

# RF PULSE COMPRESSION STABILIZATION AT THE CTF3 CLIC TEST FACILITY

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## Abstract

In the CTF3 accelerator, the RF produced by each of ten 3 GHz klystrons goes through waveguides, RF pulse compressors and splitters. The RF phase and power transformation of these devices depend on their temperature. The quantitative effect of the room temperature variation on the RF was measured. It is the major source of undesired changes during the CTF3 operation. An RF phase-loop and a compressor temperature stabilization are developed to suppress the phase fluctuation and the power profile change due to the temperature variation. The implementation is transparent for operators, it does not limit anyhow the flexibility of RF manipulations. Expected and measured suppression characteristics will be given.

## INTRODUCTION

In the context of the feasibility demonstration of the CLIC linear collider [1], the CLIC Test Facility CTF3 [2] is to demonstrate in particular the generation of the high current, so called “drive beam” of CLIC. The drive beam in CTF3 is accelerated in 3 GHz S-band travelling-wave accelerating structures. In order to reach the required RF power of over 30 MW, 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 [3].

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  $\pm 1\%$  amplitude and  $\pm 5^\circ$  phase stability. This corresponds to  $\pm 0.03^\circ\text{C}$  of maximum permitted temperature variation. Each compressor cavity is connected to an individual cooling circuit, where the mean water temperature is stabilized to this level.

Nevertheless, an important change of the pulse compression was observed during operation when the ambient room temperature in the klystron gallery changes or when the power level in the cavity was changing (Fig. 1). Since these variations require frequent time-consuming re-optimization of the RF pulse compression during CTF3 operation, the system described in the following was conceived and implemented to stabilize the RF pulse compression.

## MODEL

In the normal operation the compressed RF pulse must be high power with a low phase deviation along  $1.4\mu\text{s}$ . The klystron low-level RF phase waveform programming

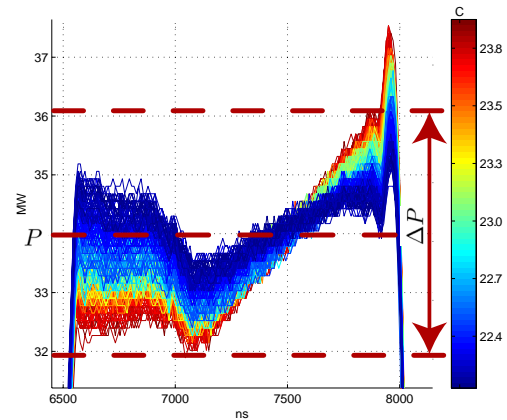


Figure 1: Power variation along the pulse at different ambient room temperature

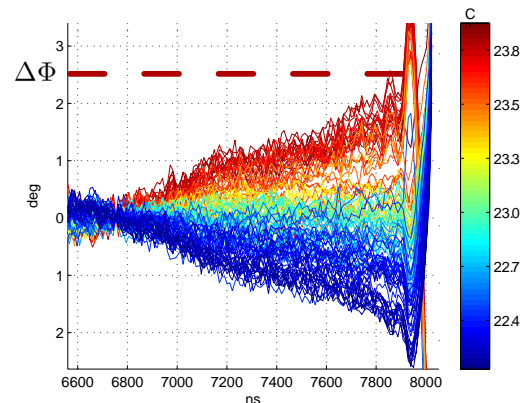


Figure 2: Phase variation along the pulse at different ambient room temperature

allows to achieve an output power gain of about two with a static second order phase variation of  $8 - 10^\circ$ . The technique of tuning of BOC- and LIPS-cavities is described in [4] in the case when the RF source frequency and the resonance cavity frequency are well matched. The flat top of the RF power bends with respect to the frequency difference between the klystron RF frequency and the resonance cavity frequency [5]. For simplicity we will consider that, when the klystron RF phase and the RF compressor are tuned as it is setup in CTF3 operation, the top parts of RF amplitude and RF phase are flat. Hence for a small resonance frequency change  $\Delta f$  the normalized transmitted

wave at the flat top can be written as:

$$E_L = A(\Delta f)e^{i(\omega+2\pi\Delta f)t+i\phi(\Delta f)} + e^{i(\omega t)}, \quad (1)$$

where  $\omega = 2\pi f_{rf}$ ,  $\phi(\Delta f)$  is the phase shift difference after the actual filling time, and  $A(\Delta f)$  is the amplitude of the emitted wave, mainly changed due to the stored energy difference. The last satisfies the following condition:

$$|A| < \frac{2\beta}{\beta + 1}, \quad (2)$$

where  $\beta$  is the coupling coefficient between the waveguide and the cavity. The cavity resonance frequency is very sensitive to the size of the cavity. The frequency shift induced by the temperature change is given by:

$$\Delta f = f_{rf} - \frac{f_{rf}}{1 + \lambda_L \Delta T}. \quad (3)$$

The linear thermal expansion can be taken for the copper material  $\lambda_L = 17 * 10^{-6} \frac{1}{^\circ C}$ . For small temperature fluctuations the frequency shift  $\Delta f$  is linearly proportional to  $\Delta T$ . Hence the temperature change of  $0.196^\circ C$  shifts the resonance frequency by 10 kHz. Using the rough approximation of the transmitted wave (1) and assuming parameters for the CTF3 case, the amplitude stability  $\frac{\Delta P}{P}$  is proportional to the square of the frequency difference and the phase variation  $\Delta\Phi$  is linearly proportional to  $\Delta f$ , thus:

$$\frac{\Delta P}{P} \sim \Delta T^2, \quad \Delta\Phi \sim \Delta T. \quad (4)$$

The last relations (4) agree with the observations. The power variation along the pulse with respect to the ambient room temperature variation is shown in Fig. 1, where the gradient of power slope  $\frac{\Delta P}{P}$  satisfies the condition (4). Figure 2 illustrates the phase variation  $\Delta\Phi$  along the pulse with respect to the ambient room temperature. The static second order phase variation of  $4^\circ$  was subtracted from the phase measurements and they were aligned with a fix point  $0^\circ$  at a certain position. The measurements were done over several hours. The observed fluctuation of the ambient room temperature of  $2^\circ C$  increases the power variation from 2% to 10% and the additional phase variation by  $4^\circ$ . The cavity temperature varies along the day with to the ambient temperature. This strong temperature influence is not acceptable for the CTF3 machine operation.

## IMPLEMENTATION OF STABILIZATION

Each RF compressor is equipped with a water cooling system. The incoming  $T_{in}$  and outgoing  $T_{out}$  temperatures are measured. At a constant water flow rate, a water temperature feedback keeps the mean temperature  $(T_{in} + T_{out})/2$  constant. All measurements above (Fig. 1 and 2) were taken with the feedback switched on. This points out that the current approach applied in CTF3 is insufficient for the RF stabilization. Below we will describe the new approach.

### 07 Accelerator Technology

#### T06 Room Temperature RF

A few assumptions should be made. The first assumption is that the water flow is turbulent enough, that at any position in the cooling tube the averaged temperature over a period of a second remains the same if the dissipation stays constant. The second, the temperature dissipation in the RF compressor is homogeneous, much faster than the ambient room temperature change (1 hour) and slower than the period between RF pulses (0.1 sec). Hence a generic temperature of the compressor  $T_{BOC}$  can be assumed. The generic temperature is not necessarily the temperature of a hardware part, it represents the resonance frequency.

The generic temperature depends on the air temperature  $T_{air}$ , the cooling water temperature and the dissipated energy  $U_{dis}$  in the cavity (Fig. 3). Using thermodynamics laws it can be expressed as

$$\begin{aligned} T_{BOCin} &= T_{in} - k_1(T_{in} - T_{air}), \\ T_{BOCout} &= T_{BOCin} - k_2(T_{BOCin} - T_{BOC}), \\ T_{out} &= T_{BOCout} - k_3(T_{BOCout} - T_{air}), \\ \frac{\partial T_{BOC}}{\partial t} &= k_3(T_{BOC} - T_{air}) + k_4 U_{dis} + k_5(T_{BOCout} - T_{BOCin}), \end{aligned} \quad (5)$$

where  $T_{BOCin}$  and  $T_{BOCout}$  - incoming and outgoing BOC water temperature,  $T_{in}$  and  $T_{out}$  - measured incoming and outgoing water temperature,  $k_1$  is the coupling coefficient between the water tube and the surrounding air,  $k_3$  is the coupling coefficient between the RF compressor and the surrounding air,  $k_2$  and  $k_5$  - the coupling coefficients between the RF compressor and the water tube. In this model the temperature loss in the lead-in tube is considered, what's why the temperatures  $T_{BOCin}$  and  $T_{in}$  are different, as well as  $T_{BOCout}$  and  $T_{out}$ . Simulations with  $2^\circ$  room temperature variation showed the BOC temperature variation of half a degree, where the standard water and copper coupling coefficients were used. Since the generic temperature changes slowly we can take  $\frac{\partial T_{BOC}}{\partial t} \ll 1$ . Thus,

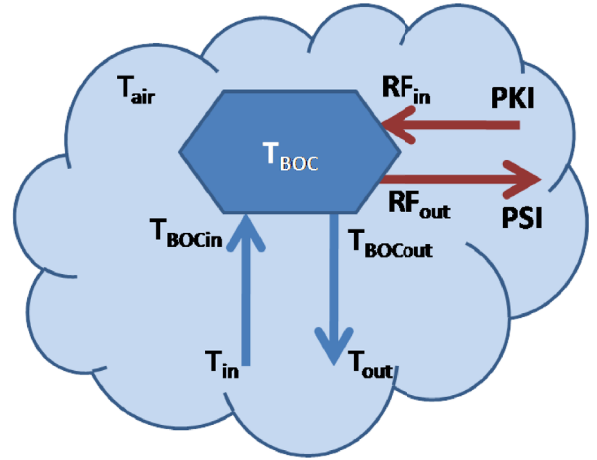


Figure 3: Scheme of actors affecting the RF compressor temperature change. Blue arrows are incoming and outgoing water cooling pipes; red arrows are klystron and compressed RF waveguides; the cloud is the surrounding air.

using equations (4) and (5) the RF phase variation along the pulse should satisfy the following equation:

$$\Delta\Phi = a_0 + a_1T_{in} + a_2T_{out} + a_3T_{air} + a_4U_{dis}, \quad (6)$$

where  $a_0, a_1, a_2, a_3$  and  $a_4$  are some constants and the dissipated energy is linearly proportional to the missing energy, which is measured using power-meters before and after the compressor. The unknown constants can be found from measured data by fitting the last equation over a period with significant temperature and dissipated power variations.

