CONTROL OF RF TRANSIENTS IN CAVITIES INDUCED BY PULSED HIGH CURRENT BEAMS[*]

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Abstract

The Cornell ERL prototype injector is operated either in a CW or in a pulsed mode. In the latter case, the bunch trains, which have a duration between 80 ns and 10 μs and a beam current of up to 100 mA, generate transients in the RF cavity fields which severely distort the beam quality and cause beam loss. In this paper, we present a scheme we use to correct the fast transients based on an adaptive feed-forward method.

INTRODUCTION

Learning feed-forward systems are commonly used to remove amplitude and phase distortions in cavity fields of pulsed accelerators. For the Cornell ERL, we developed such a system which is capable of compensating beam induced transients for very short ($0.08 - 10\,\mu s$) bunch trains with highest beam currents. We successfully tested the system with bunch train currents up to 50 mA. The design current of the ERL injector is 100 mA, and we expect the system to also work under these conditions.
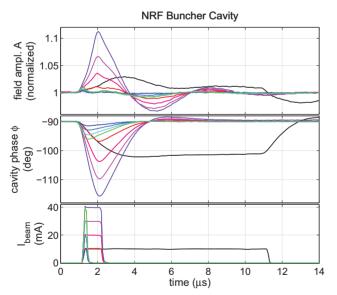
The feed-forward system is implemented by the FPGA which controls the IQ-based cavity regulations. A DOOCS server reads tables containing the I/Q error signals, which are acquired at a rate of 12.5 MHz. This data is used to calculate a correction which is added to the feed-forward tables in the FPGA. In order to make sure that the feed-forward system is stable, the feed-forward tables are regularly filtered. In addition, a small fraction of the previous correction signal is removed in each iteration. This allows us to continuously run the system, and even if beam parameters change significantly, the system will adapt to them after a short while.

MEASUREMENT RESULTS

The system is applied to two types of 1.3 GHz cavities: a single-cell, normal conducting buncher cavity and the five two-cell superconducting cavities of the ERL injector. Both cavity types have a significantly different loaded Q-value, and we present measurements for both cavity types.

Figures 1 and 3 show the transients in the fields of both cavity types, which are induced by bunch trains of various durations and currents. The buncher cavity is phased such that the beam arrives at the zero-crossing of the RF field. As a consequence, the bunch train induces a very strong transient in the phase signal, which corresponds to a
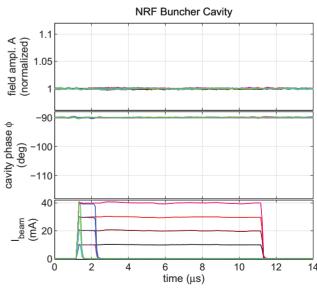

Figure 1: Amplitude and phase transients in the buncher cavity induced by bunch trains of various durations and currents.

Figure 2: Amplitude and phase transients in the buncher cavity for the same conditions as in Fig. 1, but with active adaptive feed-forward.

06 Instrumentation, Controls, Feedback and Operational Aspects   **ISBN 978-3-95450-115-1**
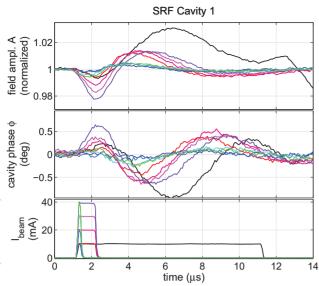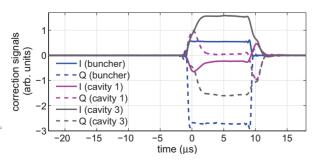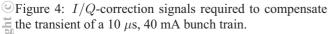
Figure 3: Amplitude and phase transients in an SRF cavity induced by bunch trains of various durations and currents.

phase shift of more than 10 deg for a 10 mA bunch train. In the superconducting cavities, which were operated at on-crest phase, the beam induced transient affects mainly the cavity field amplitude. Due to the larger loaded Q-value, the effect is significantly smaller than in the buncher cavity. The operation of 10 μs long bunch trains with currents larger than 10 mA was not possible due to heavy beam loss. These measurements of the cavity response also show that the gain parameters of the PI-regulation have not yet been fully optimized for the SRF cavities, and quite large oscillations in amplitude and phase are visible after the bunch train.

The beam induced transients are tremendously reduced by activating the adaptive feed-forward system (see Figs. 2 and 5). This also allows to run higher currents with 10 μs long bunch trains. As a preparation for high current runs, we operated the machine with 10 μs long bunch trains and a rate of up to 5 kHz for beam loss tuning before switching to CW mode. This is the highest duty cycle in pulsed mode which is currently supported by the laser system.

