MEASUREMENT OF SCHOTTKY-LIKE SIGNALS FROM LINAC BUNCHED HADRON BEAMS FOR MOMENTUM SPREAD EVALUATION

P. Kowina, P. Forck, R. Singh, GSI Darmstadt, Germany
F. Caspers, CERN, Switzerland

Abstract

We present a novel method for the measurement of Linac beam parameters in the longitudinal phase space. The longitudinal momentum spread can be evaluated by means of Schottky type signal analysis of bunched beams. There is a close similarity between a repetitive Linac bunch train and a circulating beam with a single short batch in a large machine like the LHC. A dedicated longitudinal cavity pick-up was used in the Linac where resonance frequency and Q-value were carefully selected in order to get an optimum compromise between the unavoidable coherent signal and the desired incoherent part of the beam spectrum. A time domain gating similar to the 4.8 GHz LHC Schottky front-end is applied. As a cross-check of the validity of the interpretation in terms of momentum spread, the Linac beam is analyzed in the downstream synchrotron using standard Schottky methods. In principle, this approach can be understood as an extension of Schottky analysis for circular machines with a perfect mixing between subsequent bunch trains. This contribution describes the test set-up and discusses the results of the measurements with a heavy ion beam.

INTRODUCTION

Good knowledge of the longitudinal is extremely important for any beam dynamics calculations. Especially in the case of linear accelerators the longitudinal phase space is critically influenced by any parameters variations. Usually used methods based on e.g. measurements of arrival time and time-of-flight between two particle detectors [1] or basing on the measurements using dipole magnet and kicker [2] are either 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:

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

METHODS AND RESULTS

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 36th 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 tune

[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.

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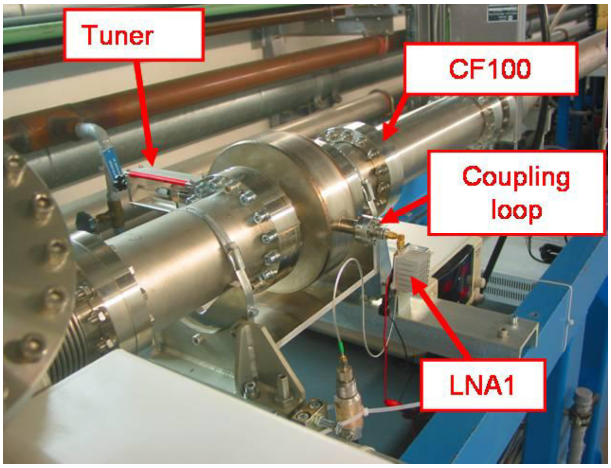

Figure 1: Cavity with the diameter of 236 mm installed in the transfer beam line between Unilac and SIS18 synchrotron.

to reach overcritical coupling which allows to keep quality factor at $Q_L = 260$ and reach 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. 2. 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].

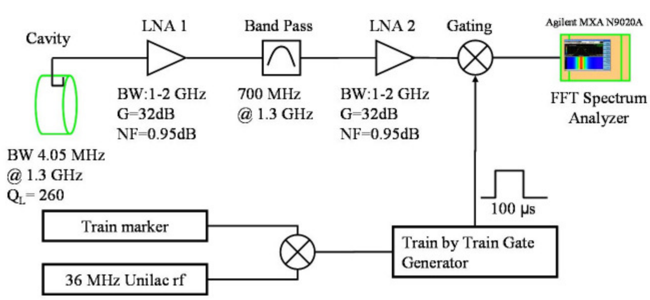

Figure 2: Signal treatment.

The general idea of experiment is presented in Fig. 3. 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 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 cross-

