NON–BEAM DISTURBING DIAGNOSTICS AT COSY–JÜLICH

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Abstract

The non–beam disturbing diagnostic elements projected for the cooler synchrotron COSY–Jülich are presented and discussed. For beam observations there are monitors for the determination of closed orbit deviations, beam intensity, bunch shape and phase, beam losses and of dynamic machine parameters; and for excitation of beam oscillations in tune measurements beam deflectors, such as the diagnostic kicker magnet and the stripline unit. The monitors are beam position monitors, wall current monitors, beam current transformer, Schottky pick–ups and beam loss monitors. Mechanical details and blockdiagrams of the electronic systems are described.

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 μsec). Total proton numbers will range from 10^9 to 10^{11}. A more detailed description of COSY and the status of the project is given in ref. [1].

Non–beam disturbing diagnosis is necessary in order to optimize the closed orbit and guarantee a good beam quality and to control working point and dynamic parameters of the machine. Components for this purpose at COSY and their measurement applications are the following: electrostatic beam position monitors for horizontal and vertical closed orbit control and storage of the instantaneous position values of several orbits in succession, wall current monitors to measure bunch shape and amplitude and the phase relative to the accelerating frequency, a beam current transformer for current measurement of the debunched beam (DC–beam), resonant Schottky pick–ups (hor. and vert.) for measurement of longitudinal Schottky noise and determination of the relative momentum spread, a stripline unit and a kicker–magnet for resonant or shock excitation of beam oscillations for tune measurements, beam loss monitors for radiation detection in cases of beam striking on material.

Beam Position Monitors (BPMs)

The BPMs are especially used for closed orbit control (horizontal and vertical) and for tune measurements. The closed orbit control is carried out at stored beam and during acceleration by measurement of the beam positions to detect steering errors and evaluation of corrections for the nominal values of magnets and the RF–cavity. Tune measurements are made by observation of beam oscillations resulting from short time deflection by the kicker magnet or resonant excitation by the stripline unit.

For these purposes 27 BPMs (about five per betatron oscillation) are projected in COSY, 16 with round cross section (ϕ 150 mm) in the straight lines and 11 rectangular ones (150 x 60 mm^2) in the bending sections. The BPMs will be electrostatic pick–ups consisting of two electrode pairs (each 100 mm long) rotated by 90° to each other and provided for horizontal and vertical beam position measurements. They must be compatible with ultra–high vacuum and bakeable to 300 °C. The frequency range is limited to ~ 100 MHz due to a resonance near 150 MHz.

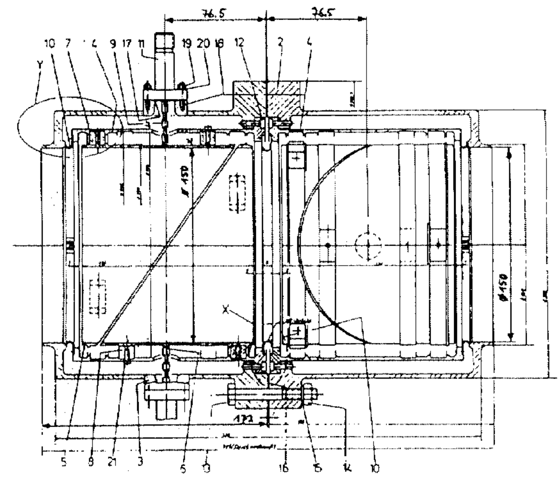


Figure 1: Mechanical design of the round BPM

Fig. 1 shows the mechanical lay–out of the round BPM. Each electrode pair consists of a diagonally cut cylinder or rectangular tube, respectively. By this the electrode signals become linearly dependent on beam position [2] and the sum(Σ)–signal proportional to the beam intensity independent of beam position. The difference(Δ)–signal is proportional to the amount of deviation of the beam from the central position. The sensitivity of the electrode signals is proportional to the number of particles per bunch and inversely proportional to bunch length and electrode capacity (~80 pF). With 10^9 protons per bunch and 40 m bunch length the electrode pulses amount to ~ 2 mV (beam in central position) and the position sensitivity to ~ 10 μV/mm.

