COMMISSIONING STATUS OF THE CHOPPER SYSTEM FOR THE MAX IV INJECTOR

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Abstract

The MAX IV facility in Lund, Sweden consists of two storage rings for production of synchrotron radiation, and a short-pulse-facility (SPF). The two rings are designed for 3 GeV and 1.5 GeV, respectively, where the initial beam commissioning of the former has recently been completed, and commissioning of the latter was started in September 2016. Both rings will be operating with top-up injections delivered by a full-energy injector. In order to reduce losses of high-energy electrons along the injector and in the rings during injection, only electrons that are within a time structure where they can be accumulated in the ring buckets are accelerated. Electrons outside this time structure are dumped before they reach the first LINAC structure by a chopper system. The performance of the chopper system during commissioning of the 3 GeV ring is presented in this paper.

INTRODUCTION

The MAX IV injector consists of 39 travelling-wave S-band LINAC structures that are fed via SLED systems [1]. It provides top-up injections for two storage rings at 3 GeV and 1.5 GeV, respectively. The injector also operates as a driver for a short-pulse-facility (SPF) [2], and might be the driver for a future free-electron laser (FEL) [3]. Initial beam commissioning of the 3 GeV ring was completed in the summer of 2016, and the facility will soon open up for the user community. The beam commission of the 1.5 GeV was started in September 2016.

For ring injections, the electron source is a thermionic S-band RF gun that delivers an electron pulse with a length of ≈ 1 µs [4]. This electron pulse is bunched with an S-band structure, and only a fraction of its charge can be accumulated in the rings during injection. The RF systems in both rings are operating at 100 MHz, and the number of S-band bunches that can be accumulated in each ring bucket depends on parameters such as available RF voltage and the radiation losses. In its final state, the number of S-band bunches that can be accumulated in each bucket in the 3 GeV ring might vary between 4 and 7, while the number might be as high as 19 in the 1.5 GeV ring [5]. Due to the SLED systems, the accelerated electron pulse has an energy chirp [6] which limits the number of ring buckets that can be injected during each LINAC shot because of the finite momentum acceptance in the transport lines to the rings [7].

Electrons that can not be accumulated during injection are dumped before they reach the first LINAC structure by a chopper system. The electron losses at high energies, as well as the emitted bremsstrahlung, are by that minimized. Apart from protecting personnel and sensitive electronic equipment from radiation, it also reduces radiation-induced demagnetization of the permanent magnets in insertion devices (IDs). Such magnet degradation does not only reduce the undulator/wiggler parameter, K, but does also result in an extra broadening of the spectral lines since the demagnetization is often non-uniform along the IDs [8] [9].

THE CHOPPER SYSTEM

The chopper system consists of two planar striplines with corrector magnets placed around them, as seen in the schematic overview in Figure 1. By adjusting the strengths of the correctors and the shape of the counter propagating TEM waves that are fed to the striplines, only the S-band bunches within the desired time structure experience a net deflecting force that is zero when passing each stripline. S-band bunches that are outside this time structure are vertically deflected and dumped at a downstream located adjustable aperture.

The first stripline is fed with a superposed signal consisting of one 100 MHz, one 300 MHz, and one 700 MHz signal. These three signals can be generated as harmonics (in a comb generator) from any of the 100 MHz main RF signals of the two rings. By doing so, the superposed signal is always phase locked to the RF system of the ring that is being injected. After the three signals have been generated, they are amplified and combined in a cavity filter and fed to the first stripline, as shown in Figure 1. Note that the combined signal is circulated through both stripline electrodes, and the total electrical length is adjusted so that the propagating mode in the stripline is an odd (differential) TEM mode at odd harmonics of 100 MHz. By adjusting the amplitudes of the three signals, it is possible to change the number of S-band bunches per 10 ns period that enters the main injector, i.e. the number of S-band bunches that are injected into each ring bucket. This is illustrated in Figure 2, where the vertical displacement at the position of the aperture is shown for the driving scheme that has been used during commissioning of the 3 GeV ring. With this driving scheme, only 3 S-band bunches per 10 ns period pass the boundaries of the aperture, while the rest are dumped. In [5], other driving schemes are presented where up to 15 S-band bunches per ring bucket are injected.

