Routine Observation of a Longitudinal Beam Emittance Behaviour in the IHEP Accelerator

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Abstract

At the operation of IHEP accelerator complex the required number of bunches from 5 up to 29 are injected from the 1,5 GeV fast cycling booster into the 70 GeV accelerator (U-70). Intensities of bunches can be various in range $(2 \div 7) \cdot 10^{11}$ particles per bunch. To obtain the optimal accelerator regime and efficient beam extraction at mode operation change it is necessary to tune different machine systems. Routine observation of a longitudinal beam emittance behaviour helps at these manipulations, specially when maximum intensities of $1,7 \cdot 10^{13}$ protons per pulse are accelerated in the U-70.

1 INTRODUCTION

The simple method to check a dilution of the longitudinal phase space density is observation on the detected sum pick-up signal. One can use peak-hold detector (PD) to measure the longitudinal peak density $\rho_R(t)$ of the bunched beam during acceleration. If we want to obtain a quantitative measure of the dilution we must compare a real result with special one $\rho_N(t)$ for the phase volume constant regime. Procedures of comparison may be different, but in any case additional signal processing is needed.

2 NORMALIZATION PROCEDURE

During beam acceleration in U-70 the parameters of the longitudinal motion change adiabaticly except in the immediate vicinity of transition energy $E_{tr} = 8,9$ GeV. If phase volume remains constant and the small-amplitude phase oscillations are considered, the bunch length l follows parameters variation with law [1]:

$$l = k\left(\frac{\alpha\gamma^2 - 1}{\gamma^3 \cdot V \cdot \sin\varphi_s}\right)^{\frac{1}{4}} \qquad (1)$$

where k - coefficient, depending on phase volume quantity at injection, α - momentum compaction factor, γ - energy in units of the particle rest energy, V - amplitude of the accelerating voltage, φ_s - synchronous phase.

It is naturally to use for comparison the formula (1) and to represent $\rho_N(t)$, as:

$$\rho_N(t) = \frac{Const}{l} = \frac{Const}{k} \cdot \left(\frac{\gamma^3 \cdot V \cdot \sin\varphi_s}{\alpha\gamma^2 - 1}\right)^{\frac{1}{4}} \qquad (2)$$

where Const - scale coefficient. Moreover, the normalization procedure can be expressed, as

$$\lambda(t) = \frac{\rho_R(t)}{\rho_N(t)} \qquad (3)$$

The computer processing used at U-70 allows to build up function $\lambda(t)$ as a piecewise linear one with time points $t_i, i = 1 \div 32$. Magnitudes of time points depend on observation goals. Required for normalization procedure values $\gamma(t_i)$; $\varphi_s(t_i)$, $V(t_i)$ are obtained at real signals processing (magnetic field B(t), derivative $B'(t)$, RF amplitude V(t)). Obviously, that $\rho_R(t)$ depends on initial beam performances at injection (longitudinal bunch mismatching, intensity). Therefore, it is necessary to build up $\rho_N(t)$ taking into account the real function $\rho_R(t)$. The additional relation are used in any accelerating cycle at the time point $t_j : \rho_N(t_j) = \rho_R(t_j)$. The choice of a point t_j corresponds to observation time scale. Moreover, the intensity value $I(t_j)$ is applied to normalize beam losses and decrease transverse motion influence on the evolution $\lambda(t)$ during acceleration. Finally, the function $\lambda^*(t)$ is displayed on screen:

$$\lambda^*(t_i) = \lambda(t_i) \cdot \frac{I(t_j)}{I(t_i)}, \qquad \lambda^*(t_j) = 1 \qquad (4)$$

It is useful to describe carefully the method of processing PD - signal U(t). Figure 1 shows a non linear characteristic of a detector. The peak density ρ_R is plotted on the horizontal axis, because ρ_R is proportional to input voltage, induced by beam.

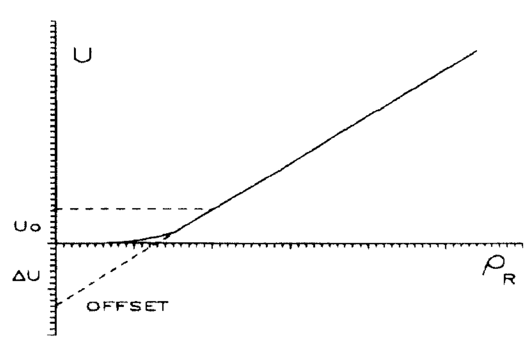

Figure 1. Peak detector characteristic

$U(\rho_R)$ is a linear function at $U \geq U_0$ and has a quadratic character if $U < U_0$. Magnitudes of U_0 and ΔU are defined with a calibration procedure, when a test signal from the pulse generator imitates a beam signal at the detector input. Therefore one can introduce the following approximation:

$$\rho_R(U) = SU_R \quad (5)$$

$$U_R = U + \Delta U, \quad if \quad U_R \geq U_0 \quad (6)$$

$$U_R = (U_0 + \Delta U) \cdot \left(\frac{U}{U_0}\right)^{\frac{1}{2}}, \quad if \quad U_R < U_0, \quad (7)$$

where S - scale coefficient.

The transformation from U(t) to $U_R(t)$ realizes at all time points t_i. The computer program uses value $U_N(t_j) = U_R(t_j)$ to calculate $U_N(t_i)$ according to dependence (2) and $\lambda^*(t_i)$:

$$\lambda^*(t_i) = \frac{U_R(t_i)}{U_N(t_i)} \cdot \frac{I(t_j)}{I(t_i)} \quad (8)$$

3 EQUIPMENT DESCRIPTION

The total measurement complex is described in the paper [2]. A block diagram of the peak detector signal processing is shown in Fig.2.

