# RECENT BEAM DIAGNOSTIC DEVELOPMENTS AT COSY−JÜLICH

J. Dietrich, J. Bojowald, V. Kamerdjiev, I. Mohos
Institut für Kernphysik, Forschungszentrum Jülich GmbH, Germany

*Abstract*

New developments of beam diagnostic devices at the cooler synchrotron and storage ring COSY at the Forschungszentrum Jülich [1] are described. A Schottky-pickup was tested and installed. The new pickup consists of four diagonally arranged plates which can be combined by means of relays to measure either in the horizontal or in the vertical plane. A new method for resonant tuning of the Schottky-pickup for transversal measurements was realized [2]. A tune meter was developed for real-time tune measurements in the acceleration ramp [3] and is used as routine diagnostic tool. For beam profile measurements, a residual-gas ionisation beam profile monitor was installed in the ring [7,8].

## 1 INTRODUCTION

The original 1m long Schottky-pickups had to be removed mainly to gain space for new installations (rf-cavity, experimental devices), but also to increase the horizontal aperture. The available space for the new pickup is only 0.8 m. The pickup can be used either as a sensitive broadband beam position monitor or as a tuneable narrowband sensor for Schottky-noise analysis with ultrahigh sensitivity. A new method for resonant tuning of the Schottky-pickups for transversal measurements was developed [2]. The differentially excited resonant circuitry enhances the sensitivity by about a factor of 30. The pickups are also used for dynamic tune measurements (tune meter) in the acceleration ramp [3]. An important tool used in the online analysis during the development of polarization conservation during acceleration is the dynamic tune measurement system. This system has been developed further, such that an automized measurement of the machine tune in the acceleration ramp is now available online. The adjustment of the start of the measurement with ms resolution allows the online control of the tune change introduced by fast quadrupoles, neccesary to preserve the polarization during the crossing of intrinsic depolarization resonances [4]. Precise information about the transverse charge density distribution and width of the proton beam is important for internal experiments as well as for the operation of COSY itself. A well known method based on residual gas ionisation is used to measure the beam profile [5].

## 2 SCHOTTKY – PICKUP DESIGN

The capacitive monitor with high impedance preamplifier has the particular advantage of a flat frequency response within a pass band. The lower cut-off frequency is determined by the electrode capacity and the preamplifier input impedance, and can be realized to 10 kHz. The upper cut-off frequency is determined by the bandwidth of the preamplifier and is larger than 100 MHz. The transfer impedance is maximized if all electrodes together entirely enclose the beam. For high sensitivity the electrode capacity $C_{el}$ must be small, i.e. the distance to the beam tube should not be made too small. Therefore the vacuum tube should rather be enlarged and the electrodes positioned in extension of the beam tube. Important for the transversal signals is the coupling capacity $C_c$ between the electrodes that reduces the amplitude. $C_c$ must be small in comparison to the electrode capacity. This also means that the electrode capacity cannot be made as small as possible.

The geometry of the new Schottky-pickup has the schematic layout shown in Fig.1. Horizontal and vertical apertures of 150 mm and 60 mm respectively were chosen. The structure is split into four electrodes that together surround the beam. To achieve a small coupling capacity (e.g. $C_c < C_{el} / 10$), the separating slits cannot be made too narrow, thus an azimuthal coverage of about 95% must be tolerated. The pickup electrodes can be combined by means of relays for horizontal, vertical or longitudinal broadband measurements as is shown in Fig.2.

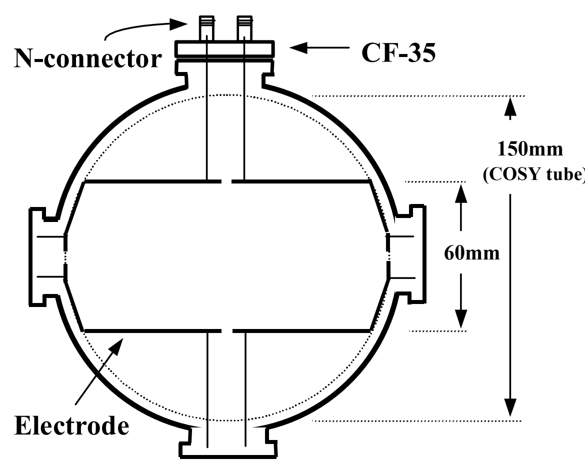


Figure 1: Layout of the new Schottky-pickup for measurements in horizontal and vertical plane (after proper switching of coax-relays).

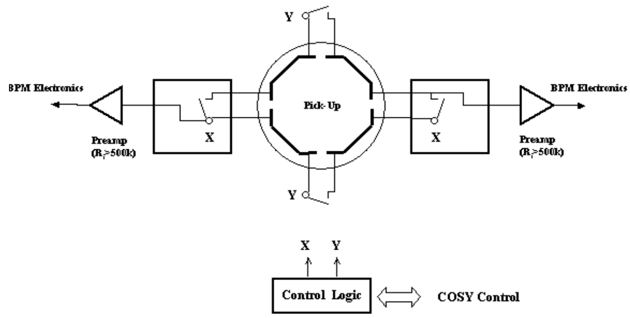


Figure 2: Broadband application of the Schottky- pickups.

