [2], which is related to its strong influence on the main beam energy. In turn any energy variation causes a luminosity decrease, which can be written as[2]:

$$\frac{\Delta\mathcal{L}}{\mathcal{L}} = 0.01 \left( \frac{\sigma_I}{7.5 \cdot 10^{-4} I} \right)^2 \quad (1)$$

In CTF3 a RF pulse compression scheme is used. It converts klystron provided  $\sim 5.5\mu s$  pulses into  $\sim 1.3\mu s$  ones of double peak power [4]. It is based on energy storage cavities that must have a very precisely tuned frequency, which in turn depends on their dimensions. Any change in temperature changes the size of the cavity and hence their resonant frequency. A change of  $\pm 0.03^\circ C$  results in an amplitude variation of  $\pm 1\%$ [5].

It should be stressed that the pulse compression system will not be used in CLIC. In CTF3 it must be used because the klystrons are inherited from the LEP injector and were optimized for different parameters.

### REFERENCE MONITOR

A specialized monitoring tool has been developed to identify the sources of the drifts and jitter in CTF3. It compares all the relevant signals to their reference values. It monitors amplitudes and phases of RF pulses, beam position, current and phase, bunch length and all the other signals that either represent or impact the state of the beam. In case the beam drifts from its set point this software permits a quick reestablishment of the desired state. The pro-

gram calculates and displays continuously the difference between the current state of a given signal and its reference. This speeds up the process of finding the devices that have changed. Additionally, it enables the user to see the correlation between different signals. This functionality allows for finding the source of a certain jitter or drift. Today, the CTF3 Reference Monitor plays a central role in identifying drifts as well as bringing the machine to a desired state. The difference between the measured signal and its

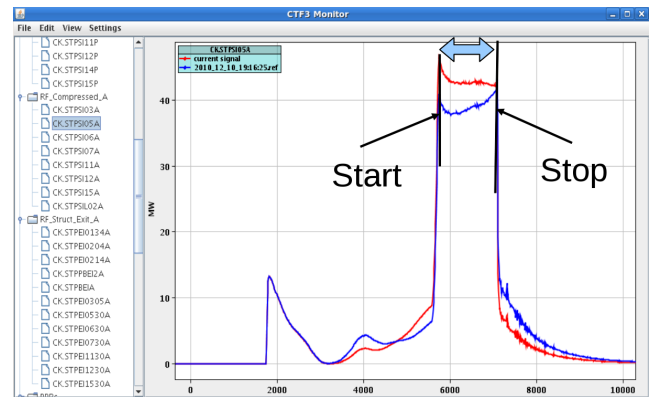


Figure 1: Screen shot of the CTF3 Reference Monitor. In red the compressed pulse read out from the machine and in blue the stored reference of the pulse.

reference is quantified with a  $\chi^2$  value that is calculated and displayed on-line:

$$\chi^2 = \frac{1}{stop - start} \sum_{i=start}^{stop} \left( \frac{x_i - r_i}{\sigma} \right)^2 \quad (2)$$

where  $\sigma$  is a user defined parameter,  $x$  is the measured signal and  $r$  is the reference signal.

### STABILITY

The stability of the beam current in the CTF3 linac was measured to be  $\frac{\sigma_I}{I} = 5 \cdot 10^{-4}$  for an individual BPM, which is well below the required  $\frac{\sigma_I}{I} = 7.5 \cdot 10^{-4}$  [3]. However, as the beam is transported further down the machine, its stability degrades [6]. Through careful study of the correlations between different signals it was possible to find that the losses downstream of the linac were correlated with the beam position observed in locations where dispersion was not zero. At the same time the losses were not correlated with beam position at zero dispersion sections. This confirmed that the beam current changes came from an energy variation of the beam and were not caused by an unstable power supply, for example. The energy of the beam is

determined by the phase and amplitude of the RF. A measurement of the RF amplitude and the beam energy, from a dispersive pickup, showed that most of the energy variation could be accounted for by the RF amplitude changes. This revealed that the amplitude variation of the RF was the main cause of the energy variation seen on the beam.

Measurement of the RF pulse at the output of klystrons, before it is compressed, has shown small impact on the amplitude after the pulse compression.

