NON-DESTRUCTIVE BEAM MONITORS FOR THE SNQ-LINAC

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Abstract

Non-destructive beam diagnostics are an important feature for high-current ion beams. Details of the diagnostic prototypes originally conceived for the 200 mA SNQ linac are presented in this paper.
The residual gas monitor for the low energy beam line consists of a commercial one-dimensional photo diode-array camera (1728 elements), with optional picture amplifier, connected to a microprocessor system for fast data acquisition. With this device we achieve an integration time of 250 µsec and a data processing time of 20 msec. First results are reported from beam tests done at SIN Zürich.
For determining the bunch length a facility for testing a 200 MHz broad band capacitive button type pick up was built. The transfer function for geometrical different kind of pick ups was measured and compared with simple analytical expressions. By applying the complex Fourier transformation technique the 200 MHz input beam pulse could be reconstructed with quite high accuracy.

Introduction

In any high current accelerator it is quite important to know the beam profile and the bunch shape for doing the right phase space matching. It is also wanted to measure these parameters nondestructively, quite accurate and more than once during the beam pulse. For the SNQ-project /1/ prototype diagnostic components for measuring the beam profile and the pulse shape were built: a residual gas monitor system /3/ and a broadband capacitive rf button pick up. For both components first experimental results are given. The residual gas monitor system was succesfully tested at the SIN injector /2/ (E = 860 keV, 60 keV, I = 10 mA), whereas for the button pick up a test facility was built.

Residual Gas Monitor

For the beam profile measurement in the low energy beamline of the SNQ Linac (50 keV and 2 MeV) a residual gas monitor is developed. This monitor consists of a one dimensional CCD (Charge Coupled Device) with 1728 pixels (diodes) of 13 µm x 39 µm each which can be cooled to -35°C with a Peltier cooling element. This CCD integrates the light emitted by the residual gas. Triggered by an external pulse the integrated signal is loaded into a shift register and the CCD is cleared. With a maximal clock frequency of 1.5 MHz this register can be read out.
In the first version the CCD is read out with a clock frequency of 100 kHz. The analog signal of the pixels is digitized with an 12 bit AD converter with a convertion time of 1 µsec per pixel. This means a total readout time of 17 ms which is also the minimal integration time. The maximal integration time depends on the temperature of the CCD: by 0°C an integration time of 60 sec is achieved. In front of this CCD an image amplifier can be mounted. A second version with a read out frequency of 1 MHz is under development.
The image amplifier is only necessary for beam energies greater than 500 keV. The control of the camera and the data aquisition is done by a 16-bit microprocessor system with an 80186 µP and 128 kbyte dual-port memory. This dual-port memory is also memory of a workstation that processes and displays the measured data.
This profile monitor is tested at SIN Zürich in the 860 keV and 60 keV beamline.

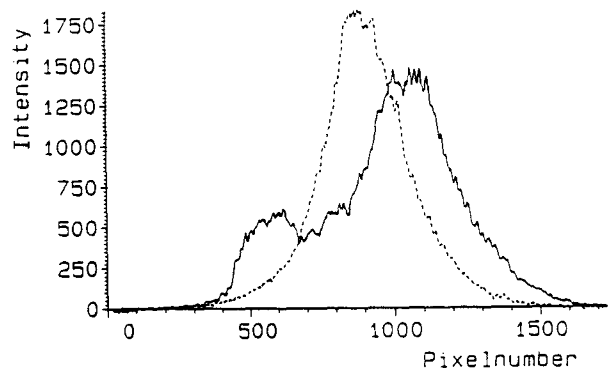

Fig. 1: The horizontal and vertical beam profile of a 860 keV H_2^+ beam of 15 µA, with an integration time of 10 sec (corrected for background)

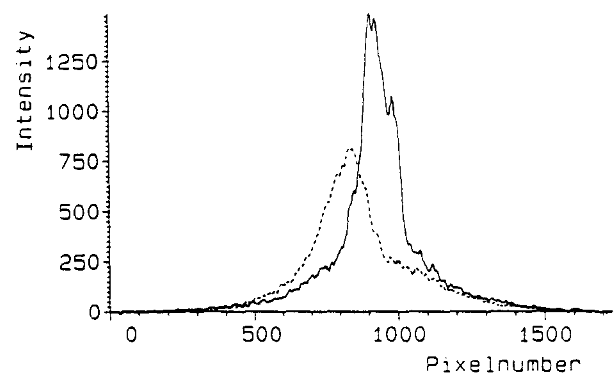

Fig. 2: The horizontal and vertical beam profile of a 860 keV proton beam of 10.5 mA with an integration time of 300 msec (corrected for background)

Fig. 1, 2 and 3 show measurements of beam profiles for different beam currents, energies and particles.
Fig. 3 and 4 show the linear dependence between the measured video amplitude, the integration time and the beam current.

