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## **Transmission Monitoring in the DESY Accelerator Chains**

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# Transmission Monitoring in the DESY Accelerator Chains

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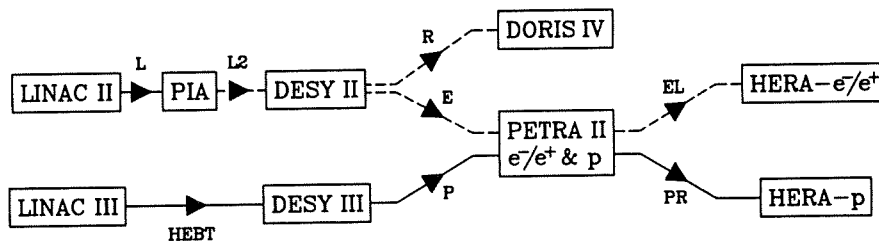
## Abstract

Standardized beam current transformers are installed in each of the accelerators and in the transport lines, close to the injection/ejection elements. Their signals are proportional to the charge in a single bunch and are suitable for both direct visualization on digital oscilloscopes and for single-pass data acquisition. Corresponding bunch current signals or signaltrains to be compared “at a glance” are arranged in perceptible tandems. We report on the technical design of the pickup electrodes, optical-fiber-based analog delay line techniques, and calibration procedures.

## INTRODUCTION

The HERA e/p collider (27 GeV  $e^+/e^-$ , 820 GeV p) and the DORIS synchrotron radiation facility (4.6 GeV  $e^+$ ) are currently in operation at the DESY laboratory in Hamburg, Germany. Pre-accelerator chains are required to boost the particle energies to inject into these machines. A schematic of the electron and proton accelerator chains is shown in Fig. 1, and a sketch of the DESY complex is shown in Fig. 2. The storage ring PETRA II is used as booster for both, electrons and protons; the stored beams orbit in opposite directions in these injection modes.

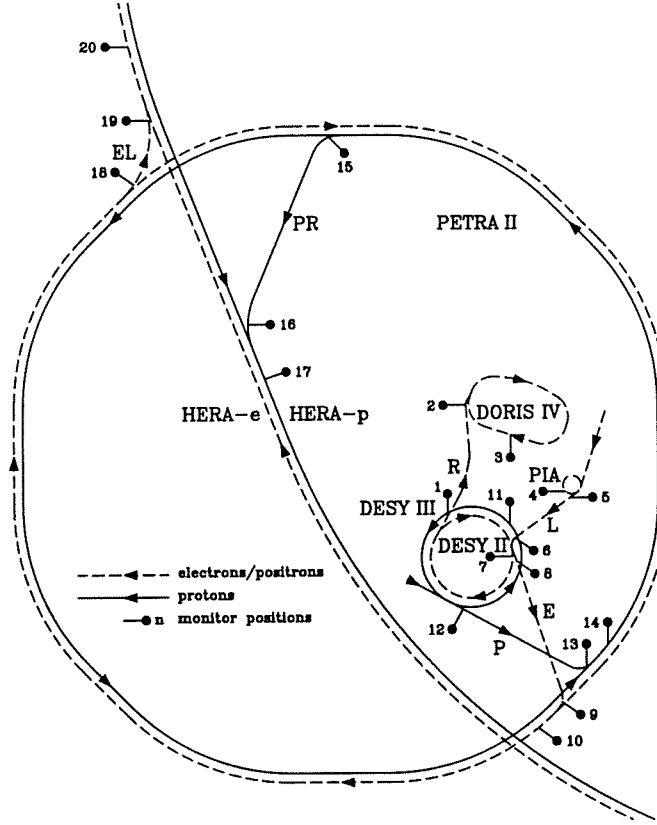
Efficient transfer through the injection chains is needed to minimize the filling times. Particle losses can also lead to local radiation heating. To achieve and maintain maximum transfer efficiency, the accelerator operators require diagnostics throughout the chains, with easily selected signals combinations for quick comparisons. Standardized measurement setups and simplicity of calibration are important design requirements.



**Figure. 1.** Schematic of the accelerator chains at DESY

In 1995 the achieved transfers in quantities of particles per bunch were:

$$\begin{array}{llll}
 e^{\pm}: & \text{PIA/DESY II} & 1 \times 6 \cdot 10^9 / 6.25 \text{ Hz} & \xrightarrow{0.5h} \text{HERA-e} & 189 \times 2.5 \cdot 10^{10} / \text{run} \\
 p: & \text{DESY III} & 11 \times 1 \cdot 10^{11} / .223 \text{ Hz} & \xrightarrow{0.4h} \text{HERA-p} & 180 \times 6 \cdot 10^{10} / \text{run}
 \end{array}$$



**Figure. 2.** HERA and the preaccelerators

## BASIC CONCEPT

The beam current monitor unit consists of a broad-band transformer pickup, directly connected to a pulse-forming low-pass filter for integration, followed by a remote-controlled attenuator (measurement range extension) and a low noise, wide-band amplifier (normalization). Twenty such devices have been installed in the accelerator chains (see Fig. 2).

