PHASE-MODULATION SLED OPERATION MODE AT ELETTRA

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Abstract

FERMI@Elettra is the soft X-ray, fourth generation light source facility at the Elettra Laboratory in Trieste, Italy. It is based on a seeded FEL, driven by a normal conducting linac that is presently expected to operate at 1.5 GeV. The former 6.15 m long linac sections used in the injector system of the Elettra Laboratory storage ring have been upgraded for use in FERMI@Elettra project.

Those sections are backward travelling wave structures, equipped with SLED systems. The high peak field built up during conventional SLED operation brings to breakdown problems inside the sections that prevented from reaching the expected gradients. To lower the peak field phase-modulation of the SLED drive power has been implemented. A description of the phase modulation of the drive power and the results achieved is reported in the following paper.

INTRODUCTION

FERMI@Elettra is the soft X-ray, fourth generation light source facility at the Elettra Laboratory covering the wavelength range from 100 nm (12 eV) to 4 nm (310 eV). It is driven by a normal conducting linac that is expected to operate at 1.5 GeV.

The S-band RF system is composed of 18 accelerating structures and 15 power plants. The last seven structures are BTW (back travelling wave) one, coming from the former injection system of the Elettra storage ring. Those structures are powered with 45 MW Thales klystrons and are equipped with PEN (Power Enhancement Network) systems as shown in Figure 1 [1].

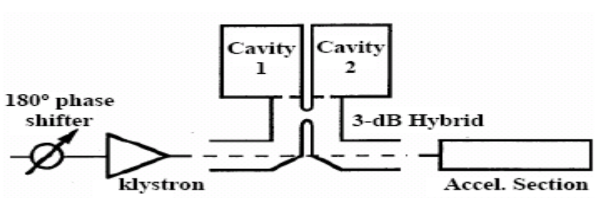

Figure 1: Sketch of the Power Enhancement Network

To reach the FERMI target energy of 1.5 GeV, each BTW structure needs to be operated with an energy gain of more than 150 MeV.

Breakdown problems inside the sections associated with the very high peak-field built up during conventional SLED operation, prevented from reaching the desired energy-gain gradient in a reliable way. An endoscope view (Figure 2) showed that there were severe arcing traces in the first cells near the RF input port [2].

Phase modulation operation mode for the SLED systems can help to lower the very high peak field inhered with conventional operation and make it flatter. The implementation of this technique was also encouraged by a FERMI Linac Review Board held in 2009.

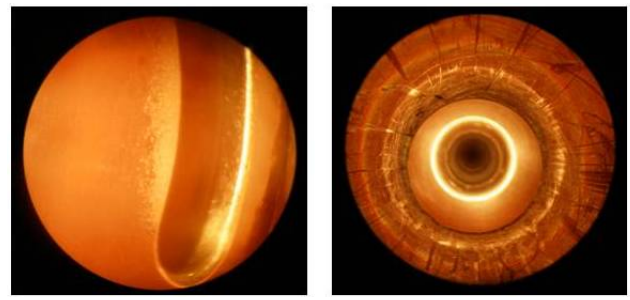

Figure 2: Endoscope views of the first cell

Instead of swooping the phase of the generator of 180º at t_1 as for conventional SLED operation (see Figure 3), the phase is swooped of φ_0 first, and then varies continuously to 180° at time t_{1B}, ($t_1<t_{1B}\leq t_2$), and remains 180° till the end of pulse, the time t_2 [3], [4].

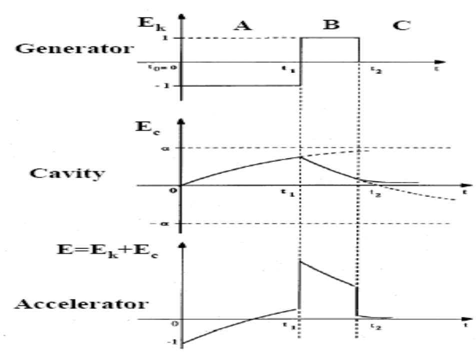

Figure 3: The waveform of conventional SLED

However, the phase-modulation leads not only to a reduction of the surface peak field but also a drop in energy gain.

Phase-modulation tests have been performed in Run7. Following the calculation performed for the energy gain and peak field in the accelerating sections operated with SLED phase modulation, different parameters were adjusted to find the optimal configuration. The results of the tests carried out will be illustrated.

IMPLEMENTATION

The phase modulation feature has been integrated in the firmware of the LLRF of Fermi. The system is an all-digital-system. Each RF plant has its own LLRF unit that is composed mainly of two boards: a RF front-end board and a digital processing board, with a FPGA and fast ADCs/DACs.

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The digital processing board performs all controls, diagnostic and external communication. Although at the time being the system is not yet using the final digital board, it is able to perform the basic functionalities required to the LLRF, such as for example phase and amplitude stabilization (better than 0.1° or 0.1 %), 180° phase reversal for the SLED operation, data communication with the controls.

