BUNCH LENGTH AND VELOCITY MEASUREMENT OF THE JHP-RFQ BEAM WITH INR BLVD

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Abstract

The bunch length and velocity of a beam accelerated with the 432-MHz, 3-MeV JHP-RFQ (Japanese Hadron Project - Radio Frequency Quadrupole) linac were measured by using a Bunch Length and Velocity Detector (BLVD) developed by INR. The measured velocity (0.08002±0.00016)c showed a good agreement with the design value. The longitudinal profiles of the bunch have been measured for various setting of the RFQ. The bunch shapes of H^- beam as well as proton beam (produced by the stripping of H^- ions) have been studied. Although the BLVD has been designed for measurement of beam core (~99% of particles) the accurate study of a beam halo has been done. An almost uniformly distributed background was observed. The amount of the integrated background signal was about 1% of the beam intensity. A possible source of the background is analyzed.

1 INTRODUCTION

Well understanding of the beam characteristics output of the JHP RFQ operating at high duty cycle [1] is major step in the design of front end of the linac for future Hadron Facility [2]. For the study of longitudinal beam parameters as well as for the beam energy measurement the BLVD has been used. The design of the BLVD was based on the long-term experience of the INR group [3]. The BLVD is an extension of the Bunch Shape Monitor (BSM) to measure absolute velocity of a bunched beam [4].

2 GENERAL DESIGN OF THE DETECTOR

The technical specifications for the BLVD are shown in Table 1. The target is a tungsten wire with a diameter of 100 μm. A proton or H^- beam with energy of 3 MeV has 57.3 mg/cm^2 or 28 μm range in tungsten, therefore total beam energy will be dissipated in the target. The heating of the wire, located on the beam axis per beam pulse can be roughly estimated using the formula $\Delta T = \dfrac{4WI\tau}{(\pi R)^2 \rho C_p d}$, where $W[eV]$ is the beam energy, $I[A]$ is the beam current, $\tau[s]$ is the pulse duration, $R[m]$ is the beam radius, $\rho[kg/m^3]$ is the target density, C_p $[J/(kg\cdot K)]$ is the specific heat of the target material, $d[m]$ is the target wire diameter. Assuming a beam radius to be equal to 2·rms value and using beam parameters for the most powerful beam one can get $\Delta T \approx 4700$ °K. The maximum temperature for the tungsten is restricted by thermal emission of electrons ~1500 °K. The simplest way to avoid target overheating is the use of a slit collimator upstream of the target. The 0.2 mm slit located 130 mm upstream of the target decreases the beam density at the target by a factor of 6 allowing to make safe measurements for whole beam pulse with maximum current of 40 mA and 50 Hz repetition rate, if necessary.

Table 1: BLVD specifications

1	Type of particles	H^- or H^+
2	Energy of particles	3 MeV
3	Minimum pulse current	0.1 mA
4	Maximum pulse current	40 mA
5	Pulse length	600 μs
6	Repetition rate	50 Hz
7	Accelerating frequency	432 MHz
8	Geometrical size along the beam	360 mm
9	Phase resolution at 432 MHz	2°
10	Range of phase measurements	180°
11	Accuracy of velocity measurement	0.2 %
12	Beam line aperture	32 mm

The simplified general assembly drawing of the BLVD is shown in Fig. 1. The beam to be analysed is moved perpendicularly to the plane of drawing. The BLVD consists of the following main elements: body of the detector (1), target actuator (2) with the target unit (9), rf deflector combined with electrostatic lens (3), registration unit (4), permanent magnet with adjustable field (5) to steer the electrons vertically, glider (6) with the actuator (7) to shift the longitudinal position of the detector. The extra port (8) is assigned for vacuum pump. The horizontal 0.2 mm slit is not seen in the drawing and located 130 mm upstream of the wire. The vertical position of the slit is adjusted by a stepping motor. There is a permanent magnet located upstream of the slit. We can select one of the two positions (one is on the beam axis and the other is far from the beam axis) of the magnet remotely. By locating the magnet on the beam axis, we can bend the small amount of particles, which are not accelerated in the RFQ, far from the target. The longitudinal glider has been designed using the Linear Motion Guide Actuator manufactured by THK, the position reproducibility is ~3 μm. In order to minimise a space along the beam pipe the stepping motor of the longitudinal glider is located off-axis, parallel to the beam pipe. The glider can move the detector over the distance of $\sim\beta\lambda/2\approx 56$ mm.

