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BEAM DYNAMICS FOR THE MAX IV TRANSVERSE DEFLECTING CAVITY BEAMLINE

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Abstract

The MAX IV 3 GeV linac delivers electron beams to two synchrotron rings and to a dedicated undulator system for X-ray beam delivery in the Short Pulse Facility (SPF). In addition, there are plans to use the linac as an injector for a future Soft X-ray Laser (SXL). For both SPF and SXL operations, longitudinal beam characterisation with a high temporal resolution is essential. For this purpose, a transverse deflecting cavity (TDC) system has been developed and is being installed in a dedicated electron beamline branch located downstream of the 3 GeV linac. This beamline consists of two consecutive 3 m long transverse S-band RF structures, followed by a variable vertical deflector dipole magnet used as an energy spectrometer. This conference contribution presents the beam dynamics calculations for the beam transport along the TDC beamline, and in particular the optics configurations for slice emittance and slice energy spread measurements. The operation of an analysis algorithm for use in the control room is discussed. The aim is to provide 1 fs temporal measurement resolution to access the bunch duration of highly compressed bunches and slice parameters for sub-10-fs bunches.

INTRODUCTION

The MAX IV light source in Lund, Sweden, consists of a 3 GeV electron linac, a 1.5 GeV storage ring and a 3 GeV storage ring [1]. The linac is used both as an injector for the two storage rings and as a source of short electron pulses for the Short Pulse Facility (SPF). The linac has also been designed as an injector to a future Soft X-ray Laser (SXL) [2].

For both SPF and SXL operations, longitudinal beam characterisation with a high temporal resolution is critical. For this purpose, a transverse deflecting cavity (TDC) system has been installed in a new, dedicated electron beamline branch located downstream of the 3 GeV linac. This TDC beamline (Fig. 1), which will be commissioned with beam in the coming months, contains two consecutive TDCs (TDC1 and TDC2), each of which is a 3 m long transverse RF structure operated at the zero crossing of the 2.9985 GHz linac RF. The TDC structures have been manufactured by Research Instruments (Fig. 2); further details of the RF design can be found in [3]. Initially, the deflecting TM_{110} mode will streak the beam horizontally, but, in the future, adjustment of the RF signal phases fed to the TDC structures will allow both horizontal and vertical beam streaking [4].

The TDC structures are followed by a variable vertical deflector dipole magnet, to be used as an energy spectrometer, deflecting the beam vertically down by 0°, 2.8° or 5.6° into three distinct beamline branches as shown in Fig. 1.

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The beamline also contains five quadrupoles (QH) for optics control, five stripline beam position monitors (BPL), five horizontal and five vertical corrector magnets (CODBX and CODBY, respectively) for trajectory correction and ten insertable YAG screens (SCRN) as shown in Fig. 1.

BEAMLINE OPTICS

The optics through the TDC beamline has been optimised, using the beam tracking code elegant [6], for the end-of-line screens (SCRN9 and SCRN10 in Fig. 1).

Beta Function

The horizontal beta function is maximised at the mid-point of the TDC structures (Fig. 3) in order to maximise the imparted horizontal kick [2], whilst the beta function is minimised both horizontally and vertically at the end-of-line screens to have a beam that is fully contained on the screen. For aperture considerations, the maximum beta function is limited to 1000 m throughout the TDC beamline.

Phase Advance

In order to maximise the horizontal deflection imparted by the TDC structures [2], as viewed on SCRN9, the horizontal phase advance from the mid-point of the TDC structures to SCRN9 has been optimised at $\frac{\pi}{2}$ (Fig. 4).

The TDC beamline will be used to perform beam emittance measurements by scanning the strength of quadrupole QH2 and measuring the vertical beam size at SCRN9. In order to maximise the change in vertical beam size at SCRN9 over the QH2 strength scan, the optimum vertical phase advance from QH2 to SCRN9 is set to $\frac{\pi}{2}$.