Conclusion

The tests at SIN Zürich showed that this profile monitor can deal with beam currents down to 10 µA. If each pulse has to be measured the integration time has to be shorter than the repetition rate. For low currents however the integration time has to be increased. In that case we have to integrated over more than one pulse and it is impossible to measure each pulse. Because of the high resolution of the CCD (resolution 13 µm per pixel) the beam position can be measured with an accuracy of better than 1/1000 of the beam diameter.

RF-Pick up

For a nondestructive measurement of the bunch shape a broad band pick up can be used.
Originally conceived for the SNQ Linac with its high beam current and its accelerating frequency of 200 MHz, we built a test facility for measuring the pick

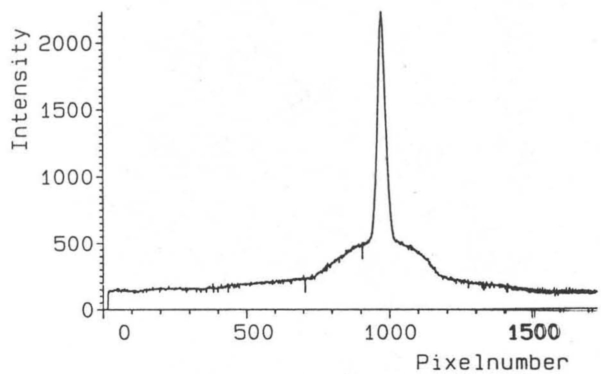

Fig. 3: The beam profile of a 60 keV H^+ and H_2^+ beam of 17 mA with an integration time of 200 msec (without image amplifier)

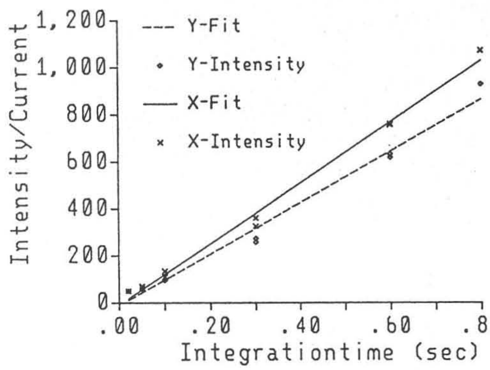

Fig. 4: The dependence between integration time and normalized video signal.

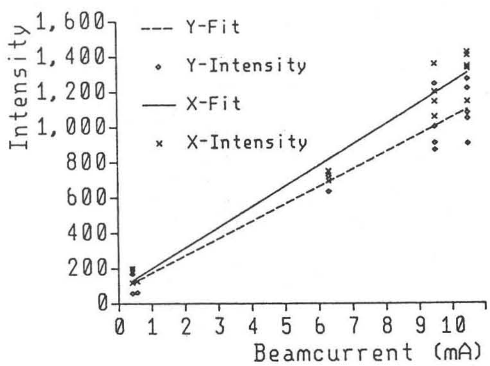

Fig. 5: The dependence between beam current and video signal.

up transfer function and testing the Fourier reconstruction technique. The test facility consists of a special coaxial 50Ω-transmission line where the capacitive button pick ups are located in the outer conductor. The test box is shown in Fig. 6, a schematic drawing of one of the pick ups itself in Fig. 7.

By a HP 8091 A pulse generator, triggered by a pulse with 200 MHz repetition rate, we simulate pulses with F.W.H.M. of minimal 500 psec and 200 MHz repetition rate. The so generated pulses and the pick up output signals can be shown on a Tektronix 7904 oscilloscope (with sampling units 7S11 and 7T11). The amplitude spectrum and the pick up frequency characteristic was measured with a Tektronix 494P spectrum analyser.