For comparison of signals and signal groups, all these monitors should have the same electrical characteristics, although they are different in their mechanical dimensions and apertures. In addition, all monitors avail on one basic measurement range with concordant calibration factors per direction. The chosen time constants of the monitors allow their signals to be digitized without

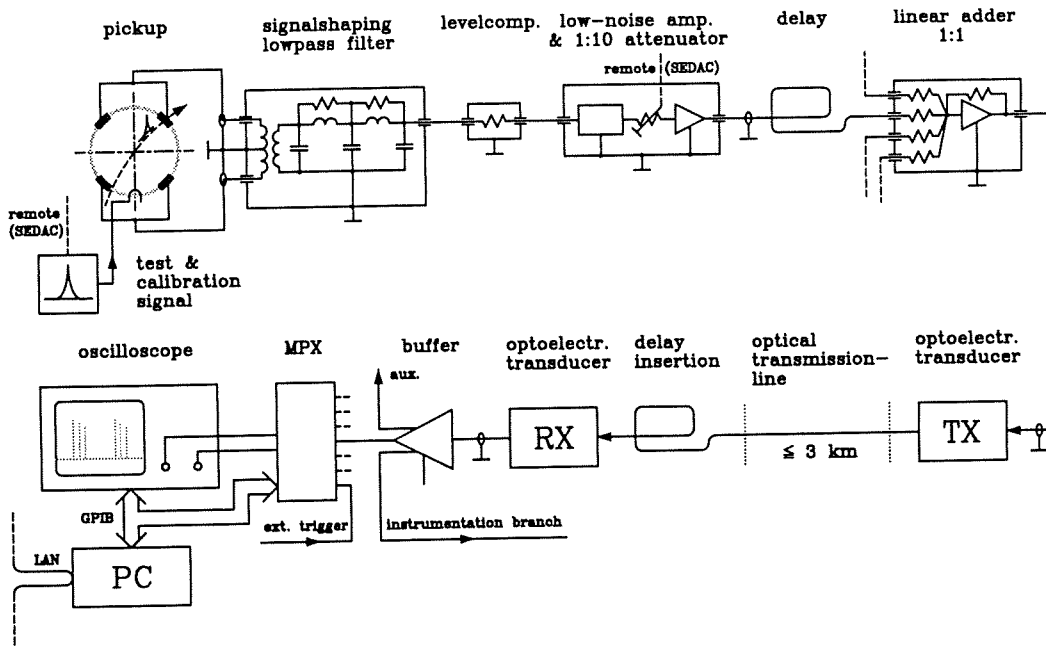


Figure. 3. Overview of a transmission monitoring setup

exceeding the minimum bunch interval of 96 ns. Individual cable or fiber insertions for analog signal delaying, electronic adder devices, together with the properties of dedicated “nailed” long transfer lines including optical TX/RX converters become an integral part of signal quality and of the absolute calibration. An advantage of this concept is that no timing or gate settings are required up to the multiplexer (MPX) input ports in the control room (BKR).

## DESIGN CONSIDERATIONS

### Mechanical Layout of the Pickup

Transformers with toroidal cores made of *permalloy*\* tape with a thickness of 0.025 mm and with various apertures in gradings between 60...230 mm in diameter serve as the sources for the beam current signals. For practical reasons we decided to arrange the pickup electrode entirely outside the vacuum. This requires a vacuum-sealed isolating gap within the setup. This gap consists of a small ring of radiation-resistant  $\text{Al}_2\text{O}_3$ -ceramic. In the case of very short bunches the inner surface of the gap may additionally be bridged for wave tapering by interleaving metallic fingers or combs.

This technical solution has significant advantages because the transformer can be cut into halfrings. By this measure, the pickup electrode can be completely finished in the lab and quickly mounted, modified, or exchanged in situ even if the vacuum system is closed. The necessary shieldings are made of

\*Permenorm 360K1, Trafoperm etc. are trade marks of VAC Vakuum Schmelze, Hanau

engineering steel or aluminium and can also be cut into halves.