Figure 4 shows an example of the corrections required

Figure 4: I/Q-correction signals required to compensate the transient of a 10 μs, 40 mA bunch train.
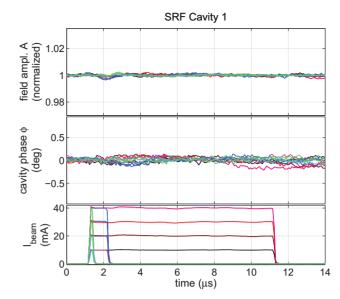
Figure 5: Amplitude and phase transients in an SRF cavity for the same conditions as in Fig. 3, but with active adaptive feed-forward.

to remove the transients. Visible is the much faster time-response of the buncher cavity. Further, the correction signals indicates that the regulation loop settings for the different superconducting cavities are currently not identical.

EFFECT OF BEAM CURRENT FLUCTUATIONS

The corrections are slowly built-up and it typically takes several seconds to properly compensate the beam induced
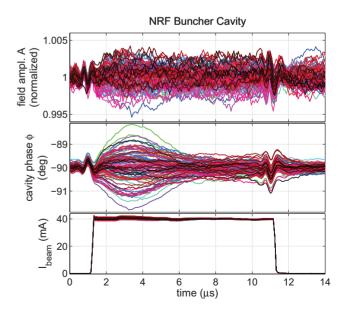

Figure 6: Effect of beam current fluctuations on the transient correction in the buncher cavity. Shown are 100 traces recorded every 0.4 s.
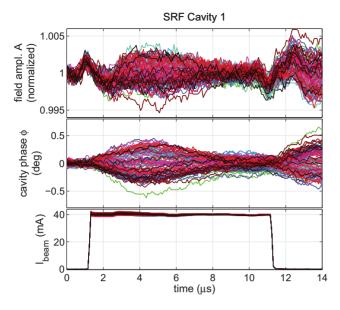
Figure 7: Effect of beam current fluctuations on the transient correction in the SRF cavity 1. Shown are 100 traces recorded every 0.4 s.

Figure 9: Noise in amplitude and phase of the SRF cavity 1 field and in the beam current.

transients once a change to the pulse duration or the pulse current was made. As a consequence, any fast fluctuations of bunch train currents are not properly accounted for in the cavity field correction signals and thus still lead to beam induced phase and amplitude transients. This is visible in Figs. 6 and 7. Note that the data acquisition of the beam current data is not synchronized with the transient data. Figures 8 and 9 show the rms fluctuations in the cavity field amplitudes and phases as well as in the beam current. Without the presence of the beam, the measured field stability is around $\sigma_A/A \approx 6 \times 10^{-4}$, and the phase stability
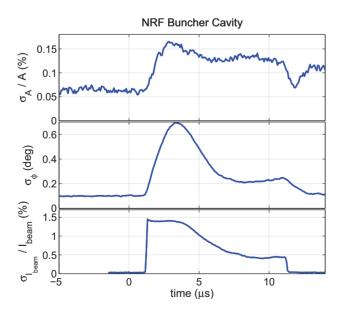
$\sigma_\phi \approx 0.1 \deg$ and $\sigma_\phi \approx 0.04 \deg$ respectively. These measurements have a bandwidth of 6.25 MHz and the cavity field fluctuations are possibly smaller than these numbers due to the noise floor of these measurements. The beam current fluctuations are around 1.5 % at the beginning of the bunch train, and our beam current feedback [1] stabilizes the beam current to around 0.5 % at the end of the 10 μs long trains. It is clearly visible that the field stability in the presence of a high current beam is largely dominated by the current stability of the beam, and a significant improvement of the beam current stability is desired.

OUTLOOK

A possible way to make the system faster and less dependent on beam current fluctuations is to scale the feedforward corrections with the actual beam current of each bunch train. These information are available in each regulation board. However, the latency required for these calculations might limit the effectiveness of this approach. An improved beam current stability is the preferred solution due to various reasons, one of them being the fact that there will be two beams in the main linac of the ERL, one of which being accelerated and one that is decelerated. The current of both of these beams would fluctuate independently which makes the approach described above more complicated to implement.

REFERENCES

[1] F. Loehl and P. Szypryt, "Active beam current stabilization in the Cornell ERL prototype injector", IPAC11 Conference, MOPO018, 2011.

Figure 8: Noise in amplitude and phase of the buncher cavity field and in the beam current.