PECULIARITIES OF BUNCH SHAPE MEASUREMENTS OF H-MINUS BEAMS IN LINEAR ACCELERATORS

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Abstract

When measuring a bunch shape of H-minus beam with the bunch shape monitor (BSM) based on a transverse scanning of low energy secondary electrons the difficulties due to presence of detached electrons arise. Fraction of the detached electrons gets into the optical channel of BSM and produce additional signals thus distorting measurement data. The results of simulation of interaction of the electrons with the BSM target and analysis of their subsequent motion in BSM electron optical channel are presented. Distortions of the measurement results are discussed. It is demonstrated both by simulations and experimentally that energy separation of the electrons essentially decreases the distortions. Other possible reasons of errors are also discussed.

INTRODUCTION

Principle of operation of BSM has been reported elsewhere [1]. Initially BSM was developed for proton beam of INR linac [2]. Later it was used in several accelerators, including machines with H^- beams, without modifying its configuration. For several MeV beams no features connected with H^- were observed [3, 4]. For tens MeV [5] experimental curves included additional hump identified to be due to detached electrons originated in a tungsten BSM wire target.

Analysis of the total electron-loss cross section in the energy range of interest (10÷1000 MeV) [6] as well as the ranges of electrons in a tungsten [7] has shown that electrons are detached in a thin near surface layer much smaller than both target diameter and CSDA ranges of electrons. In this case a flux of free electrons impinging the target can be analyzed instead of electrons detached from H^-. The energy of electrons W_e and that of H^- W_i are related as $W_e = W_i \, {m_e}/{m_i}$, where m_e and m_i are rest masses of electron and ion correspondingly. For example 5.44 keV electrons correspond to 10 MeV ions.

SIMULATION OF INTERACTION OF ELECTRONS WITH BSM TARGET

The simulation of interaction of electrons with BSM target was done with a toolkit for the simulation of the passage of particles through matter Geant4 [8]. Number of impinging electrons was 10^5 for each coordinate X across the 100 μm diameter target taken with a step of 1 μm. The result of simulation is an array of parameters of electrons escaped the target. Some of the simulation results are given in figures 1÷ 3.

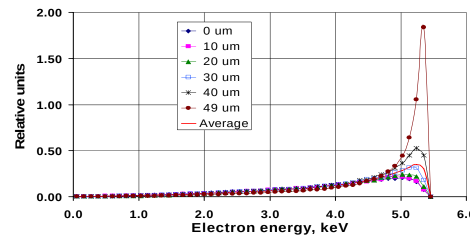

Figure 1: Energy distribution of 5.44 keV electrons after interaction with the target for different input coordinates X.

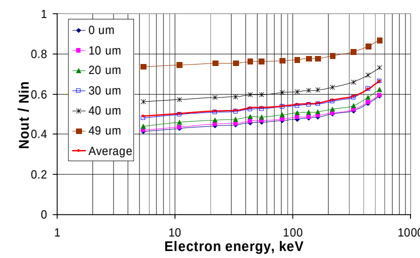

Figure 2: Fraction of electrons escaped the target for different input coordinates X.

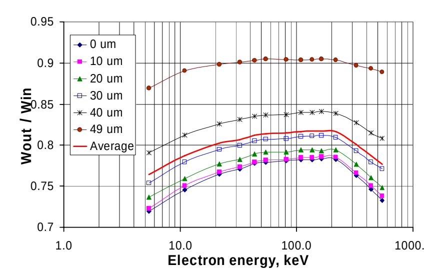

Figure 3: Average energy of escaped electrons normalized by input energy vs input energy W_{in}.

SIMULATION OF ELECTRON MOTION IN BSM OPTICAL CHANNEL.

Parameters of electrons escaped the target were further used as initial data for simulation of electron motion in BSM optical channel. These simulations were done with a specialized software package developed for BSM analysis. The geometry and electrical parameters of the detector for simulations were taken to be identical to that described in [9] because of availability of experimental results on influence of the detached electrons [5] for this BSM. Initial beam was considered to be uniformly distributed across the wire and normally distributed along the wire with a 2 mm rms size.