The fully equipped halfcore is embedded in a shielding halfcover. The mounting on the vacuum vessel is done simply by clamping both halfcovers together on their mechanical seats by screws. Long strips of flat springs inserted between the halfcovers and the framework of the ringcore keep the gaps of the cores tightly closed.

All electrical connections are made pluggable immediately outside the shielding cover using BNC- or SMA-type chassis receptacles. The first active electronics may be located up to 2 meters away from the beam pipe.

### Electrical Layout of the Pickup

The electrical layout of the pickup is defined by the requirements listed below.

1. The bunch lengths range from  $10^{-10}$  to  $10^{-8}$  seconds. The signal heights are expected to be proportional to the charge in a single bunch and independent of the real bunch shapes.
2. On one hand, the signals should decay to zero within  $2/3$  of the available 96-ns bunch-to-bunch interval. On the other hand, the peak of the signal has to be flat and long enough to allow a single pass data acquisition.
3. High frequency components produced by very short bunches should not reach the active electronics.
4. Overall calibration must be feasible at any time.

On the basis of these design goals and in combination with our experience with magnetic beam position monitors(1), in particular in DESY III, we have established the following electrical configuration.

*Permalloy* tape as core material with its circular magnetic texture was preferred, because its permeance is not strongly changed if exposed to stray fields(2),(3). The transformer core is furnished with 4 single pickup loops symmetrically spaced over the circumference. The primary loop consists of a solid, flat copper strip tightly bent around the core. A small, ferrite-loaded rf transformer for impedance matching is mechanically integrated into each loop. The secondary side carries 15 turns of enameled wire; the ends are guided directly to the outside by means of chassis receptacles. In principle all four outputs are connected consecutively in parallel: the two outputs from each halfcover are joined together by short pieces of coaxial cable of equal length. These points are then joined with equal cable lengths to the inputs of a balun transformer, which is part of the lowpass filter (see Fig. 3).

A separate single turn, wrapped around the core and positioned between two pickup loops, serves for overall calibration and test purposes.

## **ELECTRONIC COMPONENTS**

### **Low-pass Filter Module**

A strongly damped, twin LC low-pass filter inserted next to the pickup forms the final shape of the signals to be displayed and digitized. The slope of the response function softly decays passing the upper cut-off at 20 MHz. Because undesired rf components in the spectra of the bunches may be picked up through the device, the rejection band of the filter must be carefully investigated. The filter is assembled with SMDs and is separately housed in a tin box. After the filter all bunch current signals have rise and falltimes of  $\approx 16$  ns. The total length of the signal occupies 70% of the available 96-ns bunch spacing.

### **Attenuator & Amplifier**

Attenuators inserted between the filter and amplifier serve for final calibration adjustments. Variations in losses and signal levels due to differences in pickup dimensions require gains of 5 to 20 in order to attain a standard measurement with ranges of  $2 \cdot 10^{10}$  particles/Volt for electrons and  $1 \cdot 10^{11}$  particles/Volt for protons. A relay-driven attenuator in the input stage extends the measurement range by a factor of 10.

### **Adder**

Corresponding signals from e- or p-monitors to be displayed in tandem arrangements are subjected to suitable delays by means of cable insertions. Up to four pickup sources may be non-reactively combined at the ports of an operational transimpedance amplifier before they are sent via cable or fiber to the accelerator control room.

### **Signal Transfer and Delay Techniques**

The length of transmission links ranges from 60 m to over 2 km, including the required delay insertions. For short distances (up to 400 m) and in irradiated areas we exclusively use air-dielectric rigid coaxial rf cable, mainly of 5/8" or 7/8" type. For longer distances (of up to over 2 km) we make use of 50/125 gradient glass fiber cables with excellent transmission properties such as low attenuation losses and neglectable dispersion. With a specific delay of  $5 \mu\text{s}/\text{km}$  and attenuation of 2.3 dB/km, analog delays of several microseconds can be easily established. So even longer signal trains can be set serially on one trace or set congruently on parallel traces.

### **Optoelectronic Conversions**

The optoelectronic TX and RX transducers that are used are in-house developments, utilizing commercial laserdiode modules which operate in the 890

nm window. Achieved device data for a TX/RX set linked with 1 km of 50/125 fiber cable are listed in Table 1.

transmissionband	10 kHz - 40 MHz
dynamic range	> 36 dB
modulation capability	$\pm 1.5$ Volt / 50 $\Omega$
adjustable gain	-6 dB
connectors	FSMA, FC-PC, ST

Table 1. TX/RX Device Data

### Signal Display

Finally the signals end in standard setups located in the controlroom. A typical setup consists of a PC-driven coaxial multiplexer MPX (*HP3488A*) wired with a digital oscilloscope (*Tektronix TDS 540*). Menu buttons integrated in the front panel frame of the oscilloscope are used to select the various signal combinations which are updated with the relevant transfer trigger.

