Bunch Length and Velocity Detector and its Application in the CERN Heavy Ion Linac

Yu.V.Bylinsky, A.V.Feschenko, A.V.Liiou, A.A.Men'shov, P.N.Ostroumov
Institute for Nuclear Research
117312 Moscow, RUSSIA
H.Kugler, D.J.Williams
CERN, CH-1211 Geneva 23.

Abstract

A new device - a bunch shape analyzer with a capability of measuring the average velocity of a bunched ion beam - is described. The velocity is determined by moving the entire device in a longitudinal direction and measuring shapes and relative phase positions of bunches with respect to a reference rf signal for two locations of the detector. This bunch length and velocity detector (BLVD) was used for the first time for ions with a β in a range from 2% to 9% and for bunch-lengths down to 150 ps. Temporal resolution and error of velocity measurements are 10 ps and 0.3% respectively.

1. INTRODUCTION

During commissioning of a linear accelerator consisting of several types of accelerating structures it is important to control beam parameters between different parts of the linac. Techniques to measure transverse beam parameters are well known. Recently significant progress has been achieved in longitudinal beam parameter measurements including longitudinal emittance by using a Bunch Length Detector (BLD) which was originally developed in the Institute for Nuclear Research [1,2]. Now the BLD is successfully used for beam studies and accelerator tuning in several laboratories [3,4].

In many cases however, to solve a beam matching problem it is important to know, not only relative distributions of particles in the longitudinal phase plane but also the absolute value of average energy of an accelerated ion beam. This problem exists in the CERN Heavy Ion Linac at the transition regions between the RFQ and the first IH tank, between IH tanks as well as at the exit of the accelertator. It turns out that the BLD can be upgraded in order to additionally measure the average velocity of the ion beam [5]. This paper describes the operational experience with the new device – Bunch Length and Velocity Detector (BLVD) and the results of beam parameter measurements in the CERN Heavy Ion Linac [6].

2. BLVD PERFORMANCE

2.1. Principle of operation

The principle of operation, as well as operational experience, of the bunch length detector (BLD) has been reported elsewhere [1,2]. Briefly it is based on a coherent transformation of the longitudinal structure of a beam under study into one of low energy secondary electrons and then into their spatial distribution through transverse modulation by a deflecting rf field having the same frequency as, or multiple of, the accelerator rf. Normally to find a bunch shape, the intensity of separated electrons is measured with respect to the phase of deflecting field which, in turn, is varied from an arbitrary reference. The BLVD uses an additional means which enables the device as a whole to be displaced in a longitudinal direction - a fine mechanical glider. This feature enables the combination of bunch shape and time of flight measuremens in a single device. When moving the detector one can observe a relative displacement of the bunch shape functions being measured along a phase axis by a value $\Delta\varphi_0 = \omega t = 2\pi \frac{d}{\beta\lambda}$, where β is the relative velocity of the beam under study, λ is the wavelength of the deflecting rf field and d is the distance of the monitor displacement. Measuring $\Delta\varphi_0$ and d one can find the beam velocity β.

Two modes of measurements have been used for β 2% (entrance of the first IH cavity) and 9% (exit of the accelerator).

In the first case the value of detector displacement d was taken to be $\beta_0\lambda$ (about 38 mm), where β_0 is the nominal velocity of the ions. If the velocity differs from the nominal one a displacement of bunch centers $\Delta\varphi_0$ can be observed.

In the second case the value of detector movement d to provide a 2π bunch center phase displacement becomes too large. In this case an additional precise mechanical phase shifter in the deflector rf power supply line was used to compensate a beam center displacement by a value $\beta_0 d$.

Using these compensation methods, in both cases of velocity measurement, the influence of systematic errors from the main electronic phase shifter are avoided.

2.2. Mechanical design

A general layout of the BLVD is presented in fig. 1. The main units - target actuator, RF deflector and detector - are mounted on the vacuum chamber. The chamber is installed on the mechanical glider. The latter allows the precise movement of the whole detector along the beam line by a stepper motor. The displacement is measured with precision by optical position monitors. To allow the detector translation bellows are used at the entrance and the exit of the detector.