Low–noise voltage sensitive preamplifiers with high impedance inputs will be directly connected to the monitor electrodes. Via T–adapters testsignals, if required , can be coupled in. The analogue and digital electronics will be housed in a compact and well shielded case (VXI–module in VME–crate) at about 1 m distance. The digitized position information is transmitted to the control room. For these reasons operation will be possible with less noise pick–up and less cabling expense.

Fig. 2 and 3 show blockdiagrams of the analogue and digital electronics. Σ– and Δ–signals are formed by a 180°–hybrid and amplified by broadband amplifiers (60 MHz) with 80 dB dynamic range and programmable gain adjustment. Their output signals are used in three ways: (i) They are directly extracted via 10 MHz–amplifiers for "fast" measurements (e.g. tune measurements). (ii) They are fed to the frequency selective amplifier branches with computer controlled resolution bandwidth (like a spectrum analyser) for "slow" but precise measurements (e.g. closed orbit control). (iii) At the same time they are connected with limited bandwidth (3MHz) to a phase demodulator yielding the right/left

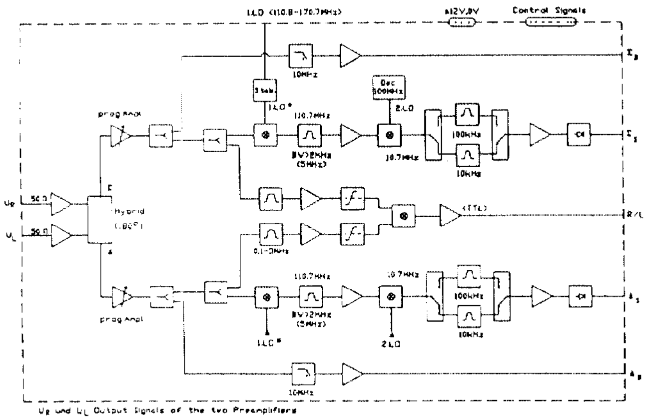


Figure 2: Blockdiagram of BPM–analoque electronics

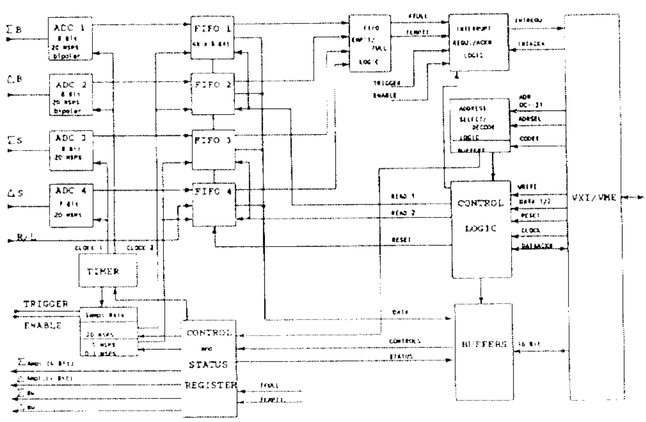


Figure 3: Blockdiagram of BPM–digital electronics

(R/L)–information (i.e. Δ–signal positive or negative, respectively), which is lost in the selective branches by mixing into other frequency ranges. The digital electronics include ADCs with 20 MHz repetition rate and FIFO–memories, which are triggered by the RF–tracked timing system in order to synchronize the position measurement to the particle bunch. The depth of the FIFO memories enables the registration of position informations of up to 200 successive turns.

The equivalent input noise amounts to ~ 0.5 μV_{rms} with 10 kHz resolution bandwidth and ~ 9 μV_{rms} with 3 MHz bandwidth. From that follows the accuracy of position measurement, which is for 10^9 protons per bunch and 40 m bunch length:

- < 0.1 mm for closed orbit control (10 kHz–filter),
- < 1.0 mm for tune measurements (3 MHz bandbwidth).