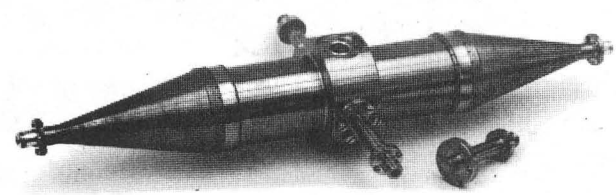

Fig. 6: Photograph of the capacitive pick up probes inserted in the center of the 50Ω -coaxial test facility

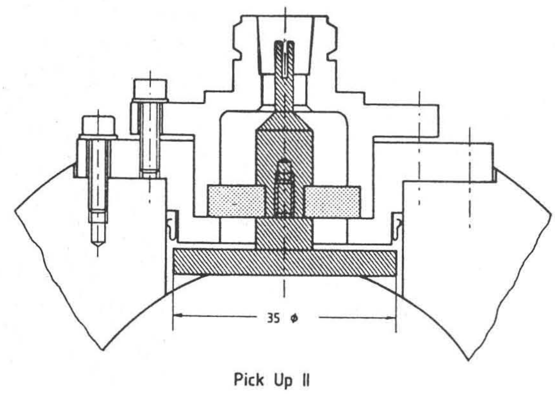

Fig. 7: Schematic drawing of pick up type II

In this paper results are only given for the reconstruction technique of the pulse shape. Details of the narrow band analysis for determing the bunch phase and the rf-current are given elsewhere /4/.
In Fig. 8 the measured frequency characteristics are shown for two capacitive button pick ups, which differ in their geometrical dimensions. The measured transfer characteristics A (f) are also compared with the theoretical prediction for the complex transfer function given by /5/.

$$A(f) = 20 \cdot \log \frac{Z(f)}{R} \tag{1}$$

$$Z(f) = \frac{Z_\infty}{\sqrt{1 + (f_c/f)^2}} \tag{2}$$

$$\varphi(f) = \arctan\left(\frac{f_c}{f}\right) \tag{3}$$

Equ. (1) - (3) are valid for wavelengths longer than the pick up dimensions, where the pick up can be considered as a pure capacity. It should be noticed that for frequencies nearby the cutoff frequency f_c the phase shift $\varphi(f)$ strongly depends on the frequency. For a circular shaped button pick up the two constants, the coupling impedance Z_∞ and the cutoff frequency f_c can be expressed by (for v = c)

$$Z_\infty = \frac{A_p}{A_r} \cdot \frac{d}{C_e \cdot c} = \frac{d^2}{8 r C_e c} \tag{4}$$

$$f_c = \frac{1}{2\pi R\, C_e} \tag{5}$$

where A_p = pick up area, A_r = tube area = $2\pi rd$, d = button diameter, r = vacuum tube radius, c = speed of light, R = termination resistance, C_e= pick up electrode capacity.
The measured values from Fig. 3 and 4 are

Z_∞ = (0.63Ω, 1.26Ω) for pick up (I, II)
f_c = (700 MHz, 230 MHz)

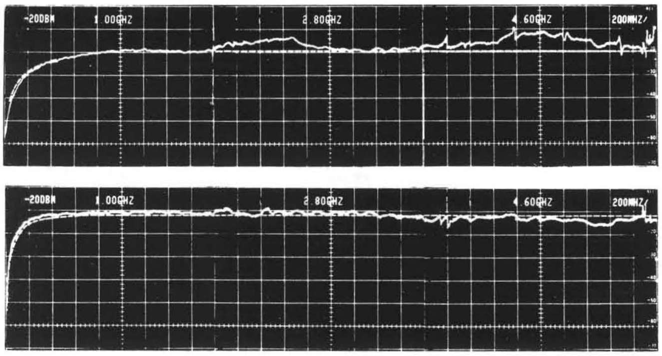

Fig. 8: Measured and calculated (dotted line) frequency characteristic curves for pick up I and II. (vert.: lower limit - 20 dB, scale div. - 10 dB; horizont: 200 MHz/div)