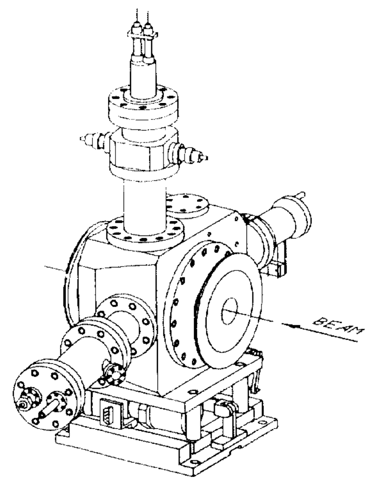

Figure 1. The CERN Bunch Length and Velocity Detector

The rf deflector frequency has been chosen to be the second harmonic of the fundamental one thus providing a 90° range of bunch lengths. The rf deflector has been designed as a parallel wire quarter wavelength cavity with deflecting plates as a capacitance. The electrodes of the line are isolated from the external shell. A HV focusing potential is applied to the electrodes. An array of ceramic capacitors is used as a short circuit for the quarter wavelength cavity thus enabling the supply of slightly different potentials to steer the electron beam. A general view of the rf deflector is shown in figure 2.

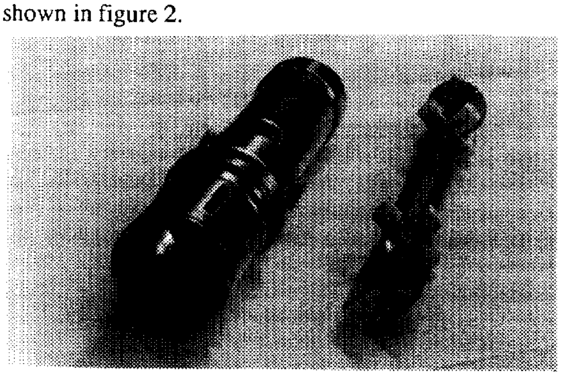

Figure 2. RF deflector.

The BLVD uses a thin tungsten wire 0.1 mm diameter to produce secondary electrons. The secondary electron line is tilted by 10° upstream of the ion beam due to the small range of ions in the target and emission of secondary electrons backwards only. A commercial electron multiplier tube is used to measure the intensity of separated secondary electrons. A typical value of separated electron current is about 10^{-12} A. The main parameters of the BLVD are shown in Table 1.

Table 1. Parameters of the BLVD

1. Phase resolution at the 101.28 MHz, deg		0.4
2. Error of velocity measurement, %		
W=0.25 MeV/amu	Systematic (max)	0.11
	Random (rms)	0.11
W=4.2 MeV/amu	Systematic (max)	0.23
	Random (rms)	0.22
3. Beam Sensitivity (minimum peak current, μA)		1
4. Maximum bunch length at 101.28 MHz, deg		90
5. Longitudinal overal dimension, mm		270
6. Beam aperture diameter, mm		40
7. Target potential, kV		-10
8. Maximum longitudinal displacement, mm		40
9. RF power consumption, W		20

2.3. Data acquisition and control system

One CAMAC and one VME crate are used for electronics hardware of the BLVD. Three HV sources, a 20 W rf amplifier, a filament heating card, stepper motor cards and an interface card are installed in the CAMAC crate. An electronic phase shifter, fast ADC, VME – IBM PC controller as well as control card developed in order to provide specific modes of operation of the BLVD are installed in the VME crate. A signal amplifier is mounted on the detector directly.

There are four modes of BLVD operation: 1) Fast bunch shape measurements when the phase of the deflecting field is scanned within a beam pulse thus enabling a longitudinal distribution to be obtained for a single pulse; 2) Slow bunch shape measurements. In this case a BLVD signal is measured during a beam pulse for a constant phase and the phase is varied from pulse to pulse; 3) Fast velocity measurement. Fast bunch shape measurements are made before and after the deflector displacement; 4) Slow velocity measurement. Slow bunch shape measurements are made before and after the deflector displacement.

2.4. BLVD commissioning

BLVD commissioning includes the following procedures: 1) rf deflector tuning; 2) electron beam optics tuning; 3) mechanical and vacuum testing; 4) calculation of detector parameters.

The results of deflector tuning: loaded Q-factor 380, VSWR = 1.2, equivalent resistance $U^2/2P = 57k\Omega$.

The electron beam optics were tuned using thermo-electrons which were produced by heating the target wire by a special HV target heater. To visually observe the thermo-electrons collimator plates are covered by phosphor. The size of the focused thermo-electron beam obtained was 0.3 + 0.4mm wide. Thermal electrons were used to verify the deflecting characteristics of the deflector: 20 W power provides 80 mm amplitude of electron scanning.

