# A THREE DIMENSIONAL BUNCH SHAPE MONITOR FOR THE CERN PROTON LINAC

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## Abstract

The development, performance and test of the Three Dimensional Bunch Shape Monitor (3D-BSM) are presented. The principle of operation is based on the analysis of secondary electrons produced by a primary beam on a 0.1 mm tungsten wire to which a potential of -10 kV is applied. The horizontal particle distribution is provided by moving the wire across the primary beam. A horizontal slit located outside the primary beam area is moved vertically in order to analyse the secondary electron density distribution in the vertical direction. The longitudinal profile is measured as in the bunch length detector developed at INR earlier. The 3D-BSM has been installed and commissioned at the CERN proton linac.

## Introduction

The distribution of charge in the real beam of linear accelerators is described by a three dimensional distribution function $I(x,y,z)$ or $I(x,y,\varphi)$. Conventional beam instrumentation devices provide projections of this function for just one of the co-ordinate axes or planes. Thus, widely used wire scanners and harps provide a one co-ordinate function. To measure the longitudinal distribution, bunch shape monitors are used [1-3]. There is also the method and device to measure two dimensional distribution in the transverse plane [4] as well as the proposal to obtain a two dimensional distribution with a combination of the longitudinal and one of the transverse planes [5].

The first idea to measure a real three dimensional distribution is described in [6]. This idea has been revised and implemented in the Three Dimensional Bunch Shape Monitor (3D-BSM) developed and built at INR for the CERN proton linac.

## General Configuration and the Design

The general configuration of the 3D-BSM is presented in fig. 1. The beam under study crosses the target (1) (tungsten wire 0.1 mm diameter) and knocks out low energy secondary electrons. A HV negative potential (-10 kV) is applied to the target. Owing to the high strength of electric field near the target, the electrons move practically horizontally and their vertical co-ordinates at the plane of the horizontal slit (2) correspond to a short vertical section of the target wire determined by the position of the slit.. If the target has a horizontal co-ordinate $X_0$ and the slit a the vertical co-ordinate $Y_0$ then the intensity of the electron current downstream of the slit is proportional to the intensity of the primary beam at the point $(X_0,Y_0)$ of the transverse plane and its temporal structure reproduces that of the proton beam. The temporal structure of the electron beam downstream of the slit is coherently transformed into a spatial one through transverse rf modulation in the deflector (3) combined with the electrostatic lens as in the conventional bunch shape monitor. This spatial distribution is measured with the 30 channel electron collector (4). For a fixed position of the target and the slit, the signal from one channel of the collector is proportional to the intensity of the protons having the corresponding transverse and longitudinal co-ordinates. The signals from all the channels represent the longitudinal distribution of protons with the transverse co-ordinates $(X_0,Y_0)$. By measuring the longitudinal distribution for different locations of the collimator one can get a two dimensional distribution $I(x_0,y,\varphi)$. A three dimensional function can be obtained if a horizontal movement of the target is added. If however, the target were displaced without the collimator and slit following it, the temporal structure and intensity of the electrons would change. To avoid these effects the target is surrounded by an electrostatic screen (5) which moves with the target. Since now the electrostatic field pattern in the target - collimator area remains constant, the temporal structure of the electrons is not modified. Similarly, the intensity of the electrons passing through the slit does not change. Variation of the drift distance from the slit to the

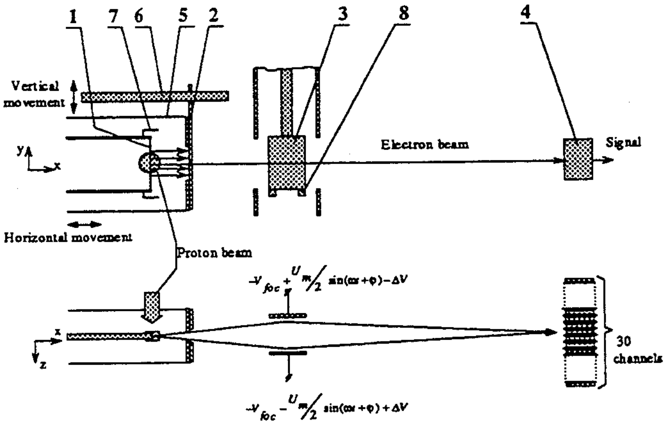

Fig. 1 General configuration of the 3D-BSM

deflector entrance results in a systematic phase error which has however, been taken into account knowing the well defined velocity of the electrons. When the position of the target, along with the screen changes with respect to the deflector-lens, the size of the focused beam at the collector varies but the variation of phase resolution is negligible.

