Beam Diagnostics at COSY-Jülich

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Abstract

A report on the status of diagnostic elements in the cooler synchrotron COSY is presented. Special emphasis is given to recently developed components and to sensitivity measurements as well as to resonant tuning of Schottky-pickups.

1. INTRODUCTION

The COSY-Jülich is a synchrotron and storage ring with electron and stochastic cooling to increase the brightness. The momentum ranges between 300 MeV/c and 3.3 GeV/c (β = 0.28-0.96) and the relative momentum spread is ~ 10^{-3}, with cooling ~ 10^{-4}. The circumference is 184 m with two straight sections of 40 m length each. For a current of 5 μA H_2^+ from the cyclotron JULIC there will be in COSY about 10^8 protons per turn of injection (2.2 μs). Total proton numbers will range from 10^9 to 10^{11}. For beam observation different monitors in the injection beamline, in the COSY-ring and in the extraction beamline will be used. A more detailed description of COSY and the status of the project are given in ref. [1].

2. INJECTION BEAMLINE

All diagnostic elements [2] are installed and functional tests with beam are going on.

2.1 *Emittance Measurement*

In the injection beamline a moveable emittance measuring device (NTG Neue Technologien Gelnhausen) was installed in the straight direction of the first bending magnet at the cyclotron exit. The emittance measuring device can be provided with a trigger signal to measure dc and pulsed beams. The device was successfully tested (Fig. 1) with a 76 MeV/600 nA H_2^+ beam extracted from the cyclotron JULIC.

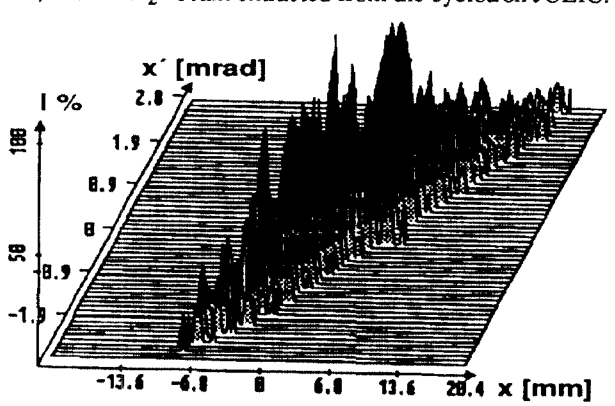

Fig. 1: Horizontal emittance scan of a 76 MeV, 600 nA H_2^+ - beam. The 95%-area in the (x,x´)-plane is 6 π mm mrad.

2.2 *Energy Measurement*

All components which are necessary to perform the measurement of the COSY injection energy are available and installed in the injection beamline. The injection energy is determined by a time of flight method. Thus, the signals of two capacitive probes at the beginning and end of a L = 28.9 m long straight section are amplified and then transmitted to the control room. Since the beam in the injection beamline is bunched, the time of flight consists of two parts, an integer one, given by the number of bunches between the two probes, N = 9 in our case, and a fractional part T_f. For a kinetic energy of 40 MeV/u, a distance of 28.9 m and a bunching frequency of 27.8 MHz, the fractional part T_f is about 16 ns, whereas the bunches by itself will have an expected bunch length of about 6 ns. T_f will be measured in a preliminary setup with a fast digital storage scope (TEK 2440) with a precision of 0.5 ns. Thus, an energy resolution of $\pm$ 0.3 % is available. This meets the requirements to check whether the injected beam properly fits to the COSY acceptance in momentum space. At a final setup the scope will be replaced by a VXI module (HP E1428A) with larger storage depth. Appropriate fit procedures are investigated to find the phase difference, e.g. the fractional part T_f with resolution < 0.1 ns.

3. COSY-RING

The main diagnostics components of the COSY-ring are described in detail in ref. [3]. At present all beam position monitors (BPM) including the electronics, the Schottky pick-ups, the diagnostic kicker magnet, halo scrapers and screen monitors are tested and installed. All components of the wall current monitor, beam current transformer and stripline unit are delivered. Tests are going on.