The main parameter of any BLD is its phase resolution. To find this parameter both experimental and theoretical data have been used [2]. The phase resolution of the BLVD was found to be better than 0.4° at 101.28 MHz which corresponds to 10 ps of time resolution.

3. BEAM MEASUREMENTS USING BLVD

Typical longitudinal profiles along a beam pulse for nominal accelerator parameters at the entrance of the first IH cavity and at the exit of the accelerator are presented in fig.3

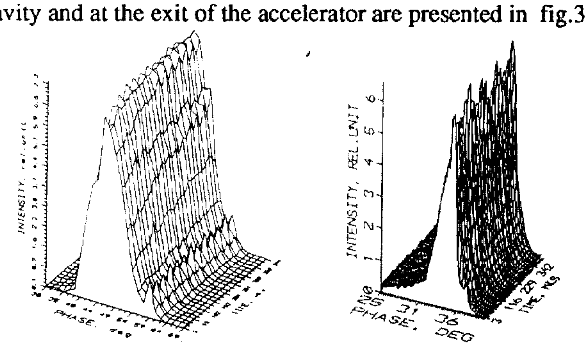

Figure 3. Longitudinal profiles along a beam pulse for 251 keV/n and 4.2 MeV/n ions.

- Determination of the optimum buncher phase. Initially bunch shapes were measured for buncher phases changing in a range 360°. An approximate buncher phase was found to provide a minimum bunch length. Then bunch shapes have been measured for different buncher phases in a range ±40° and for different amplitudes. The bunch center position as a function of buncher phase with the buncher voltage as a parameter is shown in figure 4.

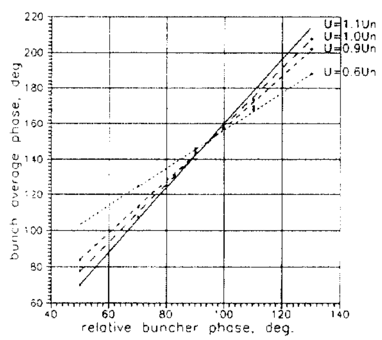

Figure 4. Bunch center vs buncher phase with buncher voltage as a parameter.

The intersection point of the curves corresponds to the right buncher phase. The optimum buncher voltage has been determined precisely by comparing the slopes of the above mentioned curves with a calculated one.

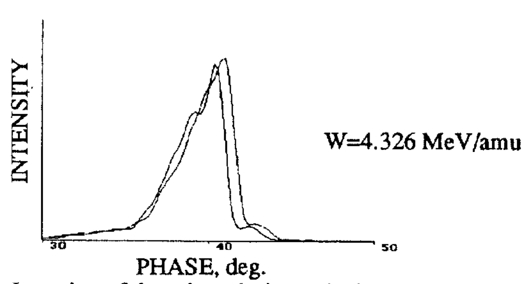

Figure 5. Location of bunches during velocity measurement.

- Mean velocity measurement. For various sets of RFQ and buncher voltages, as well as buncher phases, the mean velocity has been measured. The specified input velocity to the IH structure was adjusted by the buncher rf parameters to be equal to 0.02308 with matched longitudinal emittance. Typical locations of bunches before and after a detector displacement for the exit of the accelerator are presented in fig. 5. Our measurements have shown that the beam velocity exceeds the design value by 1.5%.

- Longitudinal emittance measurement. The bunch rms and full widths have been measured as the buncher voltage is varied in the range 0.6÷1.2 V_{nom}. The longitudinal emittance was calculated downstream of the RFQ by using known transfer matrices and least square method. The longitudinal emittance has been determined for the different RF power levels in the RFQ as well as for different conditions at the transport line. Minimum values of the emittances are:

$\varepsilon_{rms} = 0.012\pi \text{ deg } MeV/amu$ $\varepsilon_{95\%} = 0.066\pi \text{ deg } MeV/amu$

4. CONCLUSION

The operation of the bunch length detector with a heavy ion beam was demonstrated for the first time. The capability of the BLVD to measure the average velocity of the bunched beam avoided construction of a magnetic spectrometer. The longitudinal beam emittance at the exit of the RFQ has been studied and longitudinal matching at the entrance of the first IH cavity with a longitudinal acceptance has been provided. Using the BLVD was extremely helpfull in Linac3 commissioning and enabled the careful study and accurate setting of longitudinal parameters.

5. ACKNOWLEDGMENT

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