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STATUS REPORT ON DESY III

THE DESY III COLLABORATION *)
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Abstract Commissioning of DESY III, the new 7.5GeV/c proton synchrotron designed as part of the HERA injector chain, commenced in Dec. 1988. We present a description of some aspects of the major hardware systems and instrumentation. We report on first observations of beam behaviour.

INTRODUCTION

Since mid-December 1988 some 60 days of beam operation have been scheduled for DESY III. No operation was possible for ~6 weeks in April/May 89 due to necessary repairs of some defective drift tube quadrupoles in the 50MeV H^- linac injector. Progress has been steady and is best illustrated by some chronological highlights:

21/12/88 Beam survival at injection energy for 200ms ($\sim 6\times10^4$ revs).
22/02/89 Acceleration to full energy (dipole current used corresponds to ~7.35GeV/c).
09/03/89 Protons extracted onto a provisional beam dump.
30/05/89 Use of beam phase loop dramatically reduces losses during acceleration.
01/06/89 to date. Regular operation with 5×10^9 protons per bunch accelerated to full energy allows systematic beam experiