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THE DRIVE BEAM PHASE STABILITY IN CTF3 AND ITS RELATION TO THE BUNCH COMPRESSION FACTOR

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CERN, Geneva, Switzerland

Abstract

The proposed Compact Linear Collider (CLIC) is based on a two-beam acceleration scheme. The energy needed to accelerate a low intensity "main" beam is provided by a high intensity, low energy "drive" beam. The precision and stability of the phase relation between two beams is crucial for the performance of the scheme. The tolerable phase jitter is 0.2 deg rms at 12 GHz. For this reason it is fundamental to understand the main possible causes of the drive beam timing jitter. Experimental work aimed at such understanding was done in the CLIC Test Facility (CTF3) where a drive beam with characteristics similar to the CLIC one is produced. Several phase measurements allowed us to conclude that the main source of phase jitter is energy jitter of the beam transformed and amplified into phase jitter when passing through a magnetic chicane. This conclusion is supported by measurements done with different momentum compaction values in the chicane. In this paper the results of these several phase measurements will be presented and compared with expectations.

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CTF3

The CLIC Test Facility 3 [1], presented in Fig. 1, is built to test key concepts of the CLIC drive beam generation and two-beam acceleration scheme and to prove the feasibility of all aspects of CLIC. The drive beam produced in the facility has characteristics similar to the CLIC one and was used for to obtain information on achievable levels of phase variation and jitter, including identification of sources and potential mitigation techniques. By altering the momentum compaction value in the end-of-linac chicane several measurements have been obtained using four different button pick-ups (BPRs) installed at locations along the facility beam lines:

- Two in the LINAC (CL.STBPR0290 and CL.STBPR0475, or BPR 290 and 475 respectively for short)
- One in the transfer line to the combiner ring (CT.STBPR0532 or BPR 532 for short)
- One in the combiner ring (CR.STBPR0505 or BPR 505 for short)

These button pick-ups operate at 3 GHz central frequency but for consistency all results presented have been converted to phase in degrees at 12 GHz.

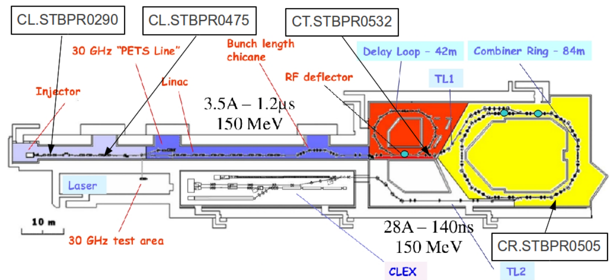

Figure 1: Layout of CTF3 and position of available phase monitors.

PHASE MEASUREMENTS

Previous measurements [2] had pointed out, as the main sources of drive beam phase jitter in CTF3, to energy fluctuations originating in the injector and transformed and amplified into phase jitter when passing through the end-of-linac magnetic chicane. The goal of the new measurements was to determine with certainty if phase instabilities are correlated to different momentum compaction values of the magnetic chicane. For this reason two quantities were measured and analysed; the pulse-to-pulse phase variation and the intra-pulse phase variation, using three different values of R56 in the chicane; 0.45, 0.2 and 0.0. Furthermore, in order to ensure the validity of results as well as reproducibility the complete measurement sequence cycled between different values for the R56 as follows:
$0.00 \rightarrow 0.20 \rightarrow 0.45 \rightarrow 0.20 \rightarrow 0.00 \rightarrow 0.45$.

Intra-pulse Phase Variation

The intra-pulse phase variation is defined as the change of the phase between sampling points along the pulse. In Figure 2 the intra-pulse phase variation is shown, comparing different values of R56 (0.00 and 0.45) for different BPRs before (CL.STBPR0290, CL.STBPR0475) and after (CT.STBPR0532, CR.STBPR0505) the chicane.

Before proceeding to the analysis of the data related to the R56 values, the origin of two features of the intra-pulse phase variation should be clarified. First of all the overall shape is linked to the RF pulse compression process, which produces a second order phase sag. RF compression will not be used in CLIC. The small oscillations along the pulse are linked to oscillations of the Klystron RF Phase coming from voltage ripples of the modulators and oscillations of the beam current of the gun. Both features are static or changing very slowly with time.

In Figure 2 it can be seen from the top Figure that

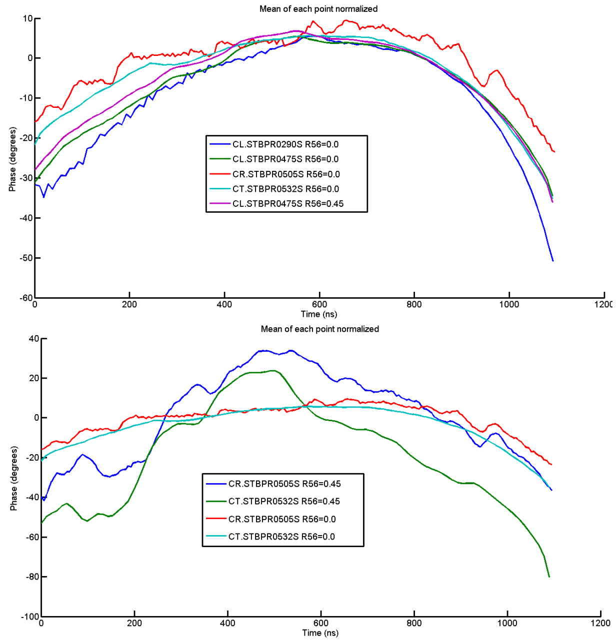

Figure 2: Comparison between intra-pulse phase variations for different BPRs in the case of R56=0.0 (top) and for both R56=0.0 and 0.45 (bottom).

the intra-pulse phase variation is similar for the BPRs in the LINAC (also for all measurement time, e.g., for R56=0.00 and 0.45) and does not change after the chicane for R56=0.00. Whereas in the case of R56=0.45 the phase variation after the chicane is much higher (bottom Figure).

The calculated standard deviations are shown in Table 1 and plotted in Fig. 3. The result that can be drawn from this data is that the rms phase jitter of the beam is the same between the LINAC and the transfer line after the chicane when the compression factor is zero but grows proportionally to the R56 when it is different than zero.

Table 1: Standard deviations for different R56 values for every phase monitor

	STD					
	R56=0.00	**R56=0.20**	**R56=0.45**	**R56=0.20**	**R56=0.00**	**R56=0.45**
CL.STBPR0290	1.98	2.01	1.95	2.05	1.97	1.96
CL.STBPR0475	1.77	1.30	0.90	1.18	0.98	1.41
CT.STBPR0532	1.63	5.45	10.16	5.02	1.65	9.91
CR.STBPR0505	8.04	9.39	12.06	8.98	8.16	13.20
BPR 505 corrected	2.41	5.42	9.31	4.67	2.79	10.74

A rather unexpected result was the growth in the standard deviation after BPR 532. In fact the BPR 505 (located in the combiner ring) gives higher values than previous monitors. A possible explanation could be a non-zero R56 value in the transfer line to the ring, however there was a strong suspicion of systematic errors in this specific BPR (CR.STBPR0505), since previous data has shown that this particular BPR is rather noisy. Indeed by correcting for the observed noise (see last line in Table 1 and Table 2 where the noise contribution is subtracted in quadrature) the std results to be constant after the chicane, as shown in Fig 4.

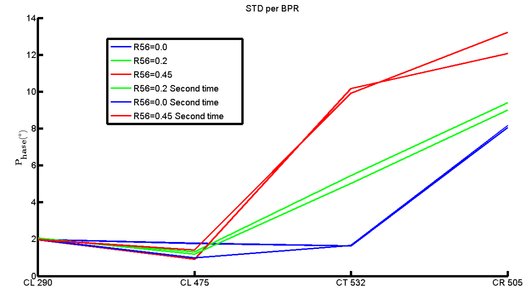

Figure 3: Standard deviations of every BPR for different R56 values, direct measurement.