### CALIBRATION AND TESTDEVICE

Because of the symmetric configuration of the pickup electrode we eliminated frequency depending couplings within their usable apertures. Finally a reliable calibration becomes feasible based on the following measures:

- All pickup transformers contain a testloop for recalibration.
- The pickup stations are calibrated by means of a stub antenna device before their installation.
- We use very short pulses with 2-ns FWHM; overshoots or reflections of the calibration current must decay to zero within the risetime of the system.
- Each station is measured twice with same charge: first using the antenna in the test device, then using the integrated test loop.
- The measured relative deviation of both outputs must be taken into account as a correction factor for future recalibrations.  
By the way, deviations of < 3 % typically have been measured.

The generation of appropriate  $\delta$ -pulses with zero baseline shift is based on the Avalanche effect(4). We only need to measure the DC portion of the periodic  $\delta$ -pulses if its period is quartz controlled. With e.g.  $f = 100$  kHz and  $i_{DC} = 1$  A, we would have to establish  $n = i/(ef) = 62.5 \cdot 10^{12}$  particles per

pulse; but at an available yield of  $3.3 \times 10^9$  particles/pulse, a current of 52.8  $\mu\text{A}$  has to be precisely measured!

A front-end active probe directly connected to the stub or loop connection is used to measure the voltage drop of the calibration current across a 50- $\Omega$  feedthrough resistor by means of a rf-blocked amplifier OP07. A pulse generator, DVM and power supply are housed in a portable backend cabinet. Accuracies attained with this method have been repeatedly confirmed in good agreement to a commercial precision parametric current transformer<sup>†</sup>. A simplified  $\delta$ -pulsar module remains plugged into the testloop port of each pickup station. For test purposes the pulser may be remotely activated at any time.

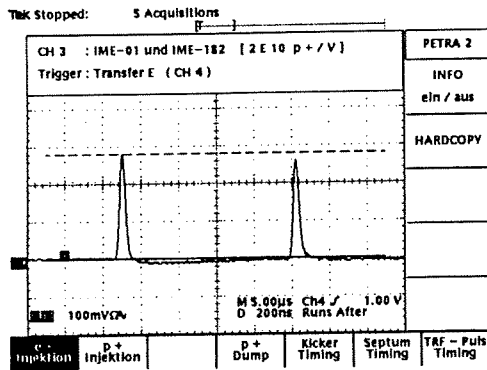


Figure. 4. Positron transfer (E-line)  
DESY II – PETRA II

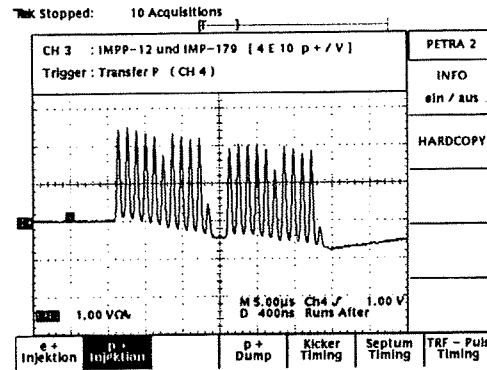


Figure. 5. Proton transfer (P-line)  
DESY III – PETRA II

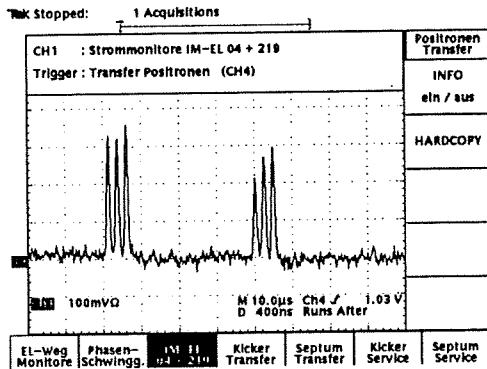


Figure. 6. Positron transfer (EL-line)  
PETRA II – HERA-e...

<sup>†</sup>PCT from *Bergoz*

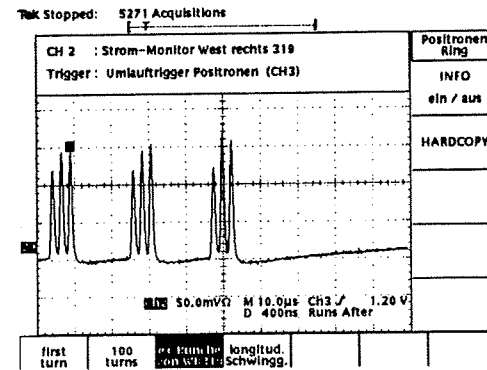


Figure. 7. ... and finally deposited in  
HERA-e



## PERFORMANCE

Figures. 4... 7 show selected signal arrangements taken as printouts from the scope stations. The attained transmission efficiency appears clearly by visual comparison of the pulses or pulsetrains.