The water mean temperature control is the actuator for the stabilization control system. In order to stabilize compressed RF phase and amplitude, one has to keep the following condition:

$$a_1\Delta T_{in} + a_2\Delta T_{out} + a_3\Delta T_{air} + a_4\Delta U_{dis} = 0. \quad (7)$$

So an adaptive discrete feedback system using second order filtering has been applied. This solution prevents unstable interactions with a lower level feedback, which keeps the mean water temperature constant. Being independent of the RF wave shapes, the controller is absolutely transparent for operators. Numerical analysis showed that this approach will significantly improve the RF stability issue close to the requirements. The stabilization system will be implemented in coming months.

## PHASE STABILIZATION

RF measurements at the input of the accelerating structure showed that the phase waveform offset changes in time. One of the sources is the phase shift  $\phi(\Delta f)$  in the RF compressor related to the cavity resonance frequency change. Another source is the temperature change of long waveguides and phase shifters. But also there exist unknown sources changing the phase offset. In total phase offset variations of over 10 degrees were observed along a day.

In addition to the stabilization of the RF pulse compression system, a low-level RF phase loop is used (Fig. 4). The RF phase at the input of the accelerating structure is measured with respect to the reference of the klystron low-level RF. The phase compensator allows to set the phase reference point to zero. The phase shifter, which is installed between the low-level RF reference and the klystron, allows to control the phase offset. In order to compensate phase offset fluctuations, a slow pulse-to-pulse feedback system with first order filtering has been applied. An ideal feedback method would be able to reduce the phase variation down to  $\pm 0.3^\circ$ . For the stabilization system in the described configuration the expected residual phase variation is  $\pm 1^\circ$ . The measured variation was around  $\pm 1.1^\circ$  and the standard deviation was between  $0.4^\circ$  and  $0.7^\circ$ , it depends on the feedback configuration for the individual circuit. The smaller standard deviation is measured for the more frequent phase adjustment, the lower limit is given by the highest machine control frequency of 0.8 Hz.

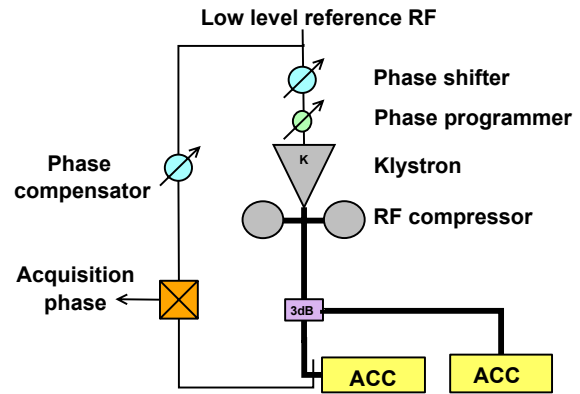


Figure 4: Phase loop layout. Bold lines are high power RF waveguides, thin lines - low level RF signals, ACC - accelerating structures.

## CONCLUSION

The effect of the daily temperature variation on the high-power RF compressor has the major impact on the RF stability in the CTF3 accelerator. An improved approach to stabilize the RF compression has been described. The analysis showed that the feedback stabilization system can suppress the RF amplitude and phase fluctuations down to  $\pm 1.5\%$  and  $\pm 6^\circ$ , respectively. The phase loop stabilization system has shown the expected ability to reduce the phase offset fluctuations down to  $\pm 1.1^\circ$ . The phase loop feedback demonstrated rigidity and reliability. The RF pulse stabilization systems should significantly improve the stability of CTF3.

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## REFERENCES

- [1] Assmann, R. W. et al., "A 3 TeV  $e^+e^-$  Linear Collider Based on CLIC Technology", Geneva, 2000, CERN.
- [2] Geschonke, G. and Ghigo, A., "CTF3 Design Report", Geneva, 2002, CERN.
- [3] Mourier, J., Bossart, R., Nonglaton, J. M., Syratheev, I. V., and Tanner, L., "Low Level RF Including a Sophisticated Phase Control System for CTF3", Geneva, 2004, CERN.
- [4] Syratheev, I. V., "RF Pulse Compression for the Future Linear Collider", in *Frontiers of Accelerator Technology*, edited by Kurokawa, S. I., Month, M., and Turner, S., pages 716-741, Japan, 1996, World Scientific.
- [5] Bossart, R., Brown, P., Mourier, J., Syratheev, I. V., and Tanner, L., "High-power Microwave Pulse Compression of Klystrons by Phase-Modulation of High-Q Storage Cavities", Geneva, 2004, CERN.