In order to add the maximum flexibility to the system and to make easier the adjustments, there are two parameters that can be modified by the operator to change the shape of the phase modulation: the initial phase (φ_0) and the phase modulation slope (m), which also determines the flat top length, as depicted in Figure 4.

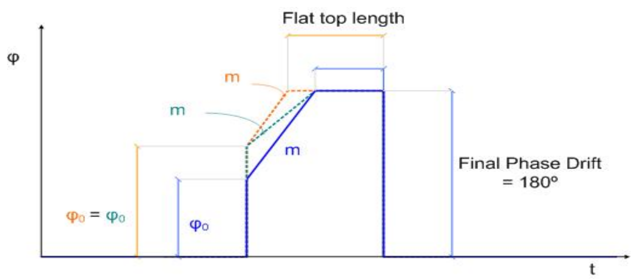

Figure 4: Phase Modulation Parameters.

PHASE MODULATION TESTS

At the beginning of Run7, one of the RF plant equipped with PEN (Power Enhancement Network) system was pushed to run at 150 MeV energy gain without any phase modulation.

To reach the desired gradient the klystron was operated at 38 MW peak power with a pulse width of 3000 ns and a phase reversal time duration of 770 ns. The measured input cavity field is shown in Figure 5.

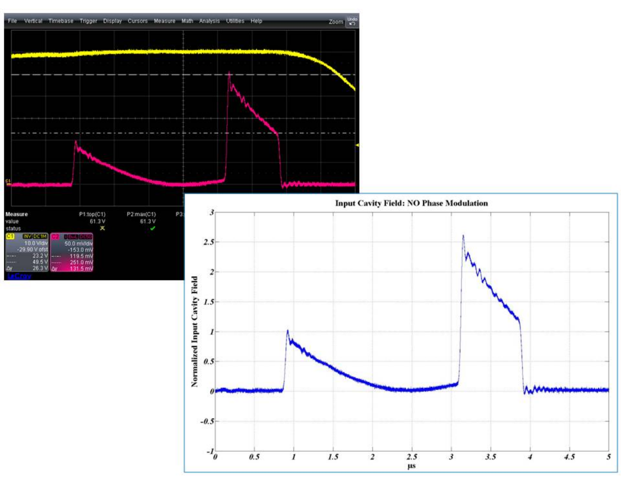

Figure 5: Measured Input Cavity Field without Phase Modulation

Let E_{peak} be the peak field due to SLED operation. As a reference parameter, let us consider E_{wo}, the input cavity field when the section is operated without SLED. As shown in the previous figure, for conventional SLED operation, the ratio E_{peak}/E_{wo} was almost 2.5.

So far, the very high peak field built up during the conventional SLED operation brought to frequent breakdown events, mainly due to arcs in the first cells of the accelerating structure.

To get a flatter pulse a continuous *non-linear phase modulation* should have been implemented raising the phase until 180° are reached [5].

However, for this preliminary implementation of the phase modulation, we just decided to use a linear modulation. Different sets of parameters were then tested to find the optimal phase modulation configuration.

The klystron output power was fixed to 38 MW, the pulse width to 3000 ns and the duration of the phase reversal to 770 ns. At first, the initial phase (φ_0) and the phase modulation slope (m) were selected to have no flat top length (i.e. 180° after 770 ns) according to the following table.

Table 1: Phase modulation configurations

	φ_0 [deg]	*m [deg/ns]*
Config. 1	*95*	*85/770*
Config. 2	*105*	*75/770*
Config. 3	*115*	*65/770*

As it is shown in Figure 6, configuration 1 (red trace) had the lowest peak field. In this case, the ratio E_{peak}/ E_{wo} was about 2.

According to the measurements, the peak field was 20% lower but the energy gain was reduced just by 4%.

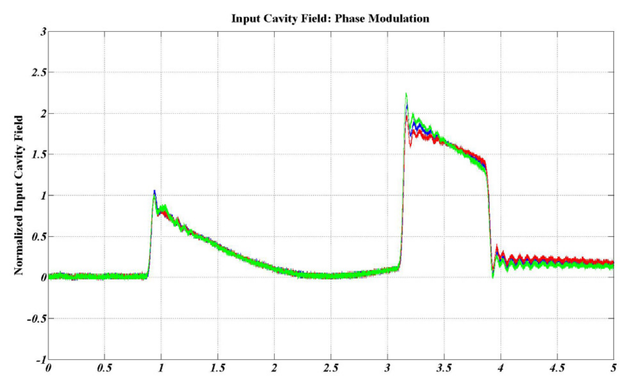

Figure 6: Input Cavity Fields for Configuration 1 (red), 2 (blue), 3 (green)

To enhance the RF performance we performed measurements for different flat top lengths. Table 2 illustrates some of the different configurations used.