The size of the resonating cavity is influenced by the temperature of the cooling water as well as by the room temperature. Temperature for each RF pulse compression system is stabilized by a cooling station, which is designed to regulate the temperature to  $\pm 0.05^\circ C$ . The temperature feedback was implemented to compensate the change of the room temperature by adjusting the cooling water temperature [5]. This feedback is essential to stabilize the RF pulses in CTF3.

Figure 2 shows the influence of the cooling water temperature on the RF amplitude. The water temperature is integrated over 10s since it takes some time for the water to change the temperature of the resonating cavity.

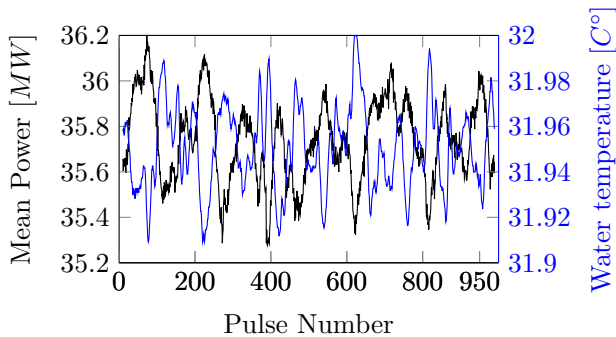


Figure 2: In blue the water temperature integrated over 8 pulses and in black the mean value of the RF power.

### IMPLEMENTATION OF FEEDBACK

The cooling station stabilizes the water temperature according to its specification, i.e.  $\pm 0.05^\circ C$ . It was necessary to find another solution to further stabilize the RF pulse amplitude. The RF pulse compression is steered by the way the phase changes along the RF pulses and is referred to as the phase program. An adjustment of the phase program impacts the output power after compression.

The feedback measures the compressed output power and compares it to the desired values. The difference is multiplied by a constant and the change is inferred on the phase program. In order to avoid changing the phase program in case the power delivered by a klystron is significantly too low the feedback ignores differences larger than 10% of the nominal amplitude. The principle of the feedback is shown in Fig. 3. There are three main factors limiting the performance of the feedback:

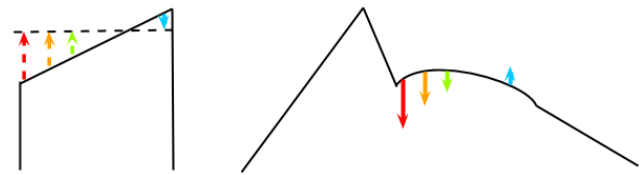


Figure 3: The left figure shows the RF pulse. The dotted line represents the desired value and the solid the actual value. The right figure shows the phase program. The arrows on the RF pulse show the difference between the measured and the desired values and the solid arrows show the inferred change for the phase program.

- The system is bandwidth limited. It is only possible to apply a correction every third pulse.
- The uncertainty of the compressed pulse measurement deriving from the noise of the measurement.
- The system is intrinsically non-linear. The output power at a certain point does not depend linearly on the amplitude of the phase program. The output power at each part depends strongly also on the overall phase program.

These limitations force us to change the phase program by sufficiently small steps so the response is still close to the linear range.

### RESULTS

The feedback stabilizing the RF amplitudes is nowadays used routinely in the daily operation. Figure 4 presents a comparison between the output power from a klystron with the feedback on and off.

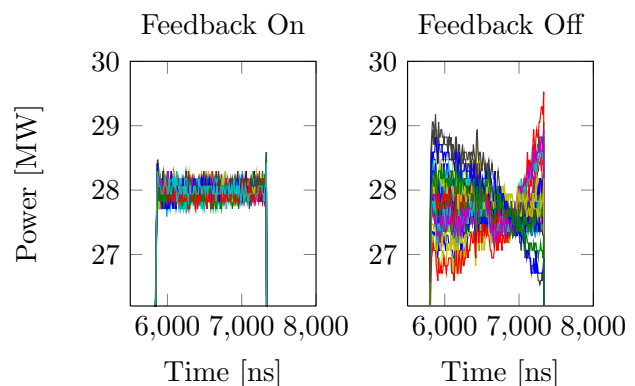


Figure 4: The power variation along the pulse, in the left figure the feedback is enabled and in the right figure disabled.

The RF feedback has been shown to damp the oscillation caused by the cooling water and fully compensate for the slower drifts. The slower drifts take place over longer time scales. They are either caused by small changes in the output power of the klystron or by slow temperature drifts of the cavity.

