MEASUREMENTS AND DIAGNOSTICS ON THE MAX RECIRCULATOR*

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Abstract

The MAX Recirculator is a unique accelerator, a two-pass linac at 500 MeV that operates as injector for three storage rings. Here are presented some discussions on measurements of beam parameters such as emittance, energy spread, and bunch length. We describe what measurements are done, by which methods, results, and how they can be improved. Also, we make an analysis of what methods and hardware are needed to perform the measurements that can't be done with the equipment in place today.

INTRODUCTION

The recirculator linac at MAX-lab that is in routine operation for daily injections obviously work, but its performance is not well known in numbers. For injection we use a RF-Gun with a thermal cathode. Gun and linac are 3 GHz structures. As the use of the linac is going to expand to be a driver of a FEL test facility, with a new gun [1] and otherwise small modifications to the present accelerator, we need control over all parameters that the beam behaves as predicted [2]. Therefore we need some means to measure all parameters. Here we deal with the set up to measure bunch lengths with the autocorrelation of far infra red (FIR) pulses from transition radiation (TR).

TRANSITION RADIATION

When a moving charge hits the intersection between two media with different dielectric constants, its corresponding fields have to rearrange themselves, and in that process they let of some portion as transition radiation in small cones, with opening angles $\theta \sim \gamma$, around the forward and backward directions [3]. By tilting the surface 45° to the incoming electrons, the backward TR comes out perpendicular to the electron beam, and can easily be used for experiments. As the radiation is created only in the transition, an electromagnetic replica is created longitudinally of an electron bunch hitting a (metal) surface. For wavelengths comparable to or longer than the electron bunch, the radiation becomes coherent and the intensity increases. However, these wavelengths tend to become so large (~mm) that the size of the screen starts to matter [SD]. Then the one electron intensity distribution goes like

$$\frac{d^2 I}{d\omega\, d\Omega} \propto \left| \frac{\omega^2}{c^2 \gamma} \int_0^R r K_1\left(\frac{\omega}{\beta c \gamma} r\right) J_1\left(\frac{\omega}{c} \sin(\theta) r\right) dr \right|^2$$

where ω is the frequency, c is the speed of light, γ is the Lorentz factor, R is the radius of the screen, K_1 and J_1 are Bessel functions. For a bunch of N electrons with the form factor f

$$I_{tot} = I\left(N + N(N-1) f\right)$$

Figure 1 is an example how the intensity distribution can look, assuming a Gaussian beam hitting a circular screen.

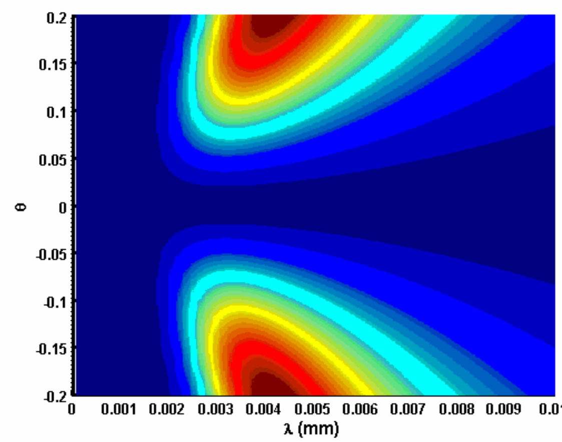

Figure 1: Intensity distribution with opening angle and wavelength.

MICHELSON INTERFEROMETER

The electromagnetic pulse is then sent through a Michelson Interferometer. There it is split in two by a stretched foil beam splitter, and each part travel back and forth to a mirror, one of which is fixed and the other can move as shown in figure 2.

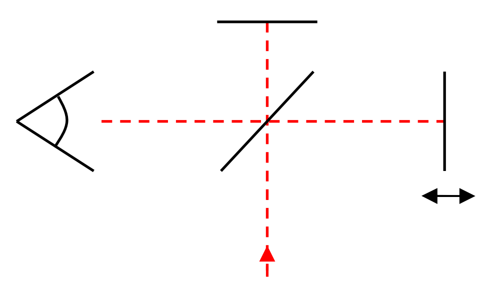

Figure 2: Principle of a Michelson Interferometer. A pulse enters, is split by the beam splitter, travels the different lengths to the mirrors and is recombined again at the beam splitter, and finally viewed with the detector.

By looking at the autocorrelation of these pulses as function of the difference in path length between the two arms, the bunch length can be deduced. As the difference is large, the detector will see the sum of the two pulses, but as the difference decreases and become smaller than the bunch length the two pulses will start two interfere

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and a larger signal will be seen. When there is no path difference, the interference is complete and the signal seen will be twice that of the completely separated ones. Thus the intensity seen by the detector should be I_0 when the path difference is large, and I_p when zero, where

$$I_0 = |E|^2 + |E|^2$$
$$I_p = |2E|^2 = 2I_0$$

The autocorrelation looks like

$$I_d(\delta) \propto 2\,\mathrm{Re}\int \left|R(\omega)T(\omega)\tilde{E}(\omega)\right|^2 e^{-i\omega\delta/c}\,d\omega$$

where δ is the difference in path length between the different arms, R is the reflectance of the beam splitter, T its transmittance, E the electric field, ω the frequency and c the speed of light.