## CONCLUSION

The design of this beam current transmission monitoring is tailored to given preconditions in the accelerator chains at DESY. The direct display of arranged but unprocessed signals is reliable and useful for daily routine operation, though the drop in the signal may be a little inconvenient. Although the length of bunch signals are far off the real bunch length, misalignments in the injection lead immediately to striking signal distortions.

Over a separately kept signal path we have investigated a "state of the art" fast data acquisition module for single-pass recordings(5). This commercial ADC has a bandwidth of 33 MHz with a resolution of 12 bit and has been successfully tested for well over a year during different injection conditions for PETRA II.

## Acknowledgements

The authors want to thank Franz Reuther and Matthias Steckel from the cable staff for establishing the long distance transfer links and to Siegfried Pätzold for arranging the menu- and display setups.

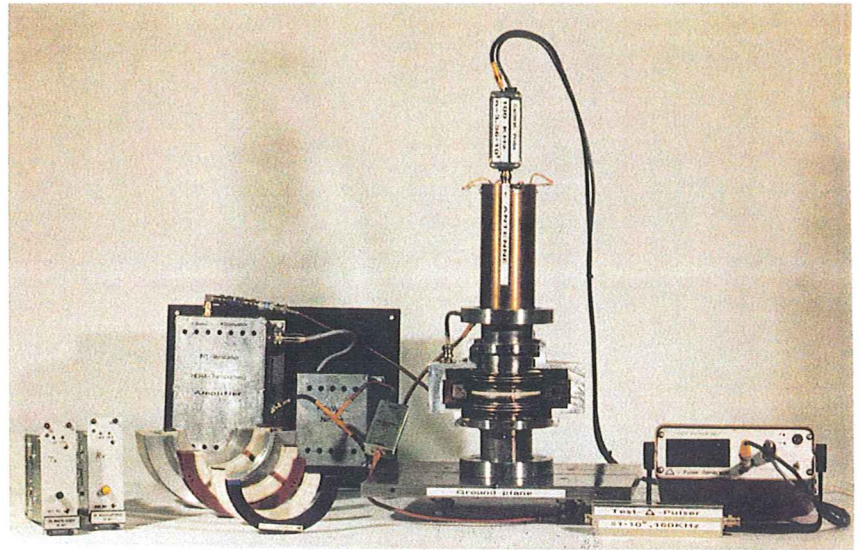
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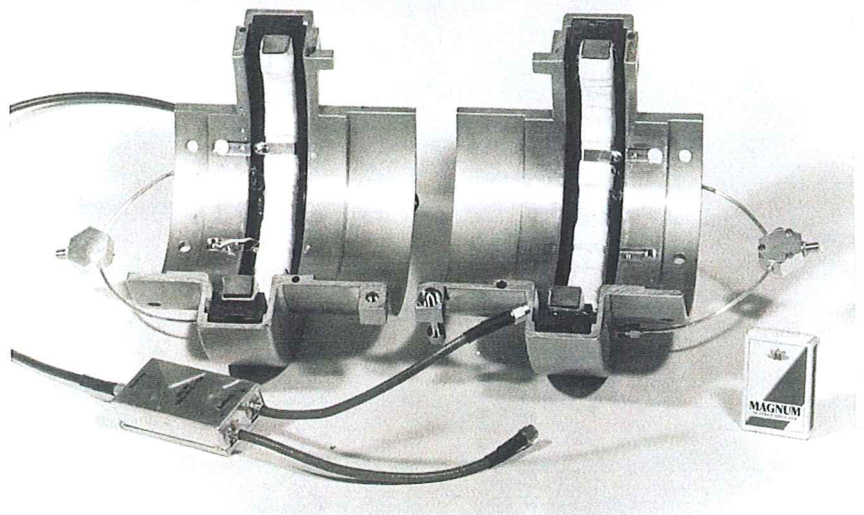
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## Appendix / Pickup - Technalities

Set of a disassembled pickup electrode, electronic components and calibration and test devices



Split pickup electrode, showing fully equipped beam transformer-halfcores embedded in their halfcovers



Same above insitu, integrated into the HERA-e vakuum system, e.g. at position WR 198