As the beam will be streaked horizontally by the TDC structures, the optimum horizontal phase advance from QH2 to SCRN9 is π in order to minimise the effect of the change in QH2 strength on the horizontal beam properties at SCRN9.

SCREEN IMAGES

A beam consisting of 200 000 particles has been tracked along the full MAX IV linac and the TDC beamline using the code elegant [6]. Figure 5 shows the beam intensity on SCRN9, with the TDC and spectrometer magnet both off.

Figure 6 shows the result of turning the TDC on. The colour-coding shows the particle arrival time, and the relationship between the horizontal beam coordinate and time is clear as expected.

Turning the TDC off, but turning the spectrometer magnet on, displays the energy structure of the beam, where the vertical position on the screen is correlated to the energy offset (Fig. 7).

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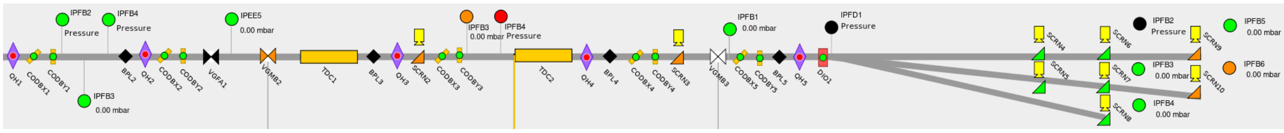

Figure 1: TDC beamline layout as viewed on the MAX IV Control Room computers [5]. The electron beam travels from left to right.

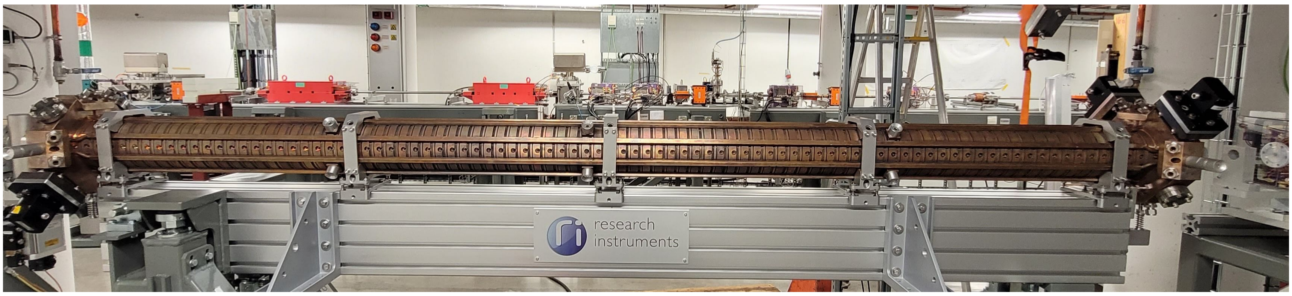

Figure 2: TDC structure installed in the beamline. The electron beam travels from left to right.

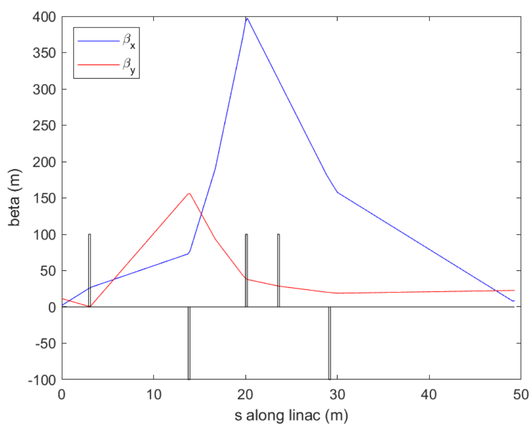

Figure 3: Horizontal β_x (blue) and vertical β_y (red) beta functions along the TDC beamline. The five black bars correspond to the locations of the five quadrupoles.