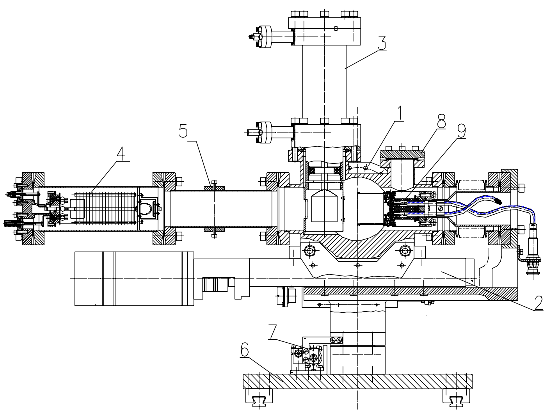

Figure1: General assembly drawing of the BLVD.

3 DATA ACQUISITION AND CONTROL SYSTEM

In order to detect secondary electrons produced on the target, a secondary electron multiplier (SEM) tube of the type of Hamamatsu R596 is used. The amplification gain of the electron multiplier can be varied within 5 orders of magnitude by changing supplied high voltage. The signal from the SEM tube is amplified by the fixed gain (0.5 V/μA) amplifier located directly on the registration unit output flange. The amplifier has an internal pulse generator to test the signal propagation. The response time of the whole signal chain is less than 1 μsec.

The control system is based on IBM PC and one CAMAC crate. Special electronic modules are housed in an additional NIM crate. There are two modes of the measurements. In the 'fast' mode the phase of the deflecting field is varied with the beam pulse and the bunch shape is measured within a beam pulse. It means that the different points of the longitudinal intensity distribution are taken along the beam pulse. In the 'slow' mode the phase is varied between the beam pulses and different points of the bunch shape are obtained for different beam pulses. In this case digitizing of the signals with 1 μsec intervals for each phase position enables to find behavior of the longitudinal distribution during the beam pulse. Obviously this procedure requires the stability from pulse-to-pulse which is perfectly provided by the accelerator.

The software for control and data acquisition system for the detector has been developed using new 32-bit version of the MOON Lab technology running under Microsoft Windows95, developed at the INR [5]. While processing the detector control and acquiring data, the software can post-process and present the data.

4 RESULTS

After the commissioning of the BLVD and optimum setting of its parameters the 3-MeV beam accelerated by the 432 MHz RFQ has been studied. The RFQ beam parameters are rather different from those in Table 1, mainly due to the performance of the ion source under development. The typical peak beam current, the maximum repetition rate and the maximum pulse length were 13 mA, 25 Hz and 300 μs respectively. In order to avoid the sputtering problem of the collimator slit, the measurements were performed with the pulse length shorter than 130 μs. Under these conditions, the wire also survives with any repetition rate less than 25 Hz. (Therefore, the collimator slit was used in order to study the relationship between the bunch shape and the vertical position.)

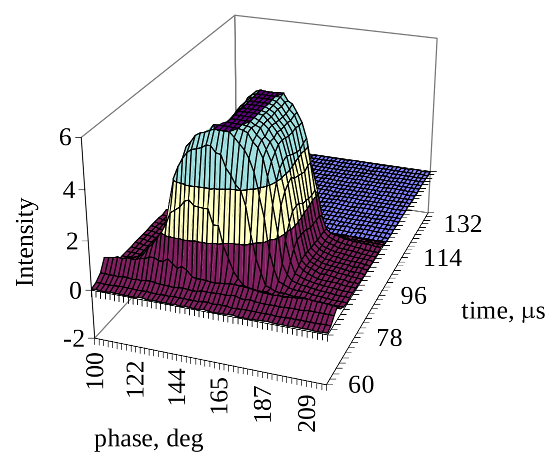

Figure 2: Bunch shape evolution along beam pulse.