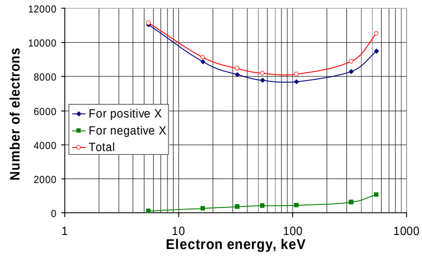

Figure 4: Number of electrons passed through input collimator.

Figure 4 demonstrates number electrons passed through 1 mm input BSM collimator vs initial electron energy for positive and negative X at the target as well as their total number. Energy distribution of these electrons for different initial energies is shown in fig. 5.

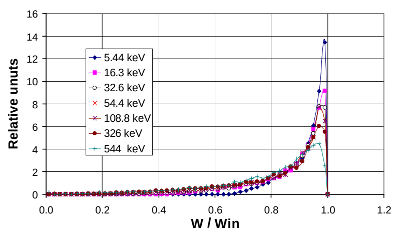

Figure 5: Energy distribution of electrons in BSM optical channel.

A detector response function representing an observable longitudinal distribution in case of a δ-function real distribution is of special interest. These functions calculated for different initial electron energies are given in fig. 6 (the legend shows corresponding H^- beam energies). As a phase resolution for low energy secondary electrons (SE) is typically better than 1° the corresponding response function for these electrons is shown as a single point. The detached electrons result in a background in a measurable function, its shape being gradually transformed with beam energy from bell-type to uniform in phase. The transformation becomes smoother when increasing amplitude of rf deflecting field. One should note that the background is proportional to an integral of the response function. In spite of relatively small dependence of the detached electron current on energy (fig. 4) the integral of response function increases essentially due to decreasing of electron beam rf deflection and focusing degradation.

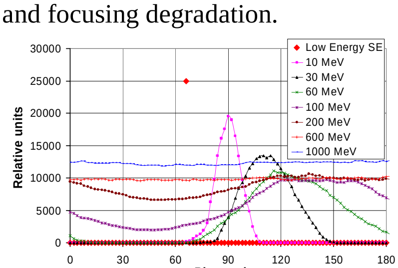

Figure 6: BSM response function for different ion energies.

Knowing a response function one can predict an experimental curve behavior. Generally, a measured distribution $\Phi(\varphi)$ and a true one $F(\varphi)$ are connected as

$$\Phi(\varphi) = \int_{\psi} K(\varphi,\psi)F(\psi)d\psi\ , \qquad (1)$$

where $K(\varphi,\psi)$ is a kernel of integral transformation. The function $K(\varphi,\psi_0)$ represents an instrument response function to a δ-function $\delta(\varphi-\psi_0)$. In our particular case the measurements with low energy SE are carried out with a resolution much better that with the detached electrons so the function thus measured can be considered as a true one. In this case instead of (1) one can write

$$\Phi(\varphi) = F(\varphi) + \alpha \int_{\psi} K(\varphi,\psi)F(\psi)d\psi \qquad (2)$$

and the curves presented in fig. 6 can be used as functions $K(\varphi,\psi_0)$. The parameter α is inserted due to uncertainty of low energy SE and detached electrons intensities and can be found by comparing experimental distribution and a calculated with (2) function.

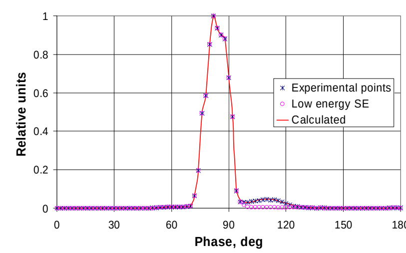

Figure 7: Experimental and calculated with (2) longitudinal distributions for 10 MeV beam.

Figure 7 shows the experimentally observed longitudinal distribution for 10 MeV beam [5], the component due to low energy SE $F(\varphi)$ and the curve $\Phi(\varphi)$ calculated with (2). The parameter α was selected to fit maximum of the calculated $\Phi(\varphi)$ with experimental point. The ratio of signal integral to noise integral in this case is equal to 15.