3.1 *BPM Sensitivity*

To measure the transverse sensitivity of the BPMs a test equipment using the BPM-prototypes (round and rectangular) was installed. A 2 MHz signal was injected to simulate the bunch current. The quantity difference $\Delta(x)$ over sum Σ of the electrode signals was measured in dependence of position x. Due to the diagonally slit construction of the BPM-electrodes the relation

$$\frac{\Delta}{\Sigma}(x) = \varepsilon_x \cdot (x - x_0) \qquad (1)$$

is expected to be valid all over the aperture. In this equation x_0 is the mechanical offset (for Δ/Σ =0) and ε_x the position sensitivity of the BPM which is determined by

$$\varepsilon_x = \frac{2}{D} \cdot \frac{C_e}{C_e + 2 \cdot C_c} \tag{2}$$

with D = distance of the electrodes (i.e. diameter for the round BPM), C_e = capacitance of BPM-electrode and preamplifier input, C_c = coupling capacitance between both BPM-electrodes. The second factor in eq. (2) is a correction term due to the non-vanishing C_c which, e.g. for the round BPM, amounts to about 0.7.

The result of a measurement with the round BPM is shown in Fig. 2. The linear relation (1) holds almost over the total BPM-aperture. From this, the position sensitivity can be determined to be $9.6 \cdot 10^{-3}$ (mm^{-1}), which is the same in both planes of the round BPM. This value is in good agreement with the theoretical value according to equation (2). For the rectangular BPM the position sensitivities are given by $7.4 \cdot 10^{-3}$ and $19.6 \cdot 10^{-3}$ (mm^{-1}) in the horizontal and vertical plane, respectively.

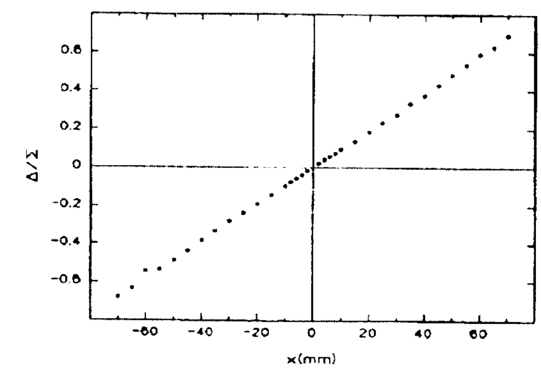

Fig. 2: Position dependence of the quotient Δ/Σ for the round BPM (position x is deviation from center position)

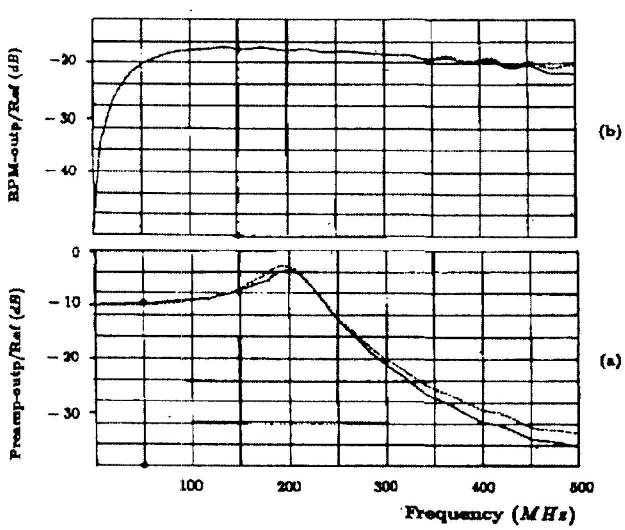

Fig. 3: Frequency dependence of BPM-signals with high impedance preamplifier (a) and 50 Ω impedance (b). The ratio of the output signals to the RF-reference signal feeding the inner conductor current is plotted. The dashed and dotted lines correspond to the upper and lower electrode.