In Fig. 2 the bunch shape evolution along the beam pulse is shown. Duration of the beam pulse injected to the RFQ was longer than the rf pulse length. The rf filed in the RFQ has been well stabilized on the top of beam pulse but there was some rf field parameters distortion in the transient. Therefore the bunch center at the beginning of the pulse is shifted in phase and due to the low level of the accelerating field in the beginning of pulse there is a fraction of unaccelerated particles. As for the top of the rf pulse from theory it is very unlikely to have unaccelerated particles after the long 3-MeV RFQ. However it was found that about (1÷2)% of integrated signal arises from the almost uniformly distributed in phase background. The insertion of the 1000 Gs bending magnet upstream of the BLVD do not indicate any reduction of the background. It was supposed that the possible source of the background is the contribution of the detached electrons from H^-. In order to avoid the contribution of the detached electrons 1 μm aluminum foil has been installed upstream of the target. The passage of the H^- beam through the foil produces a proton beam without any change of the longitudinal charge distribution. In order to measure bunch shape in wide dynamic range the measurements have been done with different gains of the SEM tube using the calibration curve. The measured particle fractions as a function of phase half-width for H^- and proton beams are shown in Fig. 3. The bunch shape of the proton beam in logarithmic scale is shown in Fig. 4. These measurements show that the background noise for proton beam is smaller than that for H^- beam (see Fig. 3), however the longitudinal tail containing ~1% of particles still remains.

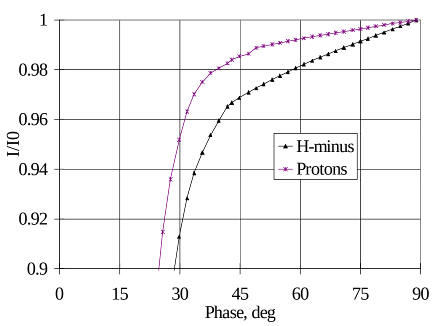

Figure 3: Particle fraction as a function of phase half-width for H^- and proton beams.

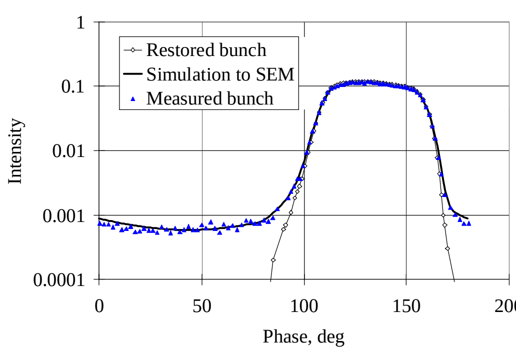

Figure 4: Bunch shape of proton beam in logarithmic scale.

Both of the H^- and proton beams have a similar longitudinal density distributions except of the halo region. The proton beam contains much less particles in the halo, but still has long tail. In order to understand the source of such signal, the secondary electron beam motion has been analyzed. A possible reason of the background formation is an interaction of the electrons with the edge of the collimator installed at the entrance of the deflector. This interaction results in increasing of energy dispersion as well as scattering of the small part of secondary electrons. In addition the beam optics can produce some aberrations. All these effects result in a diffusion of the electron beam on the detector. The secondary electron distribution $f(V_{st})$ as a function of the steering voltage V_{st} applied to the deflector plates has been measured without any rf field in the deflector. For ideally focused electron beam this function must be very narrow distribution without any background. However, in practice the very low level of background signal has been observed for whole range of steering voltage. It confirms the existence of scattered secondary electrons. The function $f(V_{st})$ has been used in order to exclude the systematic error in the measurements. Fig. 4 shows the "restored" bunch shape after excluding systematic error and the simulated bunch shape which is produced numerically using the "restored" bunch and the function $f(V_{st})$. For the restored bunch shape the bunch width on the base (see Fig. 4) is ±50° which corresponds to $3.27 \cdot \Delta\varphi_{rms}$. Where $\Delta\varphi_{rms}$ is the rms bunch width.

An ability of the target displacement across the beam provides possibility to obtain transverse parameters of the beam by processing the results of the standard measurements taken at different position of the target. The transverse profiles have been measured for different rf power levels in the RFQ. There is no change of the beam transverse position with rf power variation which means that the RFQ is well aligned and there is no transverse coherent oscillation.

The total error of energy measurement is ±12 keV (rms error is 0.13%) (including calibration of BLVD glider, statistical error due to multi bunch measurements, finding of the bunch center using longitudinal density distribution). The output energy of the RFQ is (3.02 ± 0.012) MeV which is equal to the design value.

5 CONCLUSION

A detector for the measurement of the bunch shape and average velocity for 3-MeV JHP RFQ has been developed and built. The detector has been successfully commissioned and is being used for the studies of the RFQ beam parameters.

6 REFERENCES

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