Table 2: Standard deviations for different R56 values for BPRs 532 and 505 before and after applying correction to CR.STBPR0505.

STD @	CT 532	CR 505	With Correction
R56=0.00	1.63	8.04	$\sqrt{8.04^2 - 7.67^2} = 2.41$
R56=0.20	5.45	9.39	$\sqrt{9.39^2 - 7.67^2} = 5.42$
R56=0.45	10.16	12.06	$\sqrt{12.06^2 - 7.67^2} = 9.31$
R56=0.20	5.02	8.98	$\sqrt{8.98^2 - 7.67^2} = 4.67$
R56=0.00	1.65	8.16	$\sqrt{8.16^2 - 7.67^2} = 2.79$
R56=0.45	9.91	13.20	$\sqrt{13.20^2 - 7.67^2} = 10.74$

Pulse-to-Pulse Phase Variation

The pulse-to-pulse phase variation is defined as the change in time of the mean value of the whole pulse phase. Figure 5 depicts how the mean phase of every pulse changes in time for different values of R56. The similarity between the blue and green lines, which correspond to BPR 475 (positioned before the chicane) for R56=0.0 and 0.45 respectively, shows that during the measurement the condition of the beam did not change. Lines red and cyan correspond to BPR 532, which is positioned after the chicane, for R56=0.0 and 0.45 respectively. It appears that the beam phase jitter is amplified after passing through the chicane for a momentum compaction value higher than 0.0.

The whole sequence of measurement is shown in Fig-

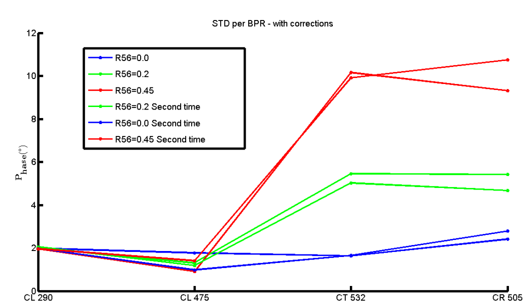

Figure 4: Standard deviations of every BPR for different R56 values with noise correction for CR.STBPR0505.

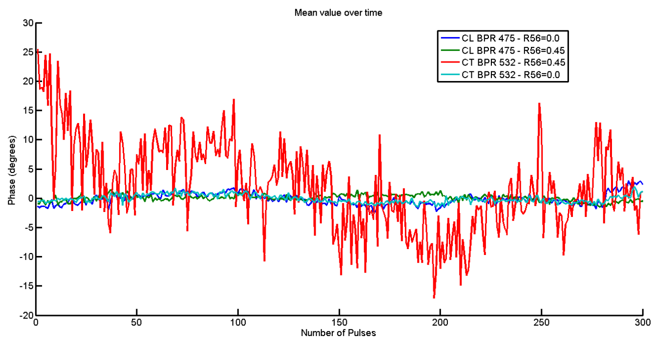

Figure 5: Mean pulse value vs. time for two BPRs (one positioned before the chicane and the other after) for R56=0.0 and R56=0.45.

ure 6. The blue line corresponds to the mean pulse phase as a function of time for BPR 532, which is positioned after the chicane. Green and red lines correspond to BPRs 475 and 290 respectively, both positioned in the LINAC. The R56 values during this measurement are marked on the horizontal axis. It becomes even clearer how the value of R56 effects the phase jitter, since there is a factor 3 difference in the rms phase jitter between R56=0.0 and 0.2 and a factor 6 between R56=0.0 and 0.2. It is now clear that the energy jitter of the beam is transformed and amplified into phase jitter when passing through the magnetic chicane.

