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STUDY OF BEAM PARAMETERS OF THE CERN PROTON LINAC USING A THREE DIMENSIONAL BUNCH SHAPE MONITOR

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Abstract

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Abstract

A Three Dimensional Bunch Shape Monitor (3D-BSM) has been developed for the CERN Proton Linac 2. A new area for beam studies at high intensities has been opened by this detector. Bunch density distributions in all three dimensions and their variations along the beam pulse can be obtained. Changing field gradients in linac quadrupoles, emittance variation along the bunch has been calculated. Measurements of beam halos become possible thanks to the large dynamic range of the device. Beam parameters at various linac settings have been measured and analysed.

Introduction

The new detector [1] allows the measurement of the three dimensional density distribution I(x,y,z) of a bunch and its evolution along the beam pulse. For example, using this distribution the first and second moments and the beam profiles in each direction (x,y,z) have been obtained. The CERN Linac 2 is a high intensity accelerator consisting of an RFQ and three Alvarez tanks producing 140 mA of protons at 50 MeV [2]. As proven during the detector commissioning, the 100 μm tungsten wire can operate safely with pulse lengths up to 145 μs. The insertion of the target in the beam does not disturb injection into the downstream booster synchrotron. Therefore the 3D-BSM can be used as a non-destructive beam diagnostic tool during linac operation.

Bunch Shape Measurements of the 50 MeV Beam

In Fig.1 the evolution of the longitudinal profile along the beam pulse is presented. The analysis of the figure as well as of the evolution of other beam parameters along the bunch shows that beam-loading is well compensated in Linac 2. There is no variation either of the bunch centre or the bunch shape along the entire pulse length. It has been demonstrated that the bunch shape changes along the pulse if beam-loading is not sufficiently compensated. This can be seen in Fig. 2 where the RF field in tank 3 has been increased by 4% while keeping the maximum power to the tank constant.

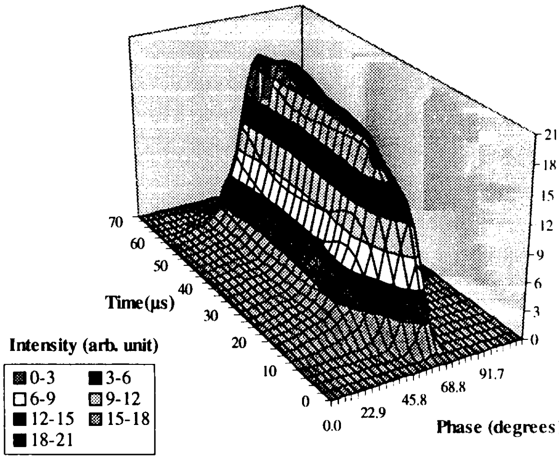


Fig. 1. Bunch shape evolution along the beam pulse for nominal settings. Linac RF frequency is 202.56 MHz.

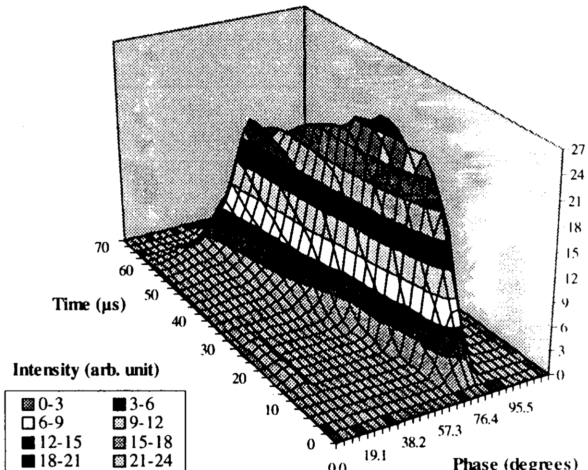


Fig. 2. Bunch shape evolution along beam pulse in case of insufficient beam loading compensation in tank 3.

When changing the phase of tank 3 in a 60° range, the bunch length varies between 13° and 30° (1 rms values) and the phase of the bunch centre (with respect to the phase of the reference line) varies by 130° (see Fig. 3). Deviation of the bunch centre phase is due to two main reasons: the energy change and the coherent oscillations in the longitudinal phase space.

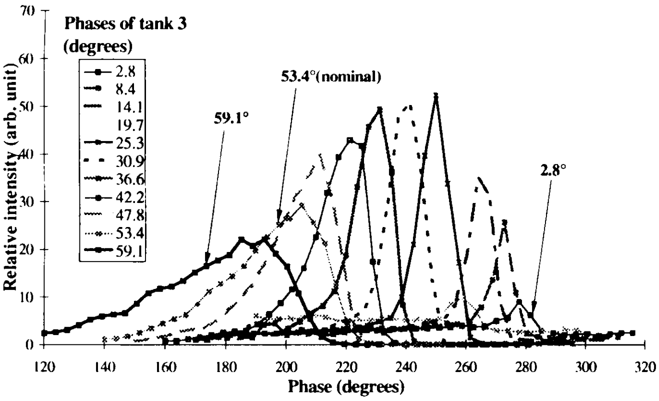


Fig. 3. Average (over entire bunch volume and whole pulse) bunch shapes for different tank 3 phases. Nominal phase of tank 3 corresponds to 53.4°.