By feeding two high-voltage pulses with different polarities to the second stripline, the total length of the electron pulse that enters the main injector can be adjusted, i.e. the number of ring buckets that are injected during each LINAC shot. These pulses are generated by commercial switch

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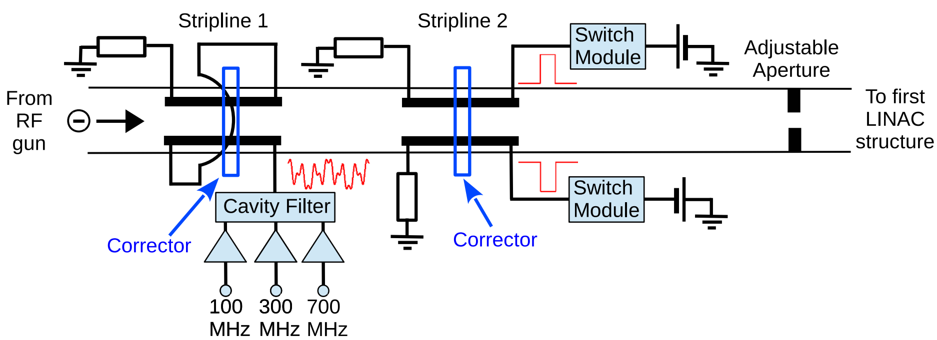

Figure 1: The basic components of the chopper system.

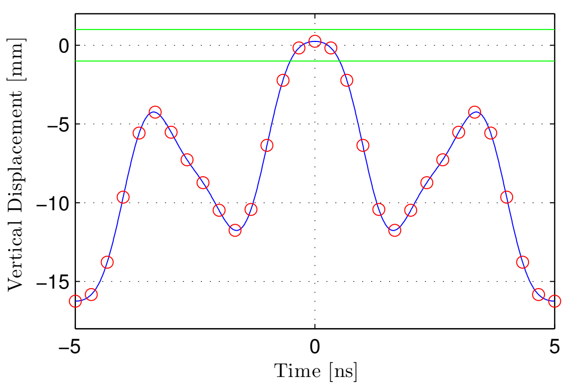

Figure 2: The vertical displacement of the beam at the position of the adjustable aperture in Figure 1 during one 10 ns period. The red circles are the S-band bunches, and the green lines represent the boundaries when a 2 mm aperture is inserted.

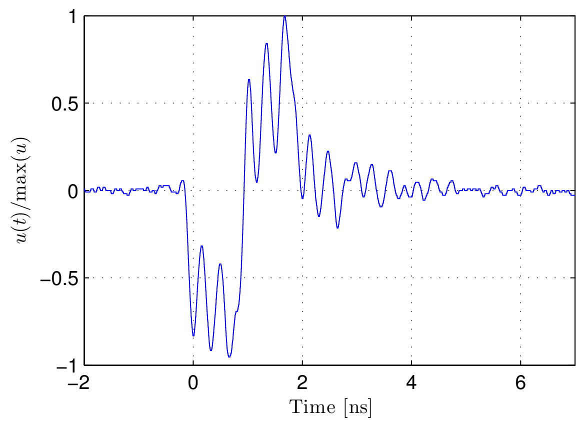

Figure 3: The induced voltage, $u(t)$, at a BPM stripline port that is located at the end of the injector obtained with a 4 GHz oscilloscope. 3 S-band bunches per ring bucket are injected ($M = 3$).

modules consisting of fast solid-state switches and capacitor banks.

The chopper system and the other component in the thermionic pre-injector are described in further details in [5] and in [10].