The frequency dependence of the sensitivity (transfer impedance) of the round BPM was measured in a 50 Ω matched coaxial system. Fig. 3 shows the amplitude measurements with high impedance preamplifiers (a) and 50 Ω impedances (b) at the BPM-connectors.

With 50 Ω impedance the transfer response is that of a high pass filter with a lower 3 dB frequency of 50 MHz and an impedance of 4 Ω at 150 MHz. These measured values agree very well with the theoretical prediction for a capacitive pickup. Here, the asymptotic impedance and the lower 3 dB frequency are given by

$$Z_\infty = \frac{L}{2\, C_e\, \beta\, c} \tag{3}$$

and

$$f_c = \frac{1}{2\, \pi\, R\, C_e} \tag{4}$$

where L is the length of BPM-electrodes (130 mm) and C_e as above. The factor 1/2 stems from the geometry factor, because each electrode covers 1/2 of azimuthal angle. R is the matching resistance, β the beam velocity in units of the speed of light c. Inserting the measured capacitance of 70 pF, we find Z_∞ = 3.1 Ω and f_c = 45 MHz.

In the case of high impedance (i.e. ≥ 500 kΩ input impedance as projected for the COSY-BPM preamplifiers) the transfer response is nearly constant in the 0.01-100 MHz frequency range. The transfer impedance at the preamplifier output is 15 Ω, consistent with 13.4 dB amplifier gain and the lowered pickup value due to the additional amplifier capacitance. Above 100 MHz the amplifier impedance varies strongly causing the signal drop seen in Fig. 3a.

With the same test equipment the sensitivity of the two BPMs in the e-cooler was measured where 1 m long coax-cables are needed between the electrodes and preamplifiers. The strong resonances due to these cables can be damped by 50 Ω series resistors as RF - terminators (in connection with the electrode capacitances) inserted at the electrode end of the cables. Unfortunately, the sensitivity is reduced by the capacitance of the inserted cables by nearly 6 dB.

3.2 *Resonant Tuning of the Schottky -Pickup*

Schottky-Pickups are utilized to measure longitudinal and transverse Schottky noise spectra, respectively. Resonant tuning will enhance signal sensitivity by almost 10 dB albeit with reduced bandwidth. In order to find out the best way of tuning the pickup, a test equipment was built which allows sensitivity measurements with and without resonant tuning. The untuned Schottky-pickup is a λ/4-coaxial line with a length of 1 m, corresponding to a maximum sensitivity at 75 MHz. The frequency response is in good agreement with theory at least up to 150 MHz. Fig. 4 clearly demonstrates the sinusoidal and linear shape of amplitude and phase for one electrode, respectively. The maximal sensitivity of 15 mV/mA is achieved at 75 MHz. Fig. 5 shows the sensitivity enhancement of about 10 dB (factor 3) obtained by resonant tuning using coax-cable RG 58 C/U. At the same time the bandwidth is strongly reduced. A larger enhancement of sensitivity is expected if cables with less transmission losses will be used. Further investigations with resonant tuning can

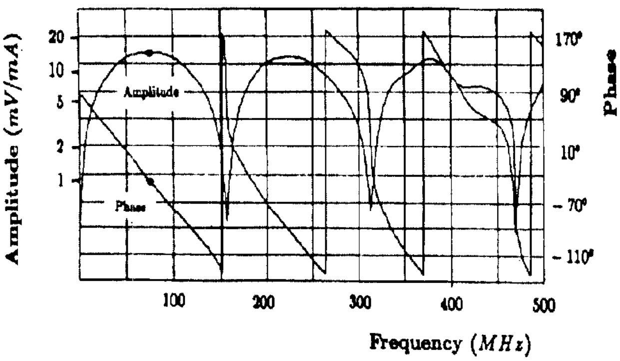

Fig. 4: Response of the Schottky-pickup signal of one electrode in frequency domain. The maximal sensitivity is reached at 75 MHz.

be performed also after installation of the pickups in COSY (i.e. without inner conductor or beam) by signal coupling in via the second electrode. Tests showed that in this case the sensitivity enhancement is similar in amplitude and shape.