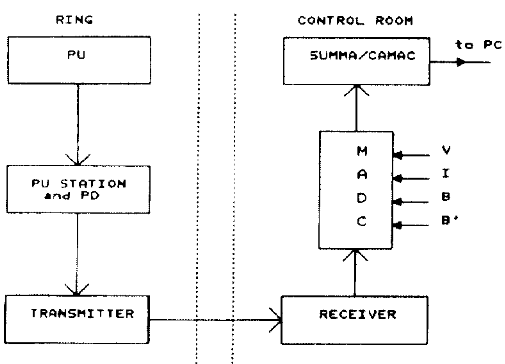

Figure 2. Block-diagram of PU signal processing

The beam signal collected by a wideband PU is fed to wideband amplifier (PU station) and then is detected (PD). At the PD input the bandwidth of measurement channel is 20 kHz÷250MHz. The resonant frequency of PU is 350 MHz. The PU circuit is realized with VHF-diodes. The detected output voltage is fed to transmitter. To isolate a low frequency signal from external noises the twistpair line between transmitter and receiver is used. The line length from the accelerating ring to the control room is equal 200 meters. Analog signals are applied to the multichannel ADC unit (MADC), which is the 10 bits conversion. The signals B(t), $B'(t)$, V(t) and intensity I(t) also is fed to the MADC. Any electronic unit have buffer memory for 32 measurements. All electronics units are in SUMMA/CAMAC standard. Between an accelerator cycles the data from the memory are transmitted to a computer for further treatment. The computer makes calculations and result is displayed on screen every cycle or is printed.

4 MEASUREMENT EXAMPLES

Figure 3 shown a typical U-70 accelerator cycle with an intensity $\sim 1,6 \cdot 10^{13}$ ppp $(5,6 \cdot 10^{11}$ protons per bunch), 1 - intensity signal I(t), 2 - output voltage from detector U(t). Any step in the growing signal I(t) corresponds to a bunch injection from the booster. The quantity U(t) starts to increase, when particles undergo acceleration. At maximum energy both fast extraction (I(t) breaks to low level) and slow resonance extraction are used. Bunches are mismatched with phase space trajectories at an injection to obtain the additional synchrotron frequency spread. This is a typically situation at high intensity.

Fig.4 and Fig.5 show behaviour U(t) and $\lambda^*(t)$, when observation starts after injection. Measurements with $2,6 \cdot 10^{11}$ proton per bunch are given in Fig.6 and Fig.7. One can see, that under the transition energy ($\tau_{tr} \sim 300$ms) a phase volume remains constant $\lambda^*(t) \simeq 1$, although phase oscillations have no small amplitude. At present operation a threshold of "microwave instability" is achieved already at $\sim 10^{11}$ proton per bunch near the transition before a γ - jump are switched on[?].

This is a main reason for very bunch mismatching at the transition crossing. The longitudinal emittance growth may be roughly estimate, as $\sim [\lambda^*]^{-2}$. The slow increase of emittance takes place above the transition. This experimental result we couple with RF - stations noises.

5 CONCLUSION

Described method of the normalized function $\lambda^*(t)$ observation is convenient at γ - jump regime optimization, feedback systems tuning and at an operative registration of the accelerating time region where collective longitudinal instability is excited. Also, this method gives an additional option for the research of incoherent effects at the high intensity. The measuring equipment and processing technique are available for any machine.

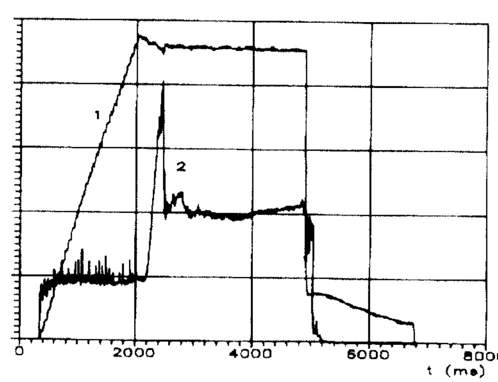

Figure 3.

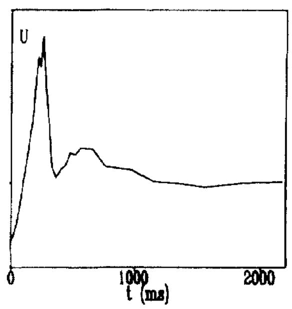

Figure 4.

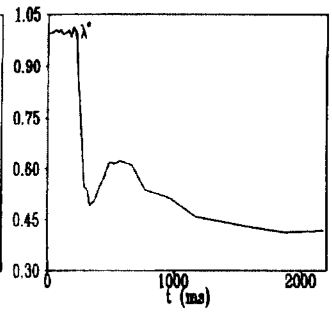

Figure 5.

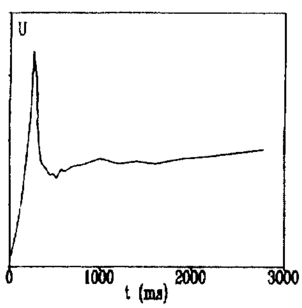

Figure 6.

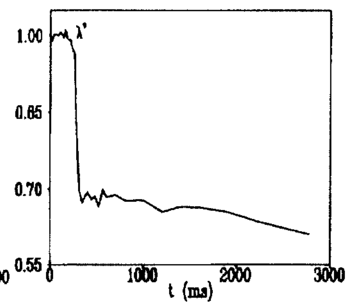

Figure 7.

6 ACKNOWLEDGEMENTS

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