Table 2: Phase modulation configurations

	φ_0 [deg]	*m [deg/ns]*	*Flat top [ns]*
Config. 4	*95*	*85/670*	*100*
Config. 5	*95*	*85/570*	*200*
Config. 6	*95*	*85/470*	*300*

The measured cavity fields are showed in the Figure 7. According to input field and beam energy measurements, configuration 5 (Figure 7, red trace) assures the best trade-off in terms of peak field and energy gradient.

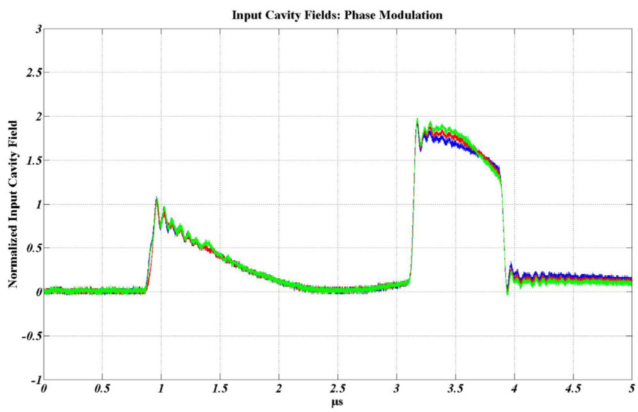

Figure 7: Input Cavity Fields for Configuration 4 (blue), 5 (red), 6 (green)

RESULTS

Different parameters for the phase modulation have been tested during the dedicated machine shift. The optimal results were achieved using an initial phase offset φ_0 of 95° and a slope *m* of 85/570 deg/ns (i.e. a flat top of 200 ns).

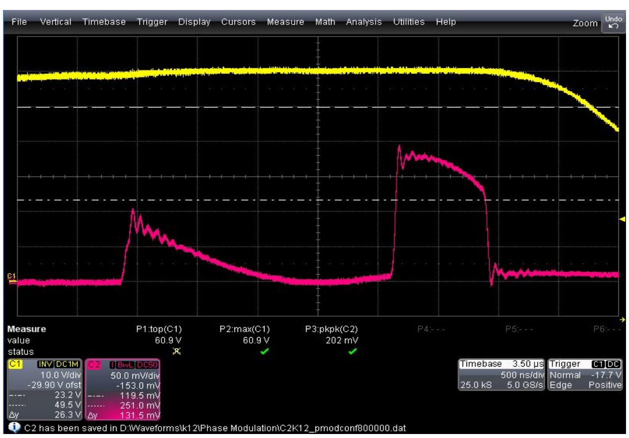

Figure 8: Input Cavity Field with Phase Modulation

With these parameters, for the same pulse length (3000 ns), the peak field was reduced by almost 20% while the energy gain was just 1% less (from 151 MeV to 149.5 MeV). Figure 9 shows a comparison between the input cavity fields with and without the phase modulation.

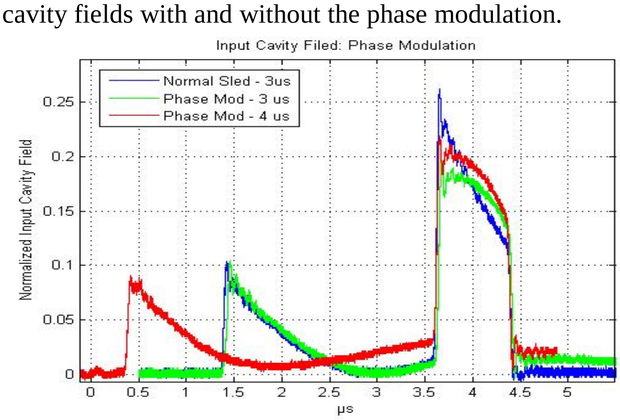

Figure 9: Comparison between Input Cavity Fields with and w/o Phase Modulation

After the optimal parameters were set, the pulse length was then widened up to 4000 ns without any breakdown event in the accelerating section. It must be noted that in the past such pulse length could never be reliably reached at this operating levels due to arcing. The energy gain achieved in the section reached 165 MeV. This result gives us a reliable margin for the operation of the FEL at 1.5 GeV beam energy.

CONCLUSIONS

During the operation of the seven BTW sections as injector for the Elettra storage ring, the very high field built up due to the conventional SLED operation, always prevented from reaching the expected gradient.

So far, to reach the FERMI target energy of 1.5 GeV, each BTW structure needs to be operated with an energy gain of more than 150 MeV.

To reach this goal in a reliable way some tests on the phase modulation operation mode have been implemented.

The phase modulation feature has been integrated in the firmware of the LLRF. After the optimal parameters were set the energy gain achieved on one section was 165 MeV, for a klystron output power of 38 MW and a pulse width of 4000 ns.

Based on the result achieved, we are now confident we will be able to reach the target energy of 1.5 GeV for phase 2 of FERMI (FEL2) without suffering of serious breakdown events in the accelerating sections.

Further studies will be done to evaluate the gain coming from a *non-linear phase modulation* to get a flatter RF pulse to the cavity.

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