COMMISSIONING OF A BUNCH LENGTH MONITOR AT AMPS

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Abstract

The Amsterdam Pulse Stretcher (AmPS) is an electron storage and pulse stretcher ring. The ring operates at energies between 300 and 900 MeV at circulating currents up to 200 mA. Operating as a pulse stretcher a 2856 MHz traveling wave structure provides the accelerating field; when used in storage mode a 476 MHz cavity can be used instead to obtain a higher accelerating potential. For a study of the longitudinal properties of the stored electron beam a device was needed with a time resolution of the order of 10 ps. For this purpose an image dissector tube was obtained from the Budker Institute of Nuclear Physics of Novosibirsk. The instrument has been installed September 1995. The 2856 MHz accelerating structure and a low energy of 380 MeV were used to get bunch lengths of 10 ps. With these short bunches it was possible to analyze the time-resolution of the dissector. The impulse response is approximately Gaussian with a σ-value of 20 ps. Bunch length measurements with 476 MHz RF showed coupled bunch instabilities. Bunch length is presently measured as function of beam current. Once the problems with coupled bunch instabilities have been solved these measurements will be used to determine the broadband impedance of AmPS.

1 INTRODUCTION

Time-resolved measurements are an essential part of the diagnostics of electron storage rings. These measurements yield a better understanding of longitudinal instabilities and provide data to determine the broadband impedance of AmPS. Bunch lengths at AmPS are in the range σ_{beam}=10–100 ps. To measure on this timescale several techniques are possible. For instance fast photodiodes, photon-counting and streak cameras have successfully been used. All these methods make use of the time structure that is present in the synchrotron radiation. At AmPS a set up with an image dissector tube (LI-602M) has been installed. Similar set ups have been used at other institutes [1, 2, 3].

2 THE IMAGE DISSECTOR

The image dissector is an electro-optical device developed at the Budker Institute of Nuclear Physics. A layout of the device is given in figure 1. Synchrotron radiation (SR) emitted from one of the dipoles is transported through an optical system consisting of lenses and mirrors to an area outside

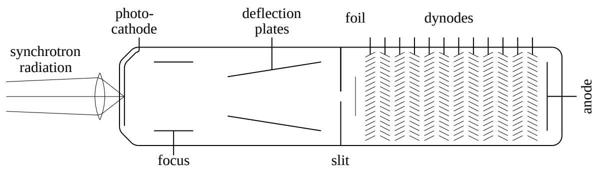

Figure 1: Layout of the dissector tube.

the accelerator vault. A strongly reduced image of the SR source is focused on the photocathode of the dissector. The emitted photo-electrons are accelerated towards the slit by a potential of typically 10 kV. The photo-electron beam can be shifted over the slit-plane with two electrostatic deflection plates. Electrons not intercepted by the slit are detected in a multiplier section consisting of a chain of dynodes.

When the deflection plates are driven by a harmonic signal that is phase locked to the repetition rate of the electron bunches a semi-static image is formed on the slit-plane. AmPS is equipped with two RF stations (476 MHz and 2856 MHz) driven by the same master oscillator. The deflection system operates at 119 MHz derived from the master oscillator. So depending on which RF system is operational the dissector is operating at the 4-th or 24-th subharmonic. The formation of the image on the slit plane operating at the 4-th subharmonic is shown in figure 2. A 50 Hz sawtooth scan is added to the RF-scan. This ramping voltage shifts the entire image over the slit such that it is converted in an output signal that is displayed on an oscilloscope. Due to non-linearity of the RF-scan accurate measurements can only be done near zero-crossing of the sinusoid. Two settings of the reference phase are commonly used: one where the images from the forward and backward scan overlap at zero crossing and one where the images from the forward and backward scan are just separated near zero crossing.

The resolution of bunch length measurements with the previously- described set up is determined mainly by:

- The transit time spread of the photo-electrons: the time spread between the impact of photons on the cathode and their arrival at the slit-plane is proportional to the reciprocal of the electric field strength between cathode and slit-plane. Kinetic energy spread of emitted photo-electrons increases the transit time spread.
- Phase jitter of the reference signal: any phase jitter in the reference signal with respect to the repetition

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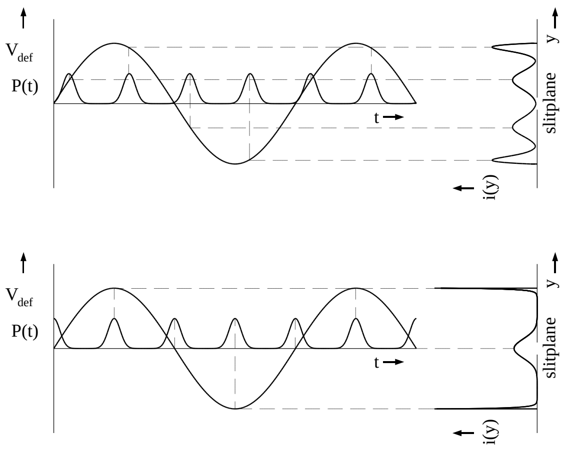

