MOMENTUM SPREAD DETERMINATION OF LINAC BEAMS USING INCOHERENT COMPONENTS OF THE BUNCH SIGNALS

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Abstract

Measurements of the momentum spread of the particles in a beam are of great importance when optimizing Linac setup for high current operation concerning controlled longitudinal phase space occupation. A new method of the momentum spread determination was tested at GSI heavy ion linear accelerator. It is based on the analysis of incoherent components of the bunch signal. A significant enhancement of signal to noise ratio was achieved by means of resonant cavity pick-up of pile-box shape. Spectra were analyzed on 36^{th} harmonic of the rf-frequency i.e. at 1.3 GHz. This reduced contribution of the coherent components in the frequency spectrum of the bunched beam. Fast digital processing and gating synchronized to the bunch train allowed a drastic reduction of the measuring time and additionally suppressed a noise in the frequency spectrum, respectively. This contribution describes the measurement setup and discusses the first results obtained with heavy ion beams. Since measurements were taken just two days before conference started the results presented here are to be treated as a very preliminary.

MEASUREMENT PRINCIPLES

In the case of the linear accelerator the longitudinal phase space is critically influenced by for any parameters variations. Therefore its knowledge is extremely important for any beam dynamics calculations and calls for precise measurements. There are several methods, e.g. based on the measurements of arrival time and time-of-flight between two particle detectors [1] or basing on the measurements using dipole magnet and kicker [2]. However, these methods are either destructive for beam [1] or require, besides diagnostics elements, an installation of an dedicated kicker [2]. A good alternative is measurements of the two projections of the longitudinal phase space using two independent but non-intercepting devices. In this case the projection of the phase deviation $\frac{\Delta\phi}{\phi}$ axis can be determined by means of e.g. Bunch Shape Monitor, as described e.g. in [3].

The other projection of the phase i.e. the momentum spread $\frac{\Delta p}{p}$ may be determined via analysis of incoherent component of the bunch signals. This would be an analogy to longitudinal Schottky noise measurements for bunched beams commonly used at nearly any circular accelerators [4]. Originally Schottky noise was analyzed for high vacuum diodes that can be considered as a kind of linear accelerator. Let us assume a large synchrotron with big number of circulating bunches like e.g. LHC [5]. At injection 2808 bunches are circulating with revolution frequency of $f_0 = 11.24$ kHz and period of $T_0 = 89\ \mu$s. An interesting question is whether one can observe any Schottky signal within measurement time reduced to let us say 80 μs, i.e. when bunches are passing Schottky pick-up only once. This situation corresponds to the measurements made at a Linear accelerator. The only difference is absence of dispersion in the Linac case. A relationship between the momentum spread and the frequency spread can be obtained from generalization of the momentum compaction function α for transfer line which should be applicable also in the particular case of Linac [6]. The relative change in orbit $\frac{\Delta L}{L_0}$ per relative momentum change $\frac{\Delta p}{p_0}$ is given by:

$$\alpha(s, s_0) = \frac{\Delta L/L_0}{\Delta p/p_0} = \frac{1}{L_0}\int_{s_0}^{s}\frac{D(t)}{\rho(t)}dt \text{ with } L_0 = \int_{s_0}^{s} dt,$$

and D and ρ being dispersion and mean bending radius, respectively. The relative change in time of flight per relative momentum spread $\eta(s, s_0)$ is:

$$\eta(s, s_0) = \frac{\Delta t/t_0}{\Delta p/p_0} = \frac{p_0}{t_0}\frac{\Delta(L/v)}{\Delta p} = \alpha(s, s_0) - 1 + \frac{v^2}{c^2},$$

where v is the velocity of the reference particle. If there is no dispersion (no dipole in lattice) one reads:

$$\eta(s, s_0) = -1 + \frac{v^2}{c^2}.$$

For ultra-relativistic particles a Linac would be isochronous i.e. all particle would arrive simultaneously. However, for GSI Linac $v/c \sim 15\%$ [7] which results in $\eta \simeq -0.98$. Therefore, momentum spread and frequency spread are related to each other via:

$$\frac{\Delta p}{p} = \frac{1}{\eta}\frac{\Delta f}{f}.$$

EXPERIMENTAL SETUP

The measurements described here were performed at GSI *Unilac* [7]. A pill-box cavity with the inner diameter of 236 mm was used as pick-up, see Fig. 1. The frequency of the TM_{010} mode was tuned to 1.30089 MHz i.e. to 36^{th} harmonics of Unilac rf-frequency of 36.136 MHz. This high harmonics number allows rejection of coherent component of the bunch signal[1]. The coupling loop was

[1]Power density of the coherent signal depend on the bunch length and decreases with the harmonic number. On the contrary, the power spectrum density per Schottky band remain constant.