Although the present phase setting of the last tank (53.4°) produces long bunches with a specific tail (see Fig. 3), it seems that the energy spread is moderate in that case, so that the beam is safely transported to the booster rings.

The high intensity beam dynamics for different phases of tank 3 have been simulated by the computer code LANA [3]. Simulations gave a bunch width about two times smaller than the observed one. The difference is mainly due to the tails. The central part of the bunch is well reproduced by LANA. The bunch centre variations with tank 3 phase are similar to simulations results (see Fig. 4). Some changes of the amplitude in tank 3 from the design values even improve the fitting.

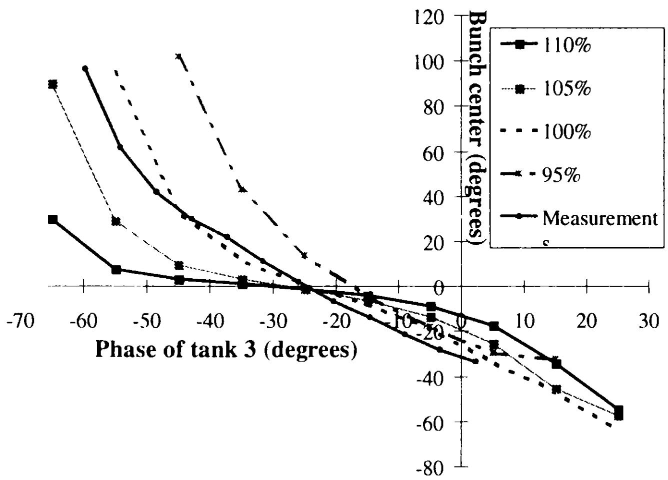


Fig. 4. Bunch centre as a function of protons arrival phase in tank 3. The experimental curve has been arbitrarily placed on this graph.

The bunch shapes have been measured for various rf field levels in the first and third tanks and different beam currents. All the measurements showed a strong dependence of the density distribution of the bunch on the parameters of the linac.

Study of Transverse Emittance Variation along the Bunch

From the measured data, the transverse rms size of the proton beam has been calculated for "slices" (in phase) through the bunch. The rms beam widths have been measured for three magnetic field gradient settings in upstream quadrupoles inside tank 3. Using these data the (rms) emittance as a function of phase along the bunch has been calculated (see Fig. 5). Due to limited time for all experiments, only the measurements enabling the derivation of horizontal emittance have been made. These studies were restricted to the central part of the bunch, where the signal level ensures a good precision. However, the beam transverse behaviour can also be studied in the bunch tails using a higher dynamic gain of the signal amplifiers of the 3D-BSM. There is a significant variation of the rms beam size with phase.

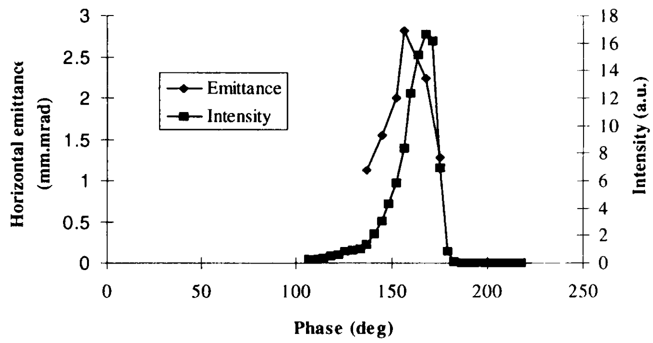


Fig. 5. Horizontal unnormalized rms emittance of beam and intensity versus phase.

The iterative use of TRACE and TRANPAR [4] allowed the derivation of horizontal transverse emittance taking into account space charge and acceleration in the last three gaps (between the quadrupoles used for the experiment) for different "slices" along the bunch (see Fig. 5 and 6). The use of the TRANPAR code alone to reconstruct emittances showed that neglecting space charge in this calculation process can induce an error of up to 50% on emittances.

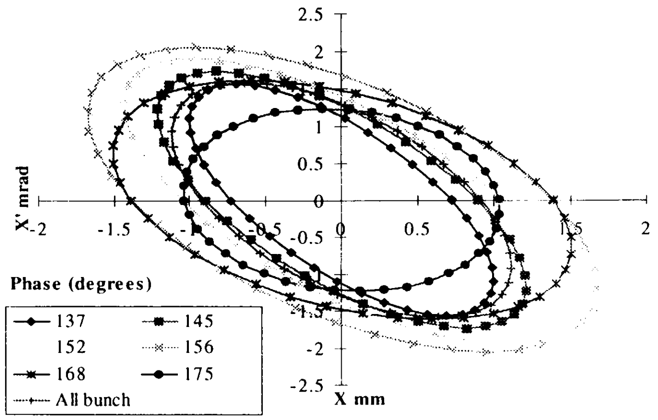


Fig.6. Evolution of the horizontal rms emittance. Only the central part of the pulse (20 to 65 μs in that case) has been taken into account.

