

# SINGLE BUNCH OPERATION AT ANKA: GUN PERFORMANCE, TIMING AND FIRST RESULTS\*

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## Abstract

A new 90 kV electron source, which was bought from RI Research Instruments GmbH [1], has been installed in the ANKA storage ring. In contrast to the previous sources, it allows multi- as well as single bunch operation [2]. For the estimation of the maximum acceptable emittance of the gun, beam transport simulations from exit of the gun to the following injector microtron were done using OptiM [3], thus resulting in an acceptance  $A \approx 20$  mm.mrad. Here the simulated emittance is compared to the measured “pepper-pot” results.

The new source also necessitated for single bunch operation, that the old timing system be replaced by an event driven system from Micro Research Finland (MRF). Further details of single bunch operation and timing are presented.

## INTRODUCTION

Routine user operation at ANKA is typically done in multi bunch mode, with three trains of 33 bunches each and a gap of about 80 empty buckets. There is, however, a growing need for single bunch operation as well as for custom made bunch patterns, driven mainly by machine physics experiments.

This work presents experimental results on a recently installed new electron source capable of providing both short pulses for single bunch injection, as well as long pulses for routine multi bunch injection into the ANKA storage ring.

The paper is organised as follows: first we present simulations done to determine the maximum emittance that can be accepted by the transport line from the gun to the injector microtron, which is used as a reference performance requirement for the gun emittance. We then proceed to describe the gun emittance measurements done with a “pepper-pot” setup. We then describe the main features of the new timing system which had to be installed to provide the required flexibility for generating arbitrary filling patterns and finally we present the conclusions.

## TRANSFER LINE ACCEPTANCE

The need for lossless current transmission from the output of the gun up to the input of the injector microtron imposes a limit to the maximum acceptable emittance of the beam produced by the gun. Given the relatively low

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energy at the output of the gun, we expect space charge effects to play an important role in determining the beam envelope evolution, so that the transfer line acceptance is defined not only by the physical aperture and focusing properties (strength of magnetic lenses along the channel) but also by the beam current. We therefore use the code OptiM [3] to calculate the beam envelope evolution along the transfer line, taking space charge, finite emittance and solenoidal focusing into account. The input Twiss parameters for the incoming beam ( $\alpha$  and  $\beta$ ) are obtained from beam optics simulations of the gun itself performed with EGUN [4]. Calculations are performed for a beam current of 300 mA and different values of input beam emittance: for each new value of emittance a manual search for the optimum focusing strengths is done looking to minimise the beam envelope all along the transfer channel. We then defined the transfer channel acceptance (for a 300 mA beam) as the gun emittance for which the beam envelope just touches the physical aperture. The calculated normalised acceptance obtained in this way is  $A \approx 20$  mm.mrad.

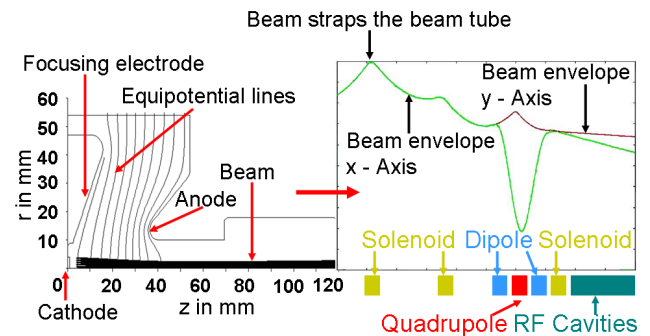


Figure 1: Determination of the acceptance. The left figure shows the beam transport inside the gun, which was calculated using EGUN, the right plot shows the further beam transport to the following microtron calculated with OptiM. The radius of the beam tube is 7 mm.