ISBN 978-3-95450-118-2

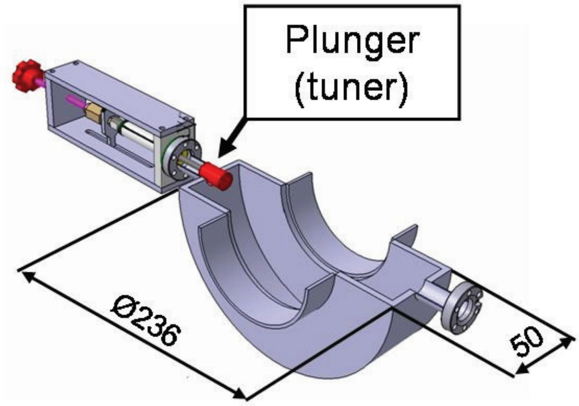

Figure 1: Model of the cavity. See description in the text.

tuned to reach overcritical coupling which allows to keep quality factor at $Q_L = 260$ and reach a desired bandwidth of 4 MHz. Fine tuning was made by means of plunger tuner within the range of $f_{res} \pm 1$ MHz. The signal of the cavity was amplified using two low noise amplifiers (LNA) as shown in Fig. 3. To reduce an inter-modulation a band-pass filtered was installed in between subsequent amplifiers. The bunch train synchronous gating allows significant reduction of noise contribution. Modern FFT spectrum analyzers make possible a signal analysis even within the relatively short measurement time of $\sim$ 100 μs. Within this time (and corresponding RBW of $\sim$ 8 kHz) one could reach a sensitivity of -100 dBm. This was proven by measurement of the thermal noise of LNA amplified in the cavity as e.g. described in [8].

The general idea of experiment is presented in Fig. 4. The cavity was installed on the beam transfer line between Unilac and injection to SIS18 synchrotron. The beam of 1.2×10^{10} U^{28+} ions was accelerated to 11.4 MeV/u in

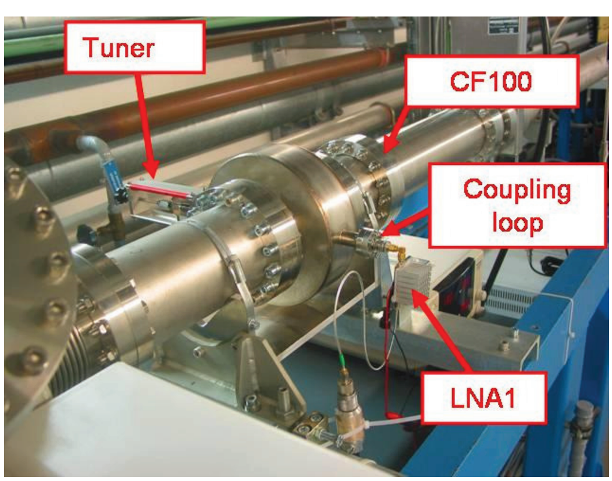

Figure 2: Cavity installed in the transfer beam line between Unilac and SIS18 synchrotron.

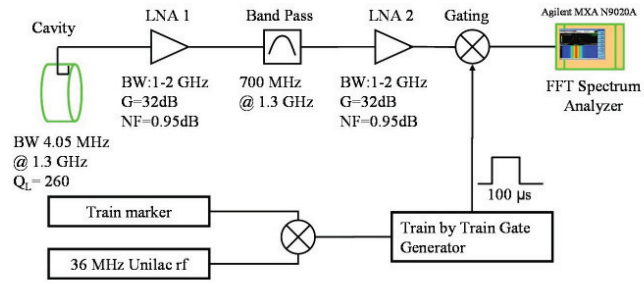

Figure 3: Signal treatment.

Unilac and was injected over the transfer line consisting of the cavity and the Bunch Shape Monitor into SIS18 synchrotron. The energy spread of the beam from Unilac was changed by means of buncher. The phase of buncher was tune such, that bunches were passing exactly at zero crossing i.e. they were not accelerated but only compressed (or decompressed). Three buncher settings were used: i) bunching (large momentum spread), ii) de-bunching (small momentum spread) and iii) buncher switched off (intermediate momentum spread). In this experiment the SIS18 synchrotron was used only as an energy analyzer. The injected beam was left over 150 ms without powered SIS18 rf-cavity. The coasting beam was analyzed using standard Schottky beam diagnostics of SIS18. Results of these measurements for three different buncher settings (different momentum spreads) are presented in Fig. 5. In this figure effects due to high beam intensity are clearly visible: the spectra are far from the Gauss-like distributions. The momentum spread is in the order of 1.5×10^3 and it changes by factor of two between extrema buncher settings (at injection $\eta_{\text{SIS18}} = 0.94$). Corresponding spectra measured using Schottky cavity installed in the transfer line are shown in Fig. 6. In these spectra the broad distribution underneath the strong coherent signal are to be related to incoherent components of the beam signals. The spectra are shown ”as they came” without any normalization. The width was determined at the hight of arbitrary chosen 40 dB from a noise floor. The spectra show same tendency as in Fig. 5: the width is smallest for the bunching case. The ratio between two extremal buncher setting is,

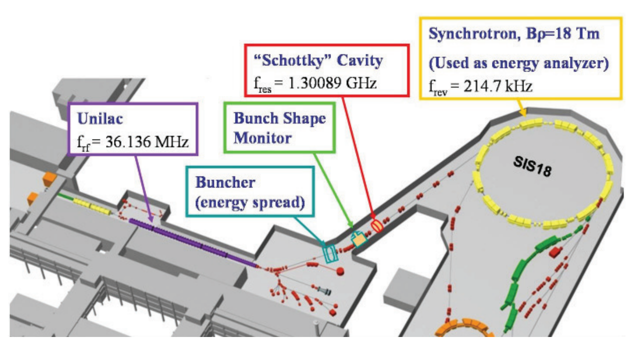

Figure 4: General idea of the experiment at GSI.