Beam Splitter

Unfortunately, the beam splitter is not ideal [HW]. Its effectiveness depends on the thickness and dielectric constant of the foil, and varies for different wavelengths. Due to internal interference of light reflected from both surfaces in the foil, some wavelengths are weakened or even cancelled. For example, the effectiveness of the foil used in our set-up is shown in figure *3*.

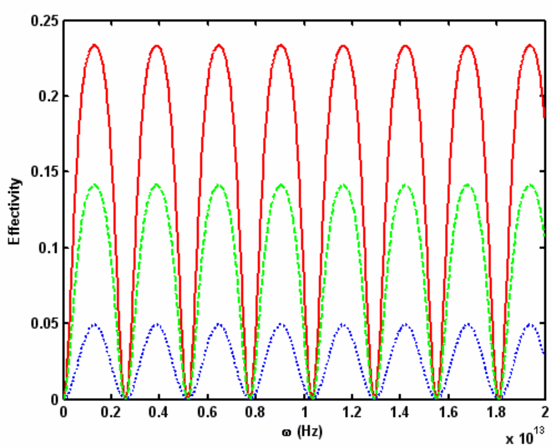

Figure 3: Beam splitter effectiveness for a 254 µm Hostaphan foil. The solid red line is for transversely polarized radiation, the dotted blue for longitudinally polarized and the dashed green is an average.

These interference effects are seen at the detector as dips flanking the peak. If the foil is too thin, these dips come so close to the peak that they cut in to it and thereby narrow its apparent width. This must be taken into consideration as the measurements are done. In figure 4 is shown the case of a square pulse of length *lb* (FWHM) incident on an ideal beam splitter, and in the cases of real beam splitters of thicknesses *t=lb, t=lb/2, t=lb/4* respectively. For the ideal case, the full width at half maximum of the observed pulse is equal to *lb*. This is also the case for real beam splitters of thickness down to about *lb/2*. If the beam splitter gets any thinner than that, the observed width will decrease as well. In fact, for the thicker ones one can actually suffer to measure a little too wide.

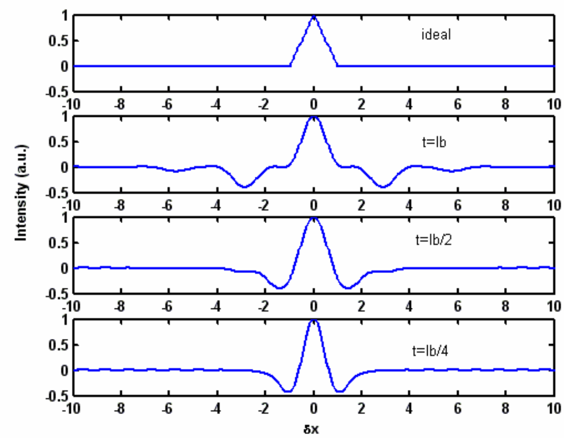

Figure 4: Expected signals if a square pulse of width *lb* FWHM goes through a Michelson interferometer with a beam splitter that is, from above: ideal, a foil with thickness t=lb. t=lb/2, t=lb/4. δx is in units of *lb*.

SET UP AND MEASUREMENT

Our set up is a little bit cramped in the place of an old beam viewer. This was mounted in a 30 cm long pipe, with diameter 2.5 cm. A fluorescent screen was placed on a thin metal window at 45° towards the electron beam, in air. The fluorescent screen was removed and replaced by a metal screen. But since we are looking at the backward radiation, it need be tilted away from the electron bunch. Therefore we could only fit a screen with 0.88 cm diameter. The electron energy at this point is about 200 MeV. If the electron beam is assumed to have a Gaussian distribution with a σ about 2 ps, the opening angle becomes rather large. This is the actual case that is shown in figure 1. Thus the aperture of the pipe is limiting and we angle the screen 40° away from the electron bunch, instead of 45°, to get most of one of the radiation lobes to reach out of the pipe, but even so only a small part will make it out clean. After the pipe, the radiation is angled 90° by a mirror, and then hits the Michelson interferometer. The optics outside of the pipe is all 5”, and the beam splitter is made of a 254 µm Hostaphan foil. The total path length from of the pipe to the detector is roughly 30 cm. The detector is a bolometer that need be cooled with liquid helium and pumped on.

With the assumptions above, that none of the radiation coming out of the pipe is lost in the optics except for in the beam splitter, and that the opening angles are not affected by the different tilt of our screen the autocorrelation can be calculated and is shown in figure 5.