## EMITTANCE MEASUREMENT

The emittance of the gun was measured in the multi bunch mode (long pulse mode: 500 ns) using a “pepper-pot” setup [2] for different currents between 46 mA and 270 mA. The emittance is estimated using the formula:

$$\epsilon_{\text{norm,eff}} = 4 \cdot \gamma \cdot \beta \cdot \sqrt{C_{xx} C_{x'x'} - C_{xx'}^2}$$

$$C_{xx} = \langle x^2 \rangle - \langle x \rangle^2$$

$$C_{x'x'} = \langle x'^2 \rangle - \langle x' \rangle^2$$

$$C_{xx'} = \langle xx' \rangle - \langle x \rangle \langle x' \rangle$$

with  $\gamma\beta = 0.62$ . The parameters  $C_{xx}$ ,  $C_{x'x'}$  and  $C_{xx'}$  are calculated according to [5] as a function of properties of

the projected intensity profiles measured at a fluorescent (YAG) screen. The image on the YAG screen is composed of a series of peaks and for each peak one must determine the peak position, width and integrated intensity. Also needed are the known geometric parameters such as the hole spacing on the “pepper-pot” and the “pepper - pot” to screen distance L.

Figure 2 shows an image of a measurement and the evaluation of the emittance based on the horizontal projection of a slice.

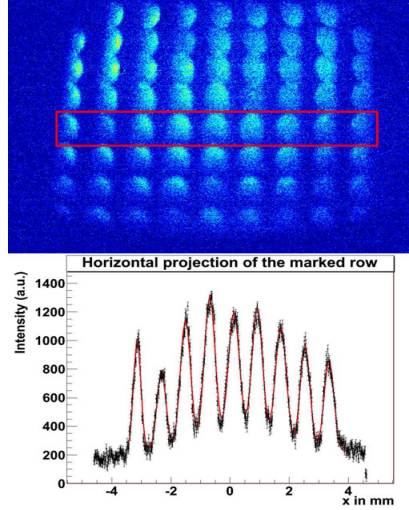


Figure 2: Imprint for 270 mA. The top plot shows an imprint of a measurement, the bottom the horizontal projection of the marked row is shown. The data are fitted with a sum of Gauss functions (red line).

To obtain the parameters of the peaks the data were fitted to a sum of Gauss functions:

$$f(x) = \sum_{k=1}^p A_k \cdot \exp\left\{-\frac{1}{2} \cdot \left(\frac{x - x_k}{\sigma_k}\right)^2\right\} + \text{const}$$

with  $x_k$  = position of the  $k^{\text{th}}$  peak at the screen,  $\sigma_k$  = width of the  $k^{\text{th}}$  peak,  $A_k$  = maximum amplitude of the  $k^{\text{th}}$  peak,  $p = 9$ , which is the number of peaks at the screen and “const” describes a constant background. The integrated intensity for each peak was calculated by analytically integrating each separate Gaussian.

The final results of the measurement are shown in figure 3.

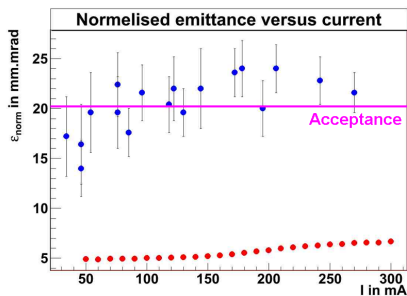


Figure 3: The measured emittance (blue dots) versus the current. The red dots represent the expected values calculated with EGUN.

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On average, the measured values are about 3 to 4 times larger than the expected values from EGUN simulations. Furthermore, the measured emittance doesn't show a dependency on the current. On the other hand, the measured normalised emittance is always in the order of the acceptance of the transport channel, thus the beam losses in the transport channel are accessible.

In figure 4, the measured and the simulated phase space plot from EGUN are both illustrated

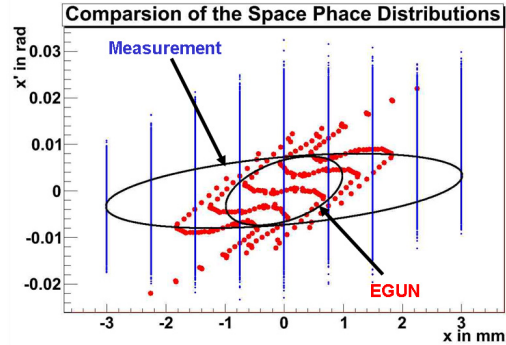


Figure 4: Phase space plots from EGUN (red) and from the measurement (blue) as well as the four sigma ellipses.