PERFORMANCE DURING RING COMMISSIONING

The structure of the electron pulse that passes the chopper can be studied at several BPM striplines situated throughout the injector. For the chopper operations described above, the induced voltage $u(t)$ at a single upstream port of an ideal BPM stripline is given by

$$u(t) = \frac{g_{||} Z_s}{8} q_b \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \Big\{ i_b(t - m \cdot T_b - n \cdot T_{\mathrm{RF}}) - i_b(t - m \cdot T_b - n \cdot T_{\mathrm{RF}} - 2L/c_0) \Big\} \quad (1)$$

where c_0 is the speed of light in vacuum, q_b the total charge in each S-band bunch, $Z_s \approx 50\ \Omega$ the characteristic impedance of a single BPM stripline electrode (in sum mode), $L =$

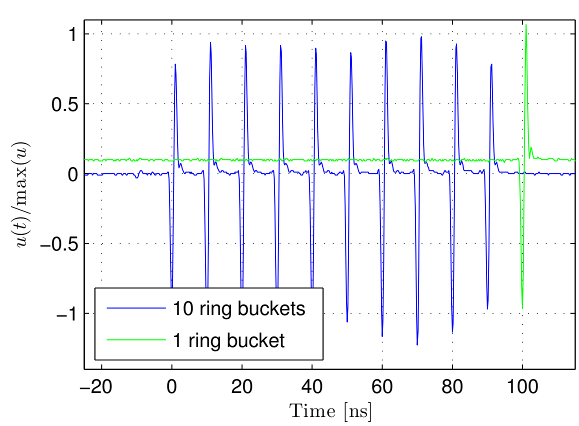

Figure 4: The induced voltage, $u(t)$, at a BPM stripline port at the end of the injector when injecting into 10 and into 1 ring buckets ($N = 10$ and 1). In both cases, 3 S-band bunches are injected into each ring bucket ($M = 3$), but this oscilloscope does not have high enough resolution to resolve individual S-band bunches. Note that the horizontal and vertical offsets in the green curve are 100 ns and 0.1 units, respectively.

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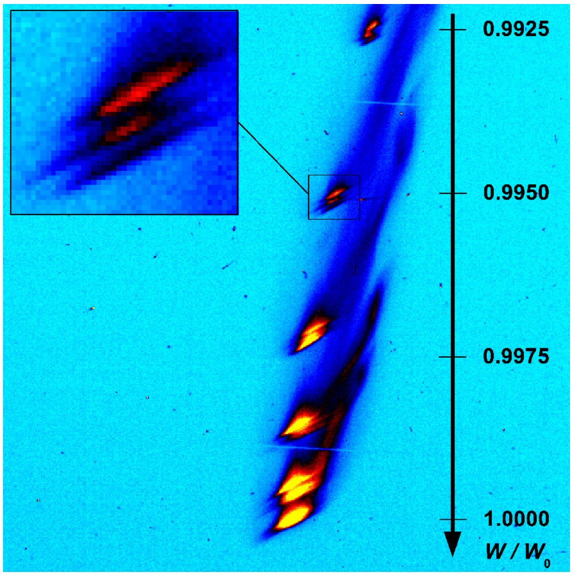

Figure 5: The projected beam of a single LINAC shot at a YAG screen in the transport line to the 3 GeV ring. The vertical dispersion is here $\eta_y = -1$ m, and the axis shows the corresponding relative beam energy W/W_0. Ten ring buckets are here injected as in Figure 4. One can distinguish the electrons that are being injected into the first six ring buckets as distinctive populations due to their larger energy spread, while the electrons that are injected into the last four ring buckets are located in the lower population. As seen, it is even possible to distinguish the three S-band bunches in the upper low-energy populations. These are clearly visible in the zoomed area of the 2nd upper population.