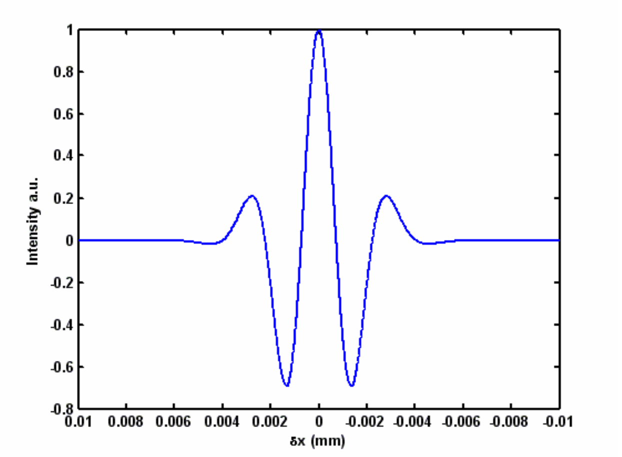

Figure 5: Autocorrelation of the radiation from a Gaussian electron beam.

Now there are two new peaks beside the dips flanking the main peak. These result from the radiation not being completely Gaussian and no longer centred at $\omega=0$.

Measurements were done scanning the mirror over 10 mm, passing over the zero path length difference, in steps of 0.1 mm. Every point is an average over 20 shots. At first, a corrector magnet upstream from the screen was used to hit as good as possible on the screen. Then the detector saturated, so we actually had to go the other way and decrease the signal. A scan is shown in figure 6, normalised to the peak value.

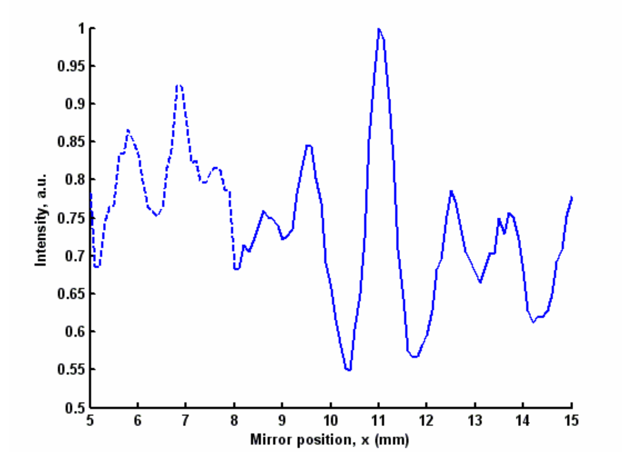

Figure 6: Measured intensity in a real scan. (There was an interrupting injection after the dotted part of the scan.)

The main peak is visible, although definitely not twice as strong as the baseline. For this we have found no particular reason, unless the bunch is so long that the flanking dips are affecting even the peak. There are the flanking dips, and the peaks seen in the larger model. The baseline however is not exactly obvious. This could be due to the scan being a bit rough, shorter steps and more shots per step should be used. Also, the experiment was performed in air, which distorts the spectrum, mainly due to water absorption. The actual difference in path length is twice the difference in mirror position. So letting $\delta x=0$ at the peak, subtracting a baseline and normalising to the peak again, the measured data can be compared to the modelled, and this is shown in figure 7. The fit is quite

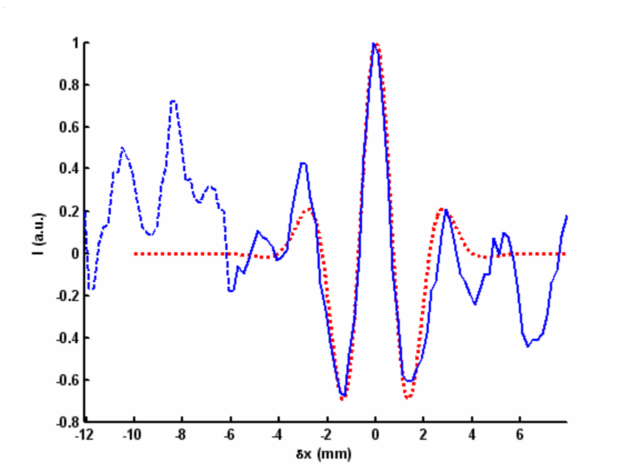

Figure 7: Measured and modelled intensities (normalised).

close when letting $\sigma=700\mu m$ for the electron bunch. However, the measured full width at half maximum (seen from the zero level) is far too small.

CONCLUSIONS

The method is seen to work, even though we run a crude set up at the moment, and a beam σ of about 2.3 ps is measured. It's worth refining for the FEL test facility and we believe we can measure the bunch length we will have then. The bunch length we have now seem to be about at the upper limit of what is possible to measure with this method. A thicker foil will be tried in future.

REFERENCES

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