When the target and the electrostatic screen are moved, the collimator plate also moves, sliding along the guide (6). Vertical movement of the collimator is provided by the vertical displacement of the guide.

There are strict requirements for the vertical uniformity of the accelerating electric field in the target region and for the focusing field in the deflector-lens. Non-uniformity of the accelerating field leads to vertical displacement of the electron beam from the working area of the collector when the collimator is moved, thus resulting in loss of information. Non-uniformity of the focusing field is the main reason why the phase resolution is dependent on the collimator position. To avoid the first effect, the correcting elements (7) are installed on the target holders. The second effect is corrected with the help of the elements (8) installed on the plates of the deflector-lens. Use of these elements helped obtain a vertical operating range of ±10 mm. There are also requirements for the uniformity of the rf deflecting field but in our case this problem was negligible.

The assembly drawing of the detector is presented in fig. 2. The 3D-BSM includes the following main units: body of the detector (1), target unit (2) with the screen and the collimator plate, target actuator (3), collimator actuator (4), rf deflector combined with electrostatic lens (5), registration unit (6) including multi-channel collector along with the viewing port and the mirror for visual observations of the thermal electrons during laboratory tests, signal preamplifier (7) and permanent adjustable magnet (8) to steer the electrons vertically.

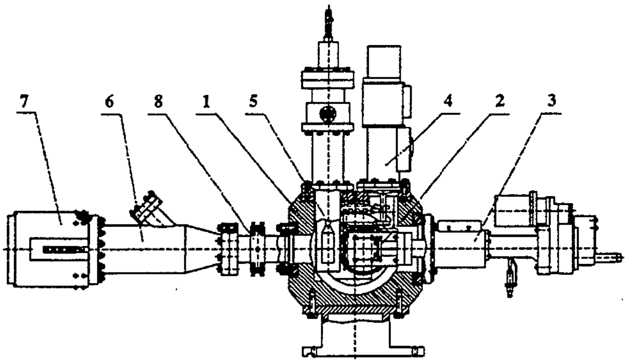

Fig. 2 Assembly drawing of the 3D-BSM

## Signal Detection and the Control System.

To detect the electron intensity a multi-channel electron collector, along with sensitive signal amplifiers are used. The 30 channel collector, developed for the 3D-BSM, is of a sandwich type consisting of collector, insulating and bias plates. The latter are used to limit the influence of secondary emission electrons from the collector plates.

The signals are amplified by fixed gain (30 mV/nA) preamplifiers followed by amplifiers with remotely controlled gains. The overall gain can be changed from 3 mV/nA to 1500 mV/nA in 10 steps. For normal operation of Linac-2 (peak current 130-140 mA) the gains of 50-100 mV/nA were used. A calibration mode with a 10 nA input signal has been incorporated. The response time of the amplifier chain is 2-3 µs and the rms noise level is about 0.5 pA/√Hz.

The 3D-BSM has an independent control system using an IBM PC and one VME crate. Special electronic modules (HV, rf, interface, stepper motor drivers) are housed in two additional CAMAC crates. Using five 8 channel STR755 digitizers gives the possibility of sampling all of the signals with 250 ns steps, thus providing information on the behaviour of the distribution in time and allowing a four dimensional function $I(x,y,\varphi,t)$ rather than the three dimensional distribution to be obtained.

The software includes three programs. The first one is used for signal observation, detector parameter adjustment and detector tuning. The measurements and the initial data processing are made with the help of the second program whilst the third gives visual presentations of the results.

Total measuring time depends on the number of points in the transverse plane. For example 20 points along the vertical and 20 points along the horizontal axis require 420 pulses of the accelerator = 504 sec. plus about 1 minute for setting up and 5 minutes for data processing.

## Parameters of the 3D-BSM

To find the vertical resolution, a simulation of electron dynamics from the target to the collimator was made. The vertical size of the electron beam emitted from a fixed point on the target was calculated to be about 0.5 mm at the slit, therefore this is the best vertical resolution that can be obtained, however, a 1 mm slit was chosen rather than risk an inadequate signal intensity.