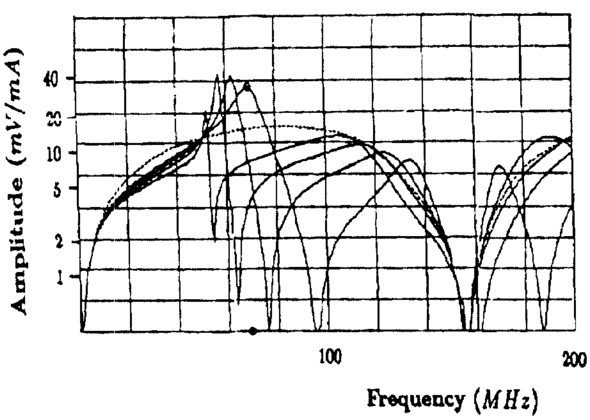

Fig. 5: Frequency dependence of the sensitivity (amplitude only) with different resonant tuning. For comparison the dotted line shows the sensitivity without resonant tuning.

Depending on proton energy, longitudinal and transverse noise analysis is limited in frequency due to Schottky band overlap. At injection energy, the limiting longitudinal and transverse frequencies are 70 and 20 MHz, respectively. With increasing particle energy, both limits are shifted to higher frequencies. For example at 200 MeV the boundaries are 400 and 100 MHz, respectively. The expected longitudinal Schottky spectral densities (for a non resonant Schottky pickup) and the corresponding noise level at room temperature (-174 dBm/Hz) are shown in Fig. 6 for different proton numbers. Note that the bump around 1 GeV is due to transition crossing. In general, the corresponding transverse Schottky densities are significantly reduced in height. E.g., for a normalized transverse rms emittance of 10 mm mrad and a beta-function of 5 m, the transverse densities are about 20 dB less than the longitudinal ones.

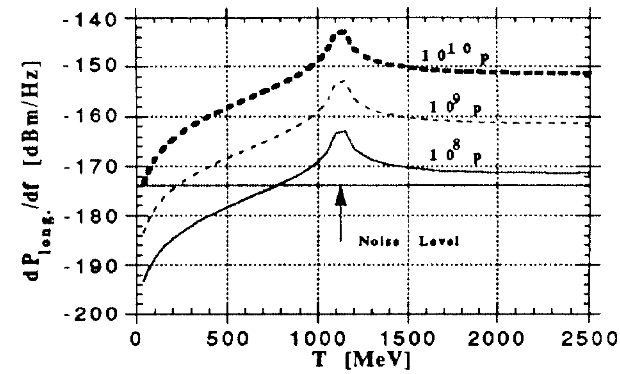

Fig. 6: Longitudinal Schottky densities for different numbers of stored protons.

4. EXTRACTION BEAMLINE

4.1 Beam Profile Measurement in the Extraction Beam Line

Beam profile and position measurements are performed at 14 positions along the extraction beam lines [4] with multiwire proportional chambers (MWPC), which were developed at GSI Darmstadt. Each station consists of a detector unit and a mechanical drive. A detector unit (64 x 64 mm^2, space resolution < 1 mm) is able to record two profiles in x- and y-direction perpendicular to the beam direction. The gas amplification is controlled within 5 decades by variation of the voltage between 50 V and 5 kV. Thus, profiles may be recorded at current densities from 10^6 to 10^{11} 1/s cm^2. The smallest time window to record one profile is 200 μs, larger integration times of 2 ms or 20 ms can be selected by software control. A MWPC prototype is under test now.

5. FAST TIMING NET

In order to observe analog signals from different points of the total system (cyclotron, injection beamline, COSY-ring, extraction beamline, experiments) a fast timing net is installed. Cables with less attenuation were used. The cable lengths are tailored to guarantee identical signal travelling times within 1 ns. All incoming signals are delivered to a central combining board outside of the synchrotron shielding.

6. REFERENCES

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[4] A. Hardt et al., Extraction Beam Lines for COSY-Jülich, this conference