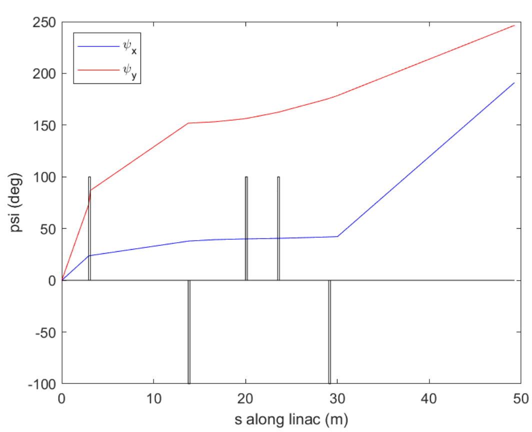

Figure 4: Horizontal ψ_x (blue) and vertical ψ_y (red) phase advance along the TDC beamline. The five black bars correspond to the locations of the five quadrupoles.

CALIBRATION

The calibration of the horizontal position on the screen to the bunch arrival time, with the TDC on, will be performed by scanning the TDC RF phase by ±1° around the zero crossing and measuring the mean horizontal position on the screen. The TDC RF phase offset can be converted to a time offset given the known RF frequency, producing the calibration plot in Fig. 8.

The calibration of the vertical position y on the screen to the fractional beam energy offset $\frac{dp}{p}$ will be given by the dispersion η, calculated for example in elegant:

$$y = \eta \frac{dp}{p}.$$

In the case of SCRN10, $\eta = 0.95$ m.

EMITTANCE MEASUREMENT

The emittance measurement consists in scanning the QH2 strength, with the TDC on and the spectrometer magnet off, and recording beam images on SCRN9. The analysis is analogous to that already used in the MAX IV linac [7], only that the beam is now sliced into tall narrow slices, and the analysis is performed on each slice independently.

For each slice, the vertical beam size squared σ_y^2 is plotted against kl of QH2 (where k is the quadrupole's strength K1 value and $l = 0.2$ m is its length). A parabola is fitted according to $\sigma_y^2 = a(kl - b)^2 + c$ where a, b, c are fit constants. The slice emittance ϵ is then given by [7]:

$$\epsilon = \frac{\sqrt{ac}}{S_{34}^2}$$

where S is the 6×6 transfer matrix from the downstream end of the quadrupole to the screen. The simulated parabolas for a streaked beam, sliced into 61 slices, is shown in Fig. 9.

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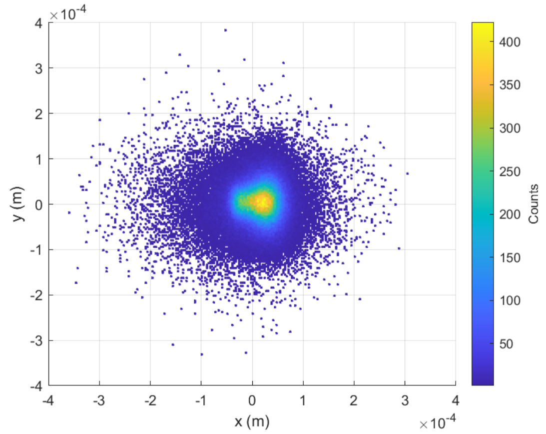

Figure 5: Simulated beam on the final screen, with both TDC and spectrometer magnet off, colour-coded according to beam intensity

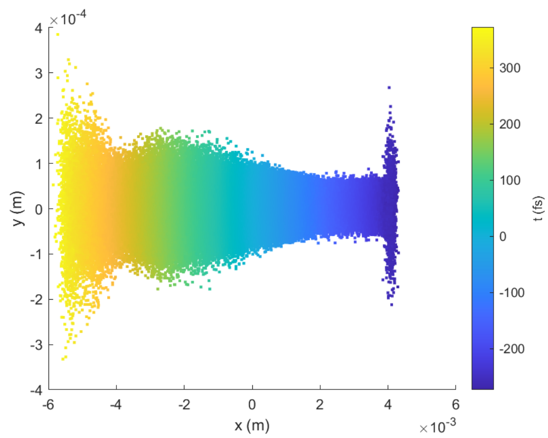

Figure 6: Simulated beam on the final screen, with TDC on and spectrometer magnet off, colour-coded according to beam arrival time t. Negative time corresponds to the head of the bunch.