A value of phase resolution of less than 1° of rf phase can be achieved. However, to fully cover the 60° rf phase of the linac bunches with the 30 channel collector, the power in the deflector was decreased from 15 W to 1.5 W thus reducing the resolution from 1° to 3°.

The detector has the following main parameters:

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|---|---|
| Horizontal resolution | <0.1 mm |
| Vertical resolution | 1 mm |
| Phase resolution | <1° |
| Horizontal range of measurements | ±10 mm |
| Vertical range of measurements | ±10 mm |
| Operating frequency | 202.56 MHz |
| RF power consumption | 1.5-15 W |
| Signal response | 2-3 µsec |

## Detector Commissioning

Laboratory commissioning included testing of the hardware and tuning electron optics using thermal electrons produced by heating the target. Selection of the shape and size of the correcting elements has also been made from observation of thermal electrons. The spiral shape of the correcting elements (8) was chosen to minimise their influence on the resonant frequency.

After installation of the detector in the beam line, it was tuned with secondary electrons; the values of the focusing voltage ($V_{foc}$), the steering voltage ($\Delta V$) and the rf voltage ($U_m$) (fig. 1) were optimised and the correspondence of the channel number to phase was determined. To find the latter, the dependencies of the channel output signals vs deflecting field phase for slow phase variations (from pulse to pulse) are measured. The functions obtained represent the same bunch shape but are shifted along the phase co-ordinate. This shift gives the function of channel to phase correspondence for given values $\Delta V$ and $U_m$.

The very first measurements proved the efficacy of the detector. However we encountered the following unexpected phenomenon. In a range of target positions from -9 mm to -3 mm the signals from all the channels increased abnormally. These signals appeared for beam currents above 50 mA, they increased with time, and after 50 µsecs considerably exceeded the signals obtained with normal beam current. Analysis of the observations enabled the following assumption to be made about the nature of the unexpected signals. On passing through the detector, the beam induces electromagnetic fields and moving the target unit with its electrostatic screen and collimator plate changes the resonant frequencies of the system. For the target positions mentioned above, resonant conditions are satisfied for high harmonics (presumed >1 GHz) of the bunch frequency. Electromagnetic fields penetrate into the deflector through its openings and initiate oscillations on the correcting elements (8) (fig. 1), initially made as spirals, and thereby cause a multipactor discharge in equipotential space between the turns. Owing to the HV focusing potential applied to the spirals, the space between the turns is equipotential and the electrons produced in the discharge are accelerated by the electrostatic field; a fraction of them reaches the collector producing the unexpected signals. This mechanism explains all the observed experimental effects.

The following improvements were made to avoid the unexpected signals: the spiral elements were replaced by plates, screening of the deflector cavity was improved and additional screening of the space between the collimator and the deflector exit was made. After the improvements the unexpected signals totally disappeared.

It was anticipated from the design calculations that the 3D-BSM target could overheat if the product of the beam current and its duration exceeded a certain value. Experimental testing of the thermal stability of the wire showed that neither thermal emission nor target destruction occurs for the maximum beam intensity during normal operation: current 140 mA and pulse duration 145 µsec.

Up to now we have no final conclusion about the influence of the beam fields on the detector operation and its parameters. Whilst increasing the target potential should decrease these effects, measurements with different target potentials have shown no change in the transverse parameters for target potentials of -7.5 kV and -10 kV.

The main results of the first experiments are presented in [7].

## Conclusion

A fundamentally new beam instrumentation device for the CERN 50 MeV proton linac has been developed, built and successfully commissioned. The 3D-BSM enables proton density distribution to be measured in real three dimensional co-ordinate space and, moreover, shows its variation along the beam pulse. Commissioning and first measurements have confirmed the validity of the principal idea and the correct choice of elements for the realisation of this detector. The complexity of the detector and its application in an area of very intense proton beams resulted in some problems during its initial operation. Most of these seem to be solved successfully. A full understanding of the device's potential and limitations will, however, require machine development studies dedicated to the characterisation of the device itself. So far no degradation of quality has been observed in the PS-Booster beam when the 3D-BSM is being used.

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