ISBN 978-3-95450-118-2

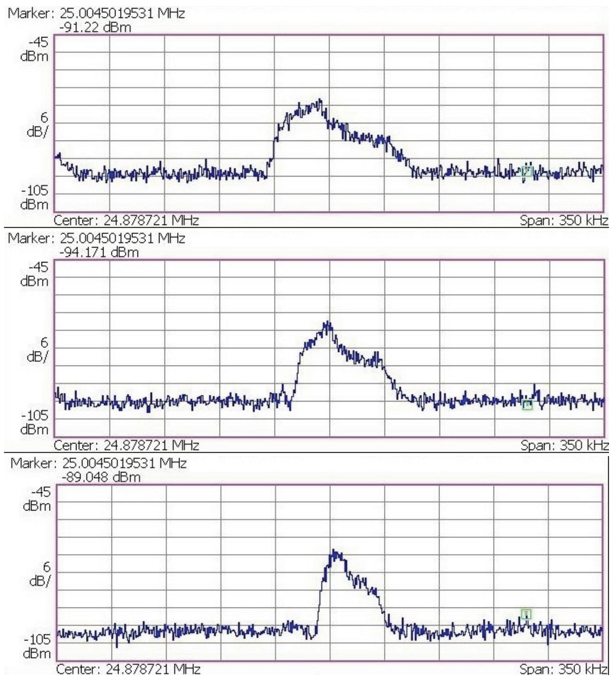

Figure 5: Longitudinal Schottky spectra measured using standard SIS18 Schottky system for different buncher settings: bunching (top), buncher off (middle) and debunching (bottom).

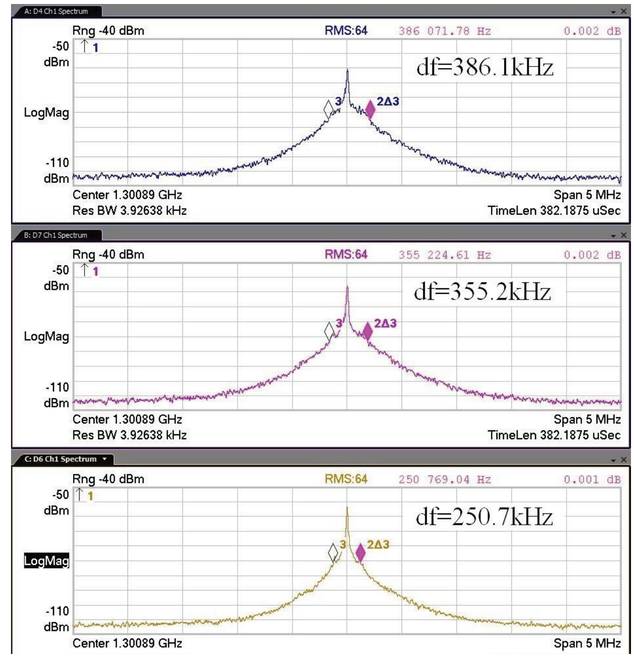

Figure 6: Spectra for Unilac beam measured using new method for different buncher settings. The order is as in Fig. 5.

in this case 1.5. Moreover, the measurements using cavity were performed simultaneously with the measurements using Bunch Shape Monitor. An analysis of the collected date is still in progress. One can expect more precise results that allow better understanding of the correlation between measured bunch length and momentum spread.

CONCLUSIONS AND PERSPECTIVES

The analysis of incoherent components of the Linac bunch signals could be an elegant and cheap method for the momentum spread determination. This new and non-invasive method was proposed and investigated in the experiment at GSI. The results of the measurements using the cavity pick-up were compared with the well established measurements of the Schottky signals for the coasting beam in synchrotron. The observed tendency is same for both methods. The results of the recent experiments can be a first indication, that there is a certain systematics that corresponds to the momentum spread of the bunched Linac beam. Further precise analysis of the experimental data is required to get quantitative results. Moreover, a theoretical model that supports or contradicts the method is desired.

ACKNOWLEDGMENT

Authors owe thanks C. Dorn, K. Gütlich, M. Schwickert, B. Zwicker from GSI Beam Diagnostics Department, W. Barth, W. Bayer, H. Vormann, L. Dahl from GSI LINAC Department, U. Scheeler, C. Wetzel, H. Rödl from Operating Group and P. Horn, D. Acker from GSI Vacuum and Montage Department. Without their help this ”just in time” experiment would not be possible.

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ISBN 978-3-95450-118-2