Wall–Current Monitors (WCMs)

Wall–current monitors [2] are broadband pick–ups for detailed measurements of beam characteristics, such as beam intensities (peak and average), bunch shape, phase with respect to the main synthesizer, synchrotron oscillations. Work on two monitors is in progress: (i) Monitor DPMH1 placed besides the h=1 cavity for the measurement of the RF–phase and the observation of synchrotron oscillations. The required bandwidth is 30 kHz – 20 MHz. (ii) Monitor DWCM in the e–cooler section for measuring the AC current and bunch shape. The bandwidth is 100 kHz – 500 MHz.

Fig. 4 shows the principle mechanical layout. The gap is sealed by an insulator. This design in comparison to other layouts [3] has the advantage, that the ferrite material – which is inserted to decrease the lower cut–off frequency and for damping reflected waves – is placed outside the vacuum. The interference by reflected waves on the COSY beam should be as weak as possible. Resonances must be damped by proper layout of ferrite materials [3].

The beam signal will be picked–up by eight symmetrically adjusted 50 Ω transmission lines. In order to make the output independent of the beam position the eight lines are added together, the resulting signal being $V = i_b \cdot Z_{tr}$ with i_b = beam current, Z_{tr} = 13.4 Ω [3].

The monitor signals will be amplified by means of low noise broadband amplifier. Bunch shape and current amplitude will be analysed with a fast digital scope, average current with low pass filter and ADC and bunch phase with a network analyzer.

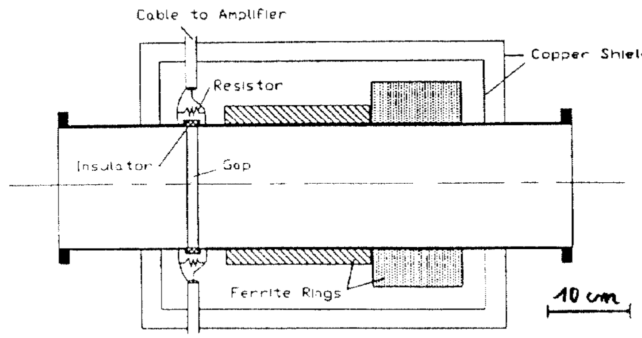


Figure 4: Mechanical layout of WCM

Beam Current Transformer (BCT)

For current measurements of the debunched beam (DC–beam) a beam current transformer is used. The sensor and amplifier electronics have been designed at CERN by K. Unser [4] and are manufactured by Bergoz, France. The maximal current range is ± 100 mA and the resolution ± 0.5 μA. The planned mechanical design is shown in fig. 5.
The BCT needs a total space of 80 cm (including magnetic shielding). The isolating gap will be AC short circuited by capacitors for frequencies > 400 kHz in order to measure signals from DC up to 40 kHz. Two high resolution DVMs will be used to read the analog outputs (beam current i and di/dt) simultaneously.

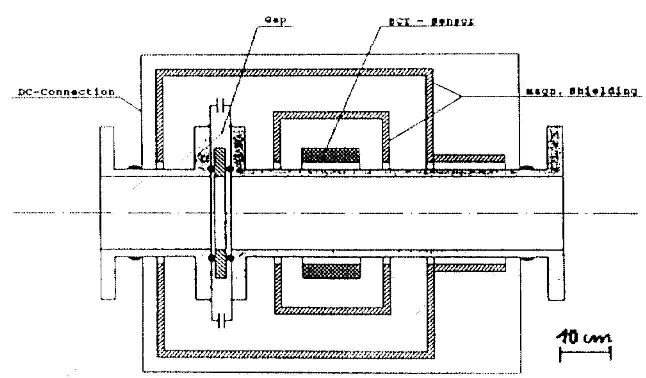
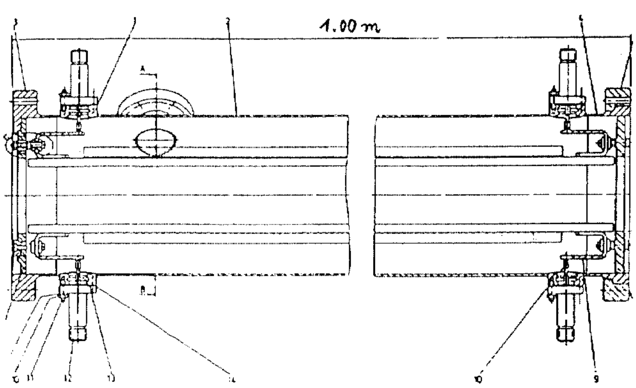