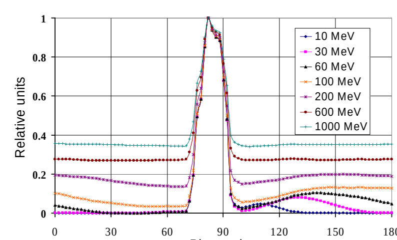

Figure 8: Prediction of experimental curves behavior for different energies (normalization by maximum value)

Low energy secondary electrons originate from ions, protons and detached electrons. Number of these electrons depends on particle ionization loss dE/dx which in its part depends on particle velocity. Hence one can expect about similar behavior of low energy SE coefficient from all three particles vs H^- ion energy. Figure 8 demonstrates a prediction of experimental curves behavior for different ion energies assuming the same true longitudinal distribution and changing the amount of low energy SE as dE/dx for protons [7]. One can observe changing of background behavior and decreasing of signal to noise ratio with energy (fig. 9). One should mention that in reality signal to noise ratio is also influenced by detection efficiency of different energy electrons.

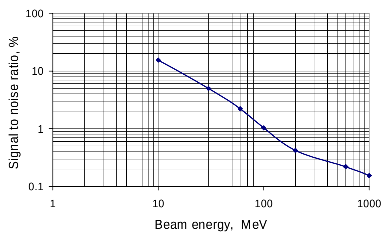

Figure 9: Integrated signal to noise ratio as a function of ion beam energy.

USING ELECTRON ENERGY SEPARATION

Energy difference of the useful low energy secondary electrons and the detached electrons enables to decrease influence of the latter using energy separation. The separation is done in a 90º magnetic spectrometer downstream of the BSM output collimator. This method was foreseen in BSMs developed for SSC linac [10] but at that time the detectors were not tested with a beam. It was first implemented and successfully tested in BSMs developed for SNS [11, 12]. With the radius of 62 mm the resolution was about ±10%. Such a low resolution was selected to avoid losses of useful low energy SE and to decrease complexity of detector tuning. The measurements were done at 7 MeV, 97.9 MeV, 101.5 MeV, 105.3 MeV and 180.7 MeV and no influence of the detached electrons was revealed. To recognize the detached electrons the measurements were done for different set points of separating magnet at 105.3 MeV. Increasing of the set point results in appearing of a hump located at the right of the main distribution (fig.11) and no humps are observed for the set points lower than the nominal one (nominal set point of 10 keV is defined by BSM target potential). The behavior of experimental curves quite corresponds to the above understanding. Vertical shift of the curves in fig. 11 is due to two different gains in signal registration line used in experiment.

One can also see that the variation of a set point does not result in full disappearing of signals within the phase range corresponding to true bunch. This effect can be explained by ionization of residual gas in a vacuum chamber of separating magnet. Positive ions can rich the exit of separating magnet and can be detected by secondary electron multiplier used as an electron detector. The distortion of signal is of the order of 10^{-3}. Also taking into account that the effect is originated from low energy SE already separated in phase one can contend that the shape of the true distribution is not distorted.

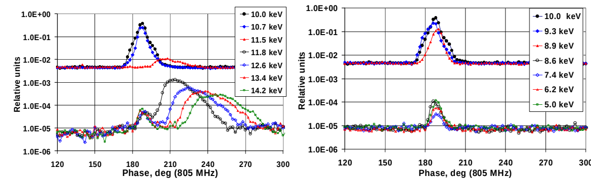

Figure 11: Measurements for different set points of separating magnet.

At the same time residual gas ionization by the detached electrons is also possible. This ionization gives rise to additional background disturbing results of precise measurements, for example longitudinal halo measurements. To diminish the effect an extra pumping of vacuum chamber of the magnet or/and using a potential barrier for ions in front of electron collector can be recommended.

SUMMARY

- The detached electrons distort the results of bunch shape measurements essentially.
- However these distortions are efficiently removed using energy separation of the electrons.
- Modification of BSM is desirable with the aim to remove residual gas ionization influence.

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