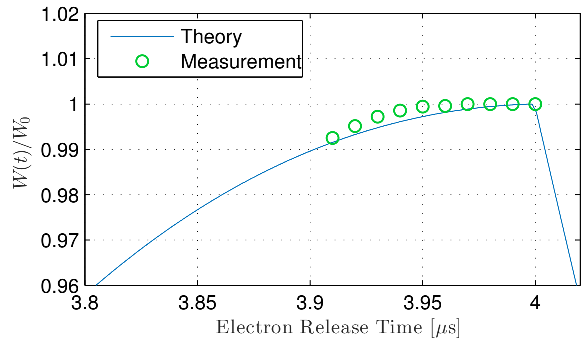

Figure 6: The relative energy gain, $W(t)/W_0$, of the MAX IV injector as a function of the electron release time. The blue curve shows the theoretical gain, while the green circles show the relative energy of the ten populations in Figure 5.

15 cm the length of an electrode, and $g_{||}$ the longitudinal geometry factor defined in [11]. $T_b = 333$ ps and $T_{RF} = 30T_b = 10$ ns are the period of the S-band bunches, and the period of the ring RF systems, respectively. M and N are the number of S-band bunches that are injected into each ring bucket, and the number of ring buckets that are injected, respectively. $i_b(t)$ is the longitudinal (normalized) charge distribution of a single S-band bunch centered at $t = 0$. The bunch length of an S-band bunch is tens of picoseconds, i.e. small compared to the operating frequencies of the chopper. In (1), it is assumed that the S-band bunches are ultrarelativistic and propagate in the center of the beam pipe.

Figure 3 shows $u(t)$ induced by the driving scheme illustrated in Figure 2 ($M = 3$). Here, three bipolar pulses (one for each S-band bunch) can be seen whose negative and positive parts are separated by $2L/c_0 = 1$ ns. The remaining oscillations are mainly caused by reflections due to the fact that the BPM stripline is far from perfectly matched to 50 Ω for the wideband spectrum of a single S-band bunch.

The blue curve in Figure 4 shows $u(t)$ when injecting into ten successive ring buckets thus $(M, N) = (3, 10)$. This is the injection scheme that has been used so far during normal beam commissioning of the 3 GeV ring. It has been possible to transport a total charge of 290 pC per LINAC shot to the injection point with a capture efficiency in the ring that is above 90 %. As seen, there is a small variation in amplitude among the ten bipolar pulses which is caused by mode beating the thermionic RF gun. The frequency of this mode beating is 16.6 MHz, and it is further described in [5].

The green curve in Figure 4 shows $u(t)$ when injecting into a single ring bucket, thus $(M, N) = (3, 1)$. In January 2016, some initial single-bunch experiments were performed in the 3 GeV ring, where only one of the 176 ring buckets was filled using this injection scheme. The maximum charge that could be accumulated in the single ring bucket during the experiments was 15 nC, while the total charge contamination in the neighbouring ring buckets was ≈ 2 %. Since then, a transverse bunch-by-bunch feedback system has been commissioned which makes it possible to perform bunch cleaning that eliminates this charge contamination by RF-knockout [12].

YAG screens located at dispersive sections along the injector can be used as spectrometers and therefore to correlate the bunch train from the chopper to the energy chirp caused by the SLED systems. Figure 5 shows the charge distribution for a single LINAC shot projected at a YAG screen, and Figure 6 shows the theoretical and measured energy spread along the injected electron pulse. As seen, the measured energy chirp is ≈ 0.75 %. The small deviation from the theoretical curve is partly due to a measurement error originating from the mode beating.

CONCLUSIONS AND FUTURE WORK

During the commissioning of the 3 GeV ring, the chopper system and the main injector delivered an electron beam with the correct time structure for injection. Apart from further optimization of the injection efficiency in this ring, the commissioning of the 1.5 GeV ring has recently started. Since the latter ring has a significantly higher phase acceptance during injection, other chopper driving schemes with higher current throughput can be used to increase the injection rate.

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