The electrode capacity C_e can be estimated from the geometry of the pick up design. The obtained values for Z_∞ and f_c agree better than 5 % with the analytical values using the measured values of C_e = 4.3 pF for pick up I and C_e = 10.9 pF for pick up II.
In order to reconstruct the input pulse shape we made a Fourier analysis of the response pulse. By assuming the validity of Equ. (2) and (3) for the complex pick up transfer function the input pulse shape can be reconstructed by Fourier synthesis. In Fig. 9 and 10 one example of an input and reconstructed pulse shape is shown together with the measured pick up response. The used input pulse has a F.W.H.M. of 1.5 nsec. We have chosen this pulse in order to demonstrate the advantage of the reconstruction technique for a non-ideal pulse shape. The Fourier analysis was restricted to the first 30 harmonics. The pulse repetition rate was 200 MHz. As it can be seen from Fig. 9, the input and the reconstructed pulses agree quite well. Their F.W.H.M. values only differ by 6 %. For a beam pulse with a F.W.H.M. value of 140 psec ($\Delta\varphi_{rms}$ = $\pm$ 5°) the values will differ by 15 % if we take the first 30 harmonics into account /4/.
From Fig. 9, 10 it is obvious that without the Fourier synthesis we can only get information about the F.W.H.M. of the beam pulse but not about the detailed pulse shape /6/.
The analysis is correct for the relativistic case where the longitudinal distribution of the beam current is equal to the wall current.
For high pulse frequencies, like 800 MHz, where it is complicated to built a broad band pick up, the rms pulse length (= F.W.H.M) can be quantitatively determined by only measuring the rf-current I_1 of the fundamental frequency (= accelerator frequency): /4/

$$\frac{I_1}{I_{DC}} = 2 - (\Delta\varphi_{rms})^2 \qquad (6)$$

where I_1 = rf-current, I_{DC} = time average current and $\Delta\varphi_{rms}$ = rms-phase width.

Equ. (6) is correct for a relativistic, well bunched beam with an arbitrary particle distribution.
For bunched beam with the values $\Delta\varphi_{rms}$ = $\pm$ (5°; 10°; 15°) Equ. (6) yields I_1/I_{DC} = (1.992; 1.970; 1.931).
If both currents can be measured with an accuracy of 10^{-3}, then quantitatively the rms phase-width can be determined in this simple way. Getting an accuracy of 10^{-3} for the rf-current I_1 and I_{DC} seems to be possible. With the above mentioned test facility and a quite sensitive beam current monitor Equ.(6) will be tested by using pulses with different pulse lengthes.

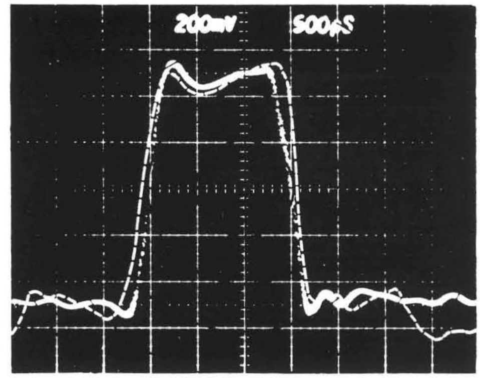

Fig. 9: Input and reconstructed (dotted line) pulse for a complete 200 MHz period

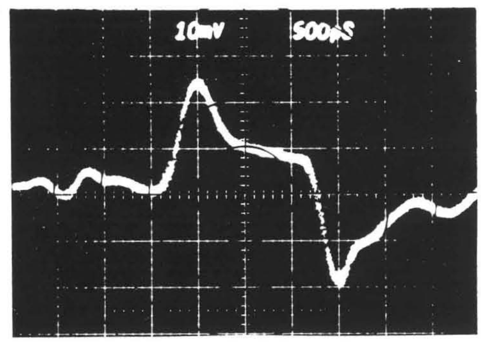

Fig. 10: Response signal of pick up II

Summary

Originally conceived for the SNQ project non destructive beam diagnostic have been built. A residual gas monitor system was succesfully tested at the SIN injector. For a 200 MHz capacitive broad band pick up a test facility was constructed. By using the measured pick up attenuation and applying the complex Fourier technique input pulses can be reconstructed quite accurately.

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References

1 C. Zettler, 1984 Lin. Acc. Conf., p. 480
and: SNQ Project Proposal for a Spallation Neutron Source, KFA Juelich Report Dec. 1984

2 M. Olivo, 1984 Lin. Acc. Conf., p. 380

3 D.D. Chamberlin et al, IEEE Trans. Nucl. Sci. 30 (3),(1983), p. 2201

4 K. Kennepohl et al, KFA Juelich Report June 1986

5 J. Borer et al, CERN LEP-Note 437, Feb. 1983

6 J. Klabunde et al, 1979 Lin. Acc. Conf., p. 297