Figure 2: Image on the slit-plane when operating at the 4-th subharmonic of the ring RF. V_{def} is the RF-scan applied on the deflecting plates, $P(t)$ is the in time varying photon flux from the SR and $i(y)$ is the averaged photon current which is a function of the position y on the slit-plane. In the upper picture the reference phase has been adjusted to see all bunches, in the lower picture the images from the rising and falling edge of the scan overlap.

rate of the bunches leads to a broadening of the output signal since the output signal is the average of many bunches.

- The image quality: this contains the size of the SR spot on the photocathode, the focusing of the photon-electron beam and the width of the slit.

In good approximation the resolution affecting mechanisms have a Gaussian profile. Therefore the widths of the contributions add up according to:

$$\sigma_{app}^2 = \sigma_{tt}^2 + \sigma_{pha}^2 + \sigma_{ima}^2 \quad , \tag{1}$$

where σ_{app} is the total width of the impulse response and the terms on the right hand side are the widths of each separate contribution. Here resolution is considered as the width of the dissector output signal when a train of infinitely short photon pulses is incident on the photocathode.

3 MEASUREMENT OF RESOLUTION

The bunch shape of a damped electron beam with low current is Gaussian with a width [4]:

$$\sigma_{beam} \propto \frac{1}{\sqrt{\cos(\phi_s) V_{cav}}} \quad , \tag{2}$$

where the magnitude of the cavity voltage, V_{cav}, is such that $\cos(\phi_s) \approx 1$. The width measured with a dissector is then:

$$\sigma_{meas}^2 = \sigma_{app}^2 + \sigma_{beam}^2 = \sigma_{app}^2 + \frac{C}{V_{cav}} \quad , \tag{3}$$

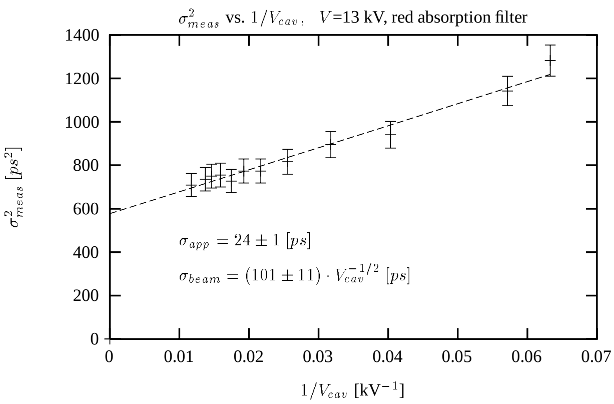

Figure 3: Determination of dissector resolution by varying V_{cav}. The resolution is found as an offset at infinite V_{cav}.

where C is a constant. Bunch lengths have been measured as function of V_{cav} and the data has been fitted with equation 3. Beam currents were 1–3 μA/bunch. An example of this measurement is given in figure 3. No bunch lengthening was observed up to 45 μA/bunch, justifying the use of equation 2.

The transit time contribution to the resolution can be improved by limiting the spectrum of the SR in order to reduce the spread in momentum of the photo-electrons. For this purpose a low-pass absorption filter and a 633 nm, 10 nm FWHM, interference filter have been used. Best results are obtained with the absorption filter; no significantly better resolution is obtained with the interference filter while the better transmission of the absorption filter results in less noise from the multiplier. Table 1 shows a summary of the results.

Table 1: Measured and calculated bunch length at two beam energies. Values are given without filter, with an absorption and an interference bandpass filter.

E [MeV]	filter	σ_{app} [ps]	σ_{beam} [ps]	σ_{theo} [ps]
380	no	31 ± 1	10 ± 1	11
380	abs.	24 ± 1	10 ± 1	11
586	no	31 ± 3	22 ± 3	22
586	abs.	25 ± 3	21 ± 2	22
586	int.	23 ± 3	22 ± 2	22

Since the transit time spread is a function of the electric field in the image section of the dissector it can be retrieved from the total resolution:

$$\sigma_{app}^2 = \left(\sigma_{pha}^2 + \sigma_{ima}^2\right) + \frac{D^2}{V^2} \quad , \tag{4}$$

where D is a constant and V the high voltage applied on the photocathode. The result of this measurement of resolution as function of the high voltage of the dissector with the absorption filter is shown in figure 4. Results show that when operating the dissector with a high voltage of V=13 kV the total resolution amounts to 24 ps, which consists of 19 ps