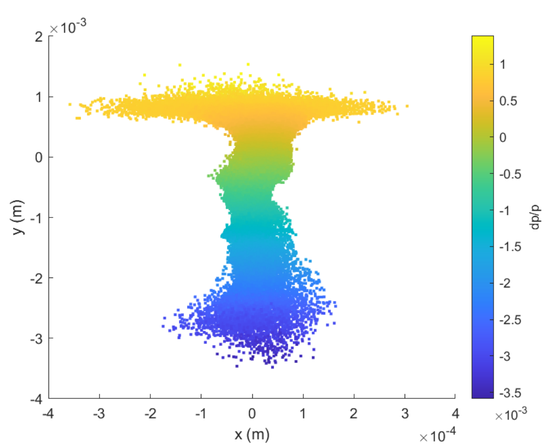

Figure 7: Simulated beam on the final screen, with TDC off and spectrometer magnet deflecting the beam by 2.8°, colour-coded according to the fractional energy offset $\frac{dp}{p}$.

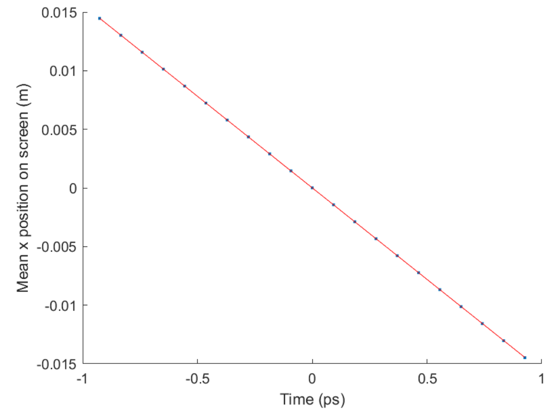

Figure 8: Simulated mean horizontal beam position on the final screen vs. beam arrival time at the TDC, relative to the RF zero-crossing, for an RF phase scan of ±1°. The straight-line fit has a gradient of −0.0156 m/ps.

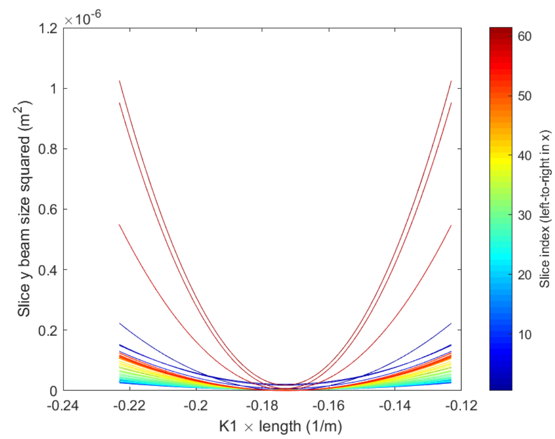

Figure 9: Quadratic fits to vertical beam size squared σ_y^2 versus the product of quadrupole QH2's K1 value and length. Each parabola corresponds to a given beam slice as indicated in the colour bar.

CONCLUSIONS

A new electron diagnostics beamline has been installed at the end of the MAX IV 3 GeV linac, and will be commissioned with beam in the coming months. The beamline consists of a TDC and a spectrometer dipole, allowing the longitudinal bunch properties and bunch energy structure to be determined.

The present conference contribution shows the beam transport simulations through the beamline, the optics design and the expected beam images on the end-of-line screens. It also presents the screen axes calibration techniques to extract both bunch time and energy, and the analysis for the sliced beam emittance measurement.

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