The phase space plot for EGUN was obtained by transforming the cylindrical EGUN results ( $R, R'$ ) into Cartesian coordinates  $(x, x')$  [6] with  $\varphi = 0$  and  $\varphi = \pi$ . For the measured phase space, particles were generated using the fit results. The position  $x$  of each particle is equal to the known  $k^{\text{th}}$  position of the “pepper-pot” hole. For the angles, a Gaussian distribution was assumed. The mean value is equal to  $x_k/L$  and for the width  $\sigma_k/L$  was taken. The number of particles per hole was chosen according to the integrated intensity.

As in the previous paragraph, the measurement differ from the exception. The ellipse from the EGUN calculation is more tilted than the measured one.

Several possible sources of systematic measurement errors were investigated including the inhomogeneity of the YAG screen and its finite decay time, dynamic range limitations of the used camera, misalignment in the setup, stray electric and magnetic fields. However, all of these effects have been estimated and found to be either too small or lead to a decrease of the measured emittance.

We believe that the most likely reason for the difference between measured and expected emittance is the emittance “blow up” due to the grid inside the gun similarly reported in [7, 8]. This is due to EGUN treating the gun as a diode, which doesn't take the defocusing effects of the grid into account [9].

THE NEW TIMING SYSTEM

The previous timing system for gun and injection elements was based on 4 Stanford delay generators. Because it didn't offer the required flexibility, it was necessary to replace the modular timing system by an event driven system that could fill different buckets automatically using predefined delays for user defined fill

patterns. The event driven system has a general output timing resolution of 8 ns period over a range greater than 100 hours, plus a further fine adjustment of 10 ps over 10 ns.

The new system from MRF consists of an event generator (EVG) and event receiver (EVR) and is illustrated in figure 5.

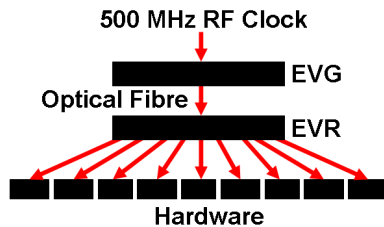


Figure 5: Timing System at ANKA. The EVG generates events which are transmitted, together with the state of an 8 bit distributed bus, via optical fibre to the EVR. From the EVR, trigger signals are distributed to the hardware, e.g. kickers. The RF clock is used as reference signal for the timing.

The EVG is phase locked to the 499.69 MHz RF signal and generates EVR events in the form of RAM addresses that are sent over a gigabit link to the EVR for decoding. An 8 bit distributed bus is also implemented which allows the simultaneous distribution of real time clock signals, such as the revolution clock.

The EVR has a wide range of output signal types such as TTL, LVPECL etc. and multiple output ports. In the case of ANKA the 17 output ports, mostly TTL, connect to the hardware over coaxial cable.

The programming and visualisation of the timing system were done with PVSS (Prozessvisualisierung- und Steuerungs-System) from ETM in Austria [11].

## FIRST RESULTS

With the new timing system, the single bunch injection was improved. To get a clean single bunch, all delays for the triggers have to be set correctly. To find the correct value for the gun trigger, the gun trigger was first varied in steps of 250 ps and the fill pattern was measured with a strip line until the worst injection situation was found. The worst setting is found when two neighbouring buckets are quite equally filled. In this case, the delay is set to inject between two buckets. To then get the correct trigger position the trigger need only be shifted by 1 ns (half a bucket length).

After further optimisations of the settings for all injection devices, the single bunch and multi bunch injection as well the generation of user defined fill pattern works very well. The maximum achieved current thus far injected in a single bunch operation is 5 mA and a total maximum current for a multi bunch operation being 200 mA. The new gun and timing allowed studies of the storage ring impedance and bunch deformations could be performed [12].

## SUMMARY

A new single bunch electron gun has been installed in ANKA facility. The emittance was measured with a “pepper-pot” setup for different currents and shows, on average, a normalised emittance of  $\epsilon_{\text{norm}} = 20 \text{ mm.mrad}$ , which is 3 to 4 time larger than simulated but on the other hand within the order of the calculated acceptance of  $A = 20 \text{ mm.mrad}$  so that a reasonable beam transport should be possible

For the single bunch injection, it was necessary to replace the old timing system by a new event driven system. To find the right gun delay, a scanning process was done to find the worst injection situation and shifting the delay by the half bucket length. After further optimisations, the single bunch injection works very well. A new feature of the timing system is the possibility to fill user defined pattern using predefined delays, which allows new experiments at ANKA.

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