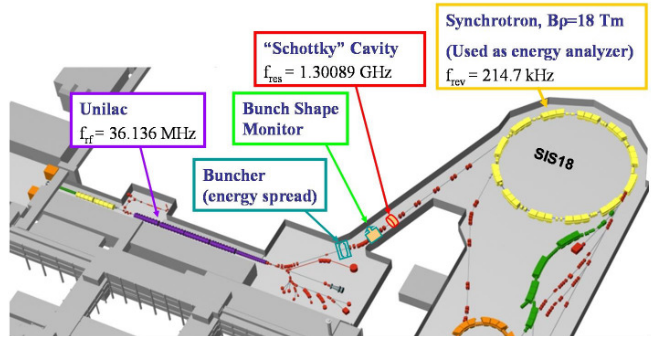

Figure 3: General idea of the experiment at GSI

ing i.e. they were not accelerated but only compressed (or decompressed). Two buncher settings were used: i) bunching (large momentum spread), ii) debunching (small 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 two different buncher settings (different momentum spreads) are presented in Fig. 4. 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 (at Injection $\eta_{\text{SIS18}} = 0.94$). Corresponding spectra measured using Schottky cavity installed in the transfer line are shown in Fig. 5. 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 without any normalization. The spectra show same tendency as in Fig. 4: the width is smaller for the debunching case. The ratio between two buncher setting is, in this case 1.5. However, at the present stage an extraction of the momentum spread can not be performed jet. An analysis of the collected date is still in progress, however one can already now expect more precise results and better understanding at least by possible correlation between measured bunch length and deducted 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 cavity pick-up were compared with 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. An increase of the method sensi-

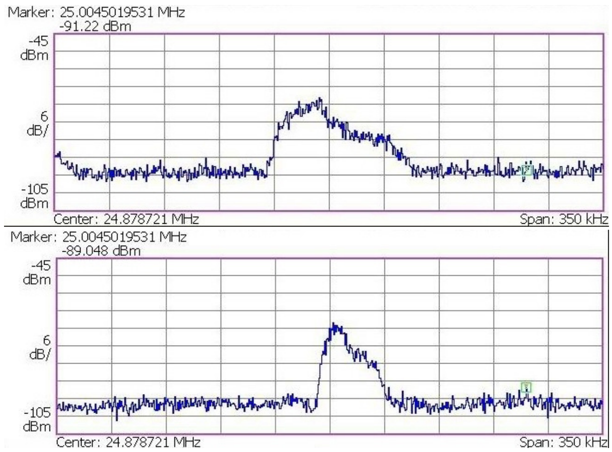

Figure 4: Longitudinal Schottky spectra measured using standard SIS18 Schottky system for two different buncher settings: bunching (top) and debunching (bottom).

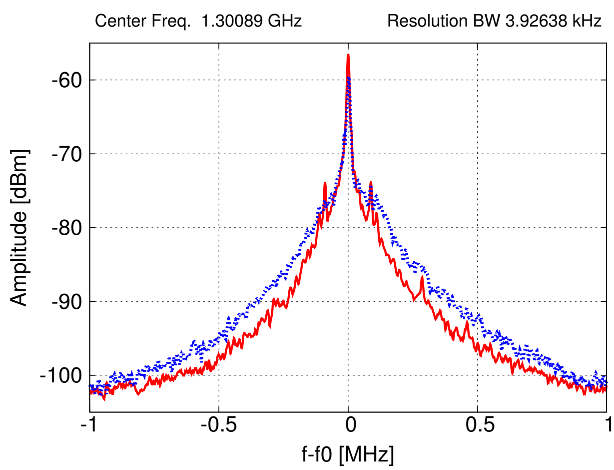

Figure 5: Spectra for Unilac beam measured using new method for two different buncher settings: bunching (blue dashed line) and debunching (red solid line).

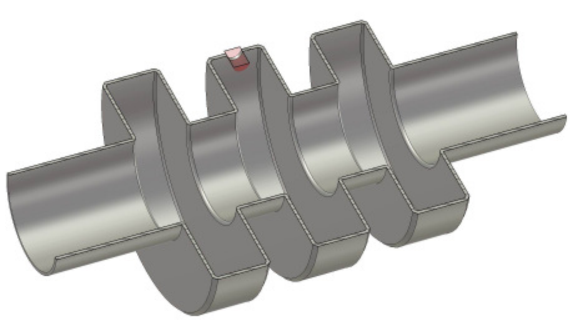

Figure 6: Schematic view of a stack of three cavities with slightly different diameter. See description in text.

tivity can be obtained by stacking of three or more cavities with the quality factor of $Q \simeq 1000$ and tuned to slightly different frequency (i.e. slightly different diameter), as schematically shown in Fig. 6. A signal to noise ratio can be increased by applying of noise-feedback as described in [9]. Moreover, a theoretical model that supports or contradicts the method is desired.

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