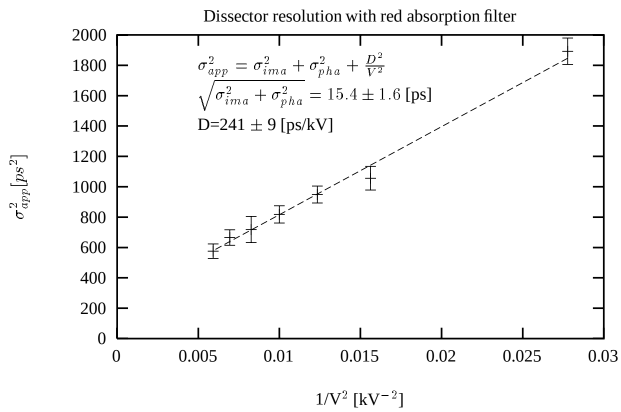

Figure 4: Resolution as function of the high voltage in the image section of the dissector.

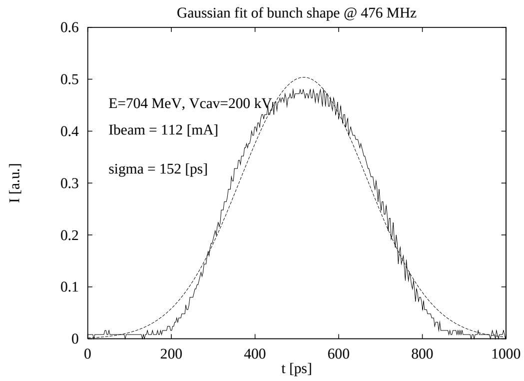

Figure 5: Dissector output signal

due to transit time effects, 15 ps due to phase jitter and a negligible 4 ps due to image quality. The latter contribution has been measured separately by switching off the RF scanning voltage.

Measured bunch lengths have been compared with values calculated from the machine parameters. The comparison is given in table 1 for a cavity voltage of V_{cav}=100 kV.

4 BUNCH LENGTH MEASUREMENTS

In storage mode AmPS is mostly operated with the 476 MHz RF station. The injection scheme at present only allows multi-bunch operation; all 336 bunches are filled equally. Contrary to the observations with the 2856 MHz RF the bunch length rapidly increases with beam current. Oscillations of the bunch shape are observed starting at currents of 60 μA/bunch. The pattern of these oscillations changes at a rate equal to the movement of the tuning plunger in the cavity. The equilibrium position of the tuning plunger can be changed with the cavity temperature. The change of cavity geometry shifts the resonance frequency of higher order modes (HOM). HOM of the cavity are not damped. With the cavity temperature increased by 5 °C the beam remains stable up to currents of 500 μA/bunch (170 mA average current). With these empirically determined best settings of the

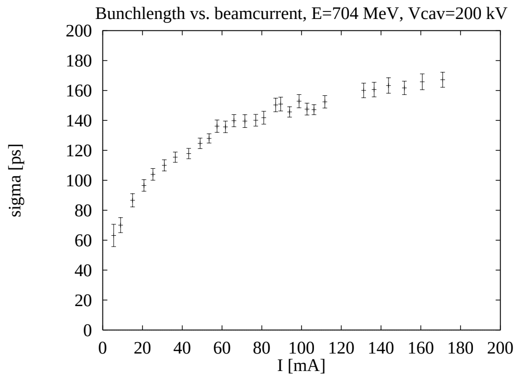

Figure 6: Bunch length measurement with 476 MHz RF. The beam current is the average circulating current divided over 336 bunches.

RF station bunch lengths have been measured as function of beam current. A typical bunch shape is shown in figure 5. The Gaussian fit shows that the bunch shape is slightly non-Gaussian. Bunch length as function of beam current is shown in figure 6. The natural bunch length for this measurement was σ_{beam}=50 ps. The data does not follow the $\sigma^3 \propto I$ relation [5] expected from the combined effect of potential-well distortion and turbulent bunch lengthening. If this relation is assumed a broadband impedance of 300 Ω is found, which is 2 orders of magnitude larger than expected. The idling 2856 MHz traveling wave structure is expected to be the main cause of the lengthening. Recently experiments have been done with both RF stations driven simultaneously. These experiments have shown a more stable beam and control of the bunch length with the phase settings of the 2856 MHz station.

5 CONCLUSION

A dissector has been commissioned successfully and its time resolution has been determined. Observed longitudinal instabilities can be cured by increasing the cavity temperature. Bunch lengthening effects need further analysis.

6 REFERENCES

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