The horizontal rms emittance averaged over the whole bunch and the whole pulse (0 to 75 μs) is 2.5 mm.mrad, which is consistent with the theoretical value from PARMILA (2.4 mm.mrad).

Measurement of the Transverse Density Distribution.

The 3D-BSM has a wide dynamic range: the signal gain can be varied by a factor 500. It can be used for the measurement of transverse cross-sections of the beam (see Fig. 7), including halo because these measurements do not require rf voltage on the deflector of the 3D_BSM [1].

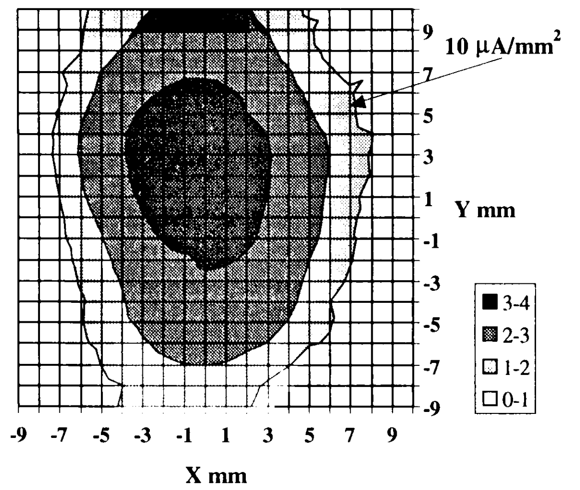
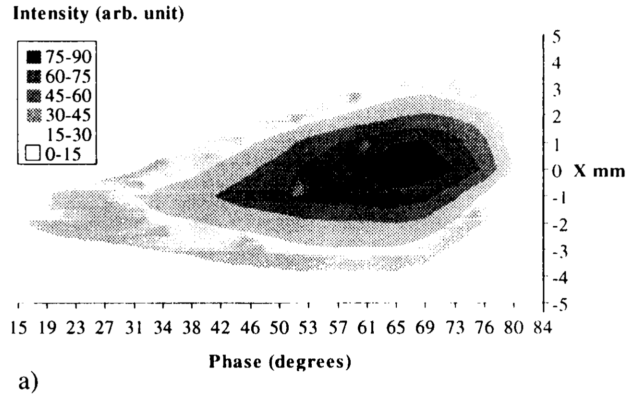


Fig. 7. Beam cross-section. This graph shows log(j) where j is the proton current density in μA/mm^2. The total current is 150 mA. The maximum current density is 3.95 mA/mm^2. The borders between shades represent 1000, 100 and 10 μA/mm^2. They contain respectively 69.0, 96.9 and 99.7% of the beam.

Bunch Distribution in φ-x Plane

The bunch length depends on the horizontal position (see Fig. 8a). The bunch length has a maximum for a horizontal position different from the mean. This effect could be due to the influence of the field created by the space charge of the proton bunch on the trajectory of the secondary electrons ejected from the tungsten wire[1]. However it is still unclear why this effect is smaller for shorter bunches, when the proton density is higher (see Fig. 8b). Therefore, it could be a real feature of the proton beam due to a misalignement of quadrupoles in the linac. It is possible to simulate such an asymmetry by arbitrarily misaligning quadrupoles in tank 1 with DYNAC [5], but large alignment errors are required. More theoretical and experimental work is required to explain this effect. For instance, the 3D-BSM will be studied by a computer model including the influence of the space charge of the bunch on secondary electrons.



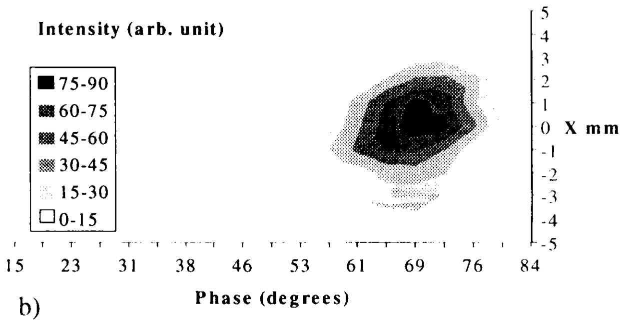


Fig. 8. Beam density distribution in φ-x plane for long (a) and short (b) bunch.

Conclusion

The study proved the effectiveness of the 3D-BSM in monitoring both transverse and longitudinal beam parameters. It has demonstrated that the bunch density distribution is very sensitive to the working parameters of Linac 2. The 3D-BSM will be an essential tool in future high intensity studies at currents greater than 180mA at the exit of the linac.

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