## 3 TUNE METER

A bandlimited broadband noise source was used for beam excitation. The transversal beam position oscillation was bunch-synchronous sampled and digitized with a high resolution ADC. The Fourier transform of the acquired data represents immediately the betatron tune.

### *3.1 Tune Meter Configuration*

Via the stripline unit, coherent betatron oscillations in horizontal and vertical direction can be raised by means of broadband transversal excitation. The cumulative effect of subsequent excitations on the circulating beam results in a coherent oscillation at resonance frequencies only. Other components of the excitation are neutralized and therefore have virtually no effect on the beam. A white noise source generates the exciting signal. A bandpass filter with fixed cutoff frequencies (BW = 100 kHz to 2 MHz) limits the excitation bandwidth. The frequency range of the noise always covers at least one betatron sideband at the fundamental frequency over the whole ramp without frequency feedback. The excitation can be enabled/disabled by means of a fast GaAs switch that is controlled by either remote commands or a timer unit. The programmable excitation level changes in real-time. A beam position monitor (or Schottky-pickup) picks up the beam response on the excitation. Low noise gain controlled amplifiers determine the level of the sum and difference signals. The bunch-synchronous pulse required for the sampling is derived from the sum signal of the same BPM (or Schottky-pickup). A phase locked loop with narrowband loop filter generates the clock pulse with low tracking jitter over the whole range between injection and flat top. With proper signal processing, the clock generator tracks also the synchrotron oscillation. For investigations of the synchrotron oscillation, a signal proportional to the synchrotron oscillation can also be derived from the tracking circuitry of the clock generator. A high resolution ADC digitizes the difference signal. The timers of the measurement trigger and of the excitation gate are synchronized. Fig.3 shows the block diagram of the FFT tune meter.

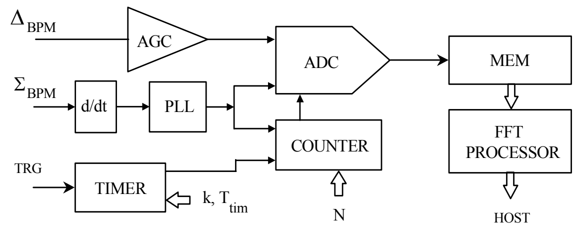


Figure 3: Block diagram of the FFT tune meter.

### *3.2 Signal and Data Processing*

The betatron oscillation appears as an amplitude modulation on the beam position signal evoking double sidebands around each harmonic of the revolution frequency and also around DC in the spectrum of the position signal of the bunched beam. The peak value of the BPM difference signal is proportional to the beam position and can be sampled by means of a fast sample and hold circuitry and digitized with a high resolution ADC. The positive edges of the bunch-synchronous clock start the sampling at the bunch peaks, i.e. at the highest betatron amplitude. The gain controlled amplifiers allow an optimum utilisation of the 14 bit ADC. The peak value of subsequent bunches carrying the betatron oscillation are recorded. The Fourier transform of this array gives the fractional betatron tune q. This method combines the functions of a synchronous demodulator and a frequency normalizer. Due to the bunch-synchronous sampling, the frequency components of the synchrotron oscillation are suppressed. The sampled data therefore contain mainly the betatron sidebands transposed into the range between DC and $f_0/2$ ($f_0$ = revolution frequency). The lowest normalized frequency is zero (DC component), the highest usable one is $f_0/2$ and the corresponding range of q or (1-q) falls between 0 and 0.5. Whether the measured value represents q or (1-q) depends on the machine lattice. Subsequently acquired spectra with the same time intervals are displayed as a waterfall diagram (Fig.4.) showing the tune as a function of time On the left edge of the screen the values of the detected tune peaks are also numerically displayed.


Figure 4: Display of a tune measurement in the ramp consisting of averaged FFT spectra.

The beam rigidity is low in the lower energy range, therefore very weak excitation is adequate for a distinct betatron response. The excitation strength in the ramp has to be increased. Hence the excitation level is programmable as a function of time. It is held as low as possible for an optimum signal to noise ratio with minimum particle losses. For this reason the excitation is switched on only for the duration of the data acquisition by means of a fast GaAs switch. The data are taken in blocks of N datawords each and stored sequentially in memory. To start the process the COSY timing system triggers an internal timing logic which in turn generates k timing pulses with constant time interval for k tune values. The number k of timing pulses and their interval must be properly chosen to cover the tune measurement time overlapping the total acceleration ramp time as desired. In one data acquisition cycle, k×N samples corresponding to k tune values are sequentially acquired. These data blocks are transformed by FFT resulting in frequency spectra with N/2 data points. As the duration of the acquisition depends on N, its value must be properly chosen, because it also determines the frequency resolution of the FFT-spectra (equal to 1/NT with $1/T = f_S = f_0$). Although the duration changes in the acceleration ramp, the resolution of the tune (1/N) remains constant. The larger the quantity of the samples is in the array used for evaluation, the higher the frequency resolution will be and consequently also the accuracy of the tune measurement. The average acquisition time (N×T) for a tune resolution of $5\times10^{-3}$ is less than 2 ms. The transformation of a record needs 35 ms in the used configuration, thus real time tune measurements can be carried out with a frequency up to 25 Hz. With fast FFT processors or with stored records and off-line processing, equivalent rates above 500 Hz can be achieved. To improve the noise floor, the spectra can be averaged. A graphic and numeric display shows the tune as a function of time.

## 4 IONISATION BEAM PROFILE MONITOR

A profile monitor using a position sensitive micro channel plate (MCP) detector [6] has been developed at the University of Bonn [7] and was tested and modified at FZ-Jülich [8]. A parallel ion drift field is maintained in the 130 mm wide gap between two electrodes. Residual gas ions are drifted onto an MCP assembly that provides a charge gain of about $10^7$. The secondary charge produced from each ion is collected by a wedge and strip anode, and then integrated, digitized and red out by means of a PC running a user friendly Cobold PC program [6] under Windows OS.

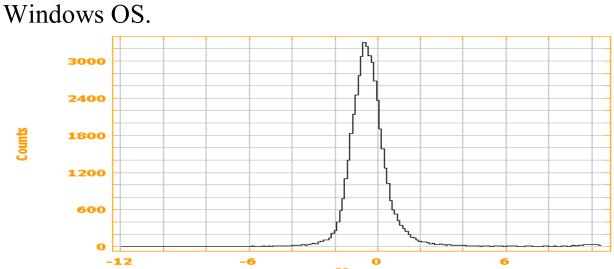


Figure 5: Vertical beam profile after electron cooling.

Since COSY operates with beam intensities up to $10^{11}$ protons and a vacuum of $10^{-10}$ mbar, there is a large risk of radiation damage of the detector. Hence the MCP voltage is switched on only during the measurement (typically a few seconds). Also a pneumatically driven protection screen is installed to prevent detector irradiation during the routine operation of the accelerator [8]. Profile measurements have been carried out for beam intensities up to $5\times10^8$ protons. Fig.5 shows the vertical beam profile after electron cooling for $6\times10^7$ protons at 40 MeV.

## 5 CONCLUSIONS

The resonant tuning of the Schottky-pickup is now being tested in the machine. For tune measurements including the tune meter the Schottky-pickup is routinely used.

The advantages of the tune meter include: (1) Spurious peaks with constant frequency can easily be recognized and separated. (2) No frequency feedback on the excitation is necessary. (3) The acquisition time is short, thus nonlinear changes of the tune have less influence on the accuracy. (4) Because of the bunch-synchronous sampling, all higher betatron sidebands are transposed down and the FFT-spectra contain only the frequency range up to $0.5\times f_0$. (5) Due to the tracking clock, the longitudinal and transversal spectra are separated. (6) The gated low level excitation causes no noticeable particle losses. (7) The method with some additional signal conditioning can easily be implemented at multiple bunch machines.

The ionisation beam profile monitor is used in routine operation. There exist some problems with the interpretation of the measured beam profiles, especially in the case of electron cooled proton beams. The optics of this monitor is under further investigation. The lifetime of the channel plates and the event rate are crucial issues for the measurement of intense proton beams.

## 6 REFERENCES


[1] R. Maier, “Cooler synchrotron COSY–performance and perspectives,” Nucl. Instrum. and Methods A 390, 1- 8 (1997).

[2] I. Mohos et al.,”New Schottky-pickup for COSY-Jülich”, DIPAC’01, Grenoble, May 2001.

[3] J. Dietrich et al.,” Real time betatron tune measurement in the acceleration ramp at COSY-Jülich”, DIPAC’99, Chester, May 1999.

[4] U. Bechstedt et al.,”Polarized beam in COSY”, IKP Annual Report 1999, Jül-3744.

[5] B. Hochadel,“ Ein Strahlprofilmonitor nach der Methode der Restgasionisation für den Heidelberger Testspeicherring TSR”, MPI H- 1990-V- 19I.

[6] RoentDek Handels GmbH, Frankfurt, Germany.

[7] M. Schulz-Rojahn,“ Messung von Strahlprofilen am internen COSY-Protonenstrahl mittels Restgasionisation“, Doctor’s thesis, Bonn, 1998.

[8] V. Kamerdjiev, Master’s thesis, FZ Jülich, 2000.