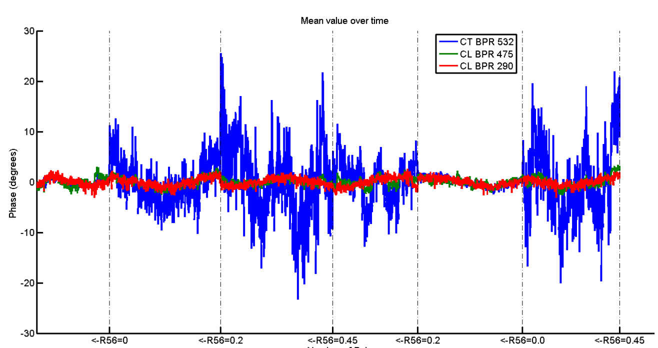

Figure 6: Mean phase value vs. time for two BPRs (one positioned before the chicane and one after), during the whole measurement, covering different R56 values in the chicane.

Correlation between BPRs

From the correlation plots shown in Figure 7 the dominant mechanism of phase jitter in CTF3 can be better understood. Both plots show a good correlation between phase jitter before and after the chicane. For higher momentum compaction, the jitter is amplified in a coherent way and the correlation is stronger. The interpretation is that RF phase jitter in the injector generates a correlated energy jitter in the linac, which in turns is converted in phase jitter when the chicane has a large momentum compaction. For R56 = 0 the initial phase jitter is conserved but not amplified, and the noise contribution is more evident.

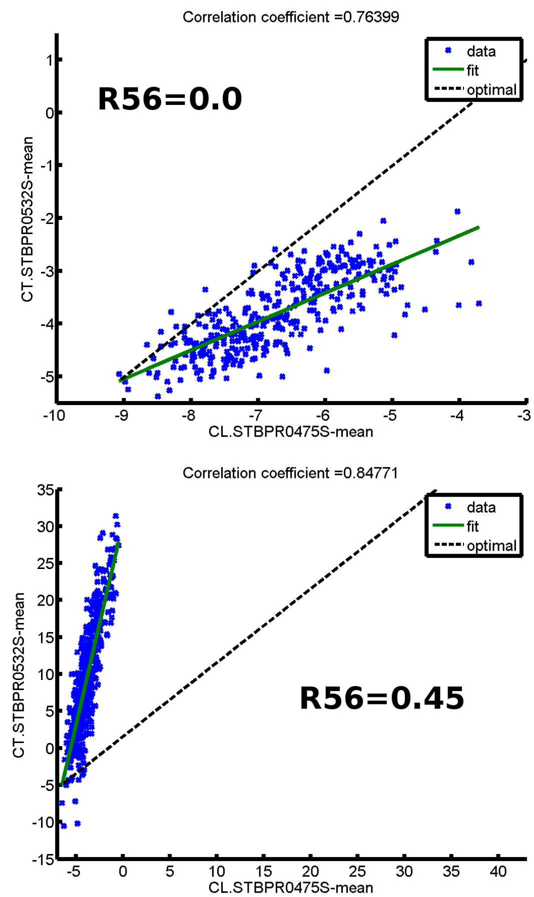

Figure 7: Correlation between BPRs 475 and 532 for different values of R56.

CONCLUSIONS

It was confirmed that the main source of phase jitter in CTF3 is energy jitter of the beam (from RF phase and power jitter of klystrons in the injector) transformed into phase jitter and amplified when passing through a magnetic chicane, for non-zero momentum compaction factor. The results for R56=0.0 show that beam phase jitter can be controlled to a level which will allow a full demonstration of CLIC requirements in the frame of the planned phase feed-forward experiment in CTF3 [3].

Further measurements and analysis will be done with the newly installed drive beam phase monitors from INFN-Frascati, recently tested with promising results [3].

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[3] P. K. Skowronski et al.,"Experimental Verification of the CLIC Two Beam Acceleration Technology in CTF3", IPAC 2013, Shanghai, May 2013, ID: 2908 - TUPFI040.