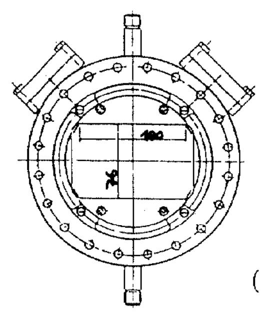
Figure 5: Mechanical layout of BCT

Schottky Pick–ups

Schottky pick–ups are utilized to measure the longitudinal (sum of electrode signals) and transverse (difference of the signals) Schottky noise spectrum. By means of resonant tuning the sensitivity is enhanced (narrow band) and shifted to a proper frequency range. The longitudinal Schottky noise spectrum is measured near 50 MHz and is used to determine the relative momentum spread of the particles, the transverse Schottky noise spectrum measured near 10 MHz allows the determination of the non–integer part of Q–value and of the beam emittance [2,5]. At COSY two pick–ups (each 1 m long) are designed for horizontal and vertical Schottky–noise measurements. They are constructed according to the pick–ups in ACOL at CERN with some modifications for adaptation to COSY and for RF–test possibilities. Fig. 6 shows the mechanical layout.



(a) Longitudinal section



(b) Cross section

Figure 6: Mechanical design of Schottky pick–up

The resonant tuning for the desired frequency will be made at each electrode with cables of $\lambda/4$–length and tuning capacitors. Low noise preamplifiers with 50 Ω input impedance will be coupled to the cables at the point of 50 Ω (power matching) [6]. By means of the 180°–hybrid the sum(Σ) and difference(Δ) signals are formed for the measurement of longitudinal and transverse spectrum, respectively. These can be recorded directly using a spectrum analyzer or with more sensitivity and higher speed using an FFT–analyzer if the narrow band measuring signals are mixed down into the 0–100 kHz frequency range of the FFT–analyzer. For this purpose a mixer with high mirror frequency rejection is necessary [6].

From the width Δf_h of the lines in the longitudinal Schottky–noise spectrum the relative momentum spread $\Delta p/p$ can be determined [2,5]. In the transverse Schottky noise spectrum side bands for all harmonics appear as result of modulation of the revolution frequency by the betatron oscillation of the particles. From their distance to the harmonic lines the non– integer part of the Q–value can be determined and from their shape the emittance of the beam [5].

Diagnostic Kicker Magnet and Stripline Unit

The purpose of the diagnostic kicker magnet and the stripline unit is to excite the beam particles to collective transverse oscillations which run with betatron frequency and allow the determination of the non–integer part of the Q–value [5]. By means of the kicker magnet the beam is short time deflected and the resulting beam position oscillation in one BPM is measured for up to 200 successive turns. Via the stripline unit the beam is excited with white noise or with a frequency tracked RF–voltage. Resonant beam position oscillations occur, if the exciting frequency corresponds to the overlap of betatron frequency and harmonics of the revolution frequency.

The short time kicker–deflection is, in contrast to the time consuming resonant excitation by the stripline unit, appropriate to measure the tune also during the acceleration ramp. The stripline unit on the other hand can be used for horizontal and vertical beam deflections, the kicker magnet only for horizontal.

The design of the stripline unit, which contains electrodes in 50 Ω–stripline technique, is in progress. The kicker magnet and the associated electronics is constructed at CERN [7]. It is a window frame magnet with single turn, bakeable to 300 °C and situated in UHV machine vacuum. It will be loaded from a 12.5 Ω–pulse forming cable (4x50 Ω in parallel), resonantly charged to –33 kV and discharged via appropriate timed main and dump thyratron switches. The kick–pulsewidths, which vary with particle energy, correspond to the sum or difference of the pulse forming cable time delay (~ 0.8 μsec) and the time difference (up to ± 0.6 μsec) between the actuation of the switches. These are controlled by the RF–tracked timing system in order to synchronize the kick–deflection time to the circulating particle bunch.

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