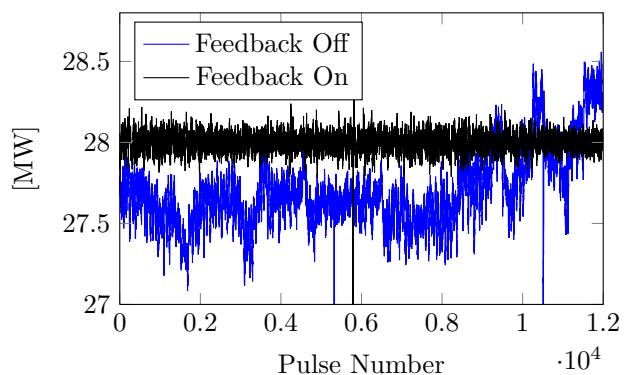


Figure 5: The mean power variation of klystron MKS 06. In black the feedback is on and in blue it is off.

Table 1: The variation of the individual klystrons with and without feedback. The quoted values are the interval where 95% of the pulses were in for 12000 consecutive pulses. The klystrons power ranges from 25MV to 41MW.

Klystron	Feedback ON	Feedback OFF
MKS 03	0.21 MW	0.41 MW
MKS 05	0.22 MW	0.97 MW
MKS 06	0.24 MW	1.03 MW
MKS 07	0.41 MW	1.11 MW
MKS 11	0.22 MW	0.65 MW
MKS 13	0.39 MW	1.14 MW
MKS 15	0.20 MW	0.24 MW

In table 1 the improvements for each individual klystron are shown. The reduction factors vary from 50% up to 75%. Figure 6 illustrates the improvement of the energy

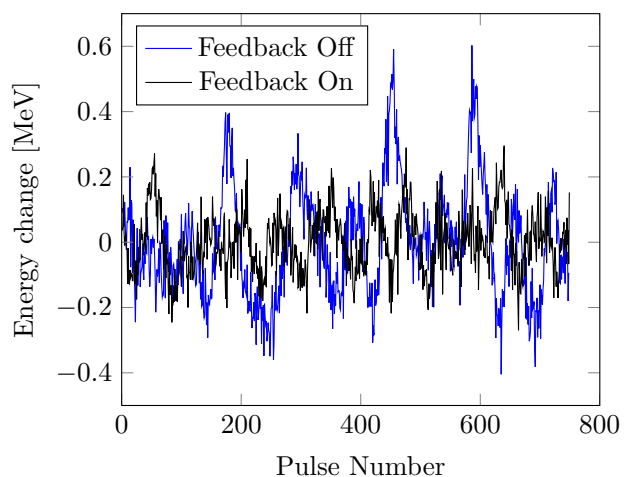


Figure 6: The beam energy variation measured from a dispersive pickup. The blue trace is with the feedback disabled and the black is with the feedback enabled.

stability achieved. The measurement of the energy was done using a dispersive pickup.

The reduction of the energy variation peak to peak is

40%. When performing the measurement over larger time scales the improvements can go up to 55%.

The described feedback, together with other improvements, has played a key role in the quest to reach the beam current stability required by CLIC also downstream of the linac. During 2011 the measured beam stability in the Combiner Ring for a beam obtained after recombination (factor 4 increase in current), when bypassing the delay loop, was  $\frac{\sigma_I}{I} = 1.01 \cdot 10^{-3}$  and this value is close to the CLIC requirement. Even with all the extra complications, such as the pulse compression system and hardware not designed for this purpose, the drive beam in CTF3 reaches this level of stability. It is a very encouraging result.

## CONCLUSION

The CTF3 Reference Monitor is used to bring the machine to a desired state as well as a tool to find sources of drifts. With its help the main cause of the energy variation has been established to be the variation of the amplitude of the RF. The primary underlying cause of these variations has been found to come from the fluctuations of the cooling water temperature. The implementation of a new feedback used to stabilize the output RF has been described. A significant improvement in the stability has been shown both in the measured RF pulses and in the beam energy stability. As a future step to improve the beam stability a feedback that measures the beam energy from the dispersive pickups and uses it as an input to regulate the output power of the last klystron is foreseen.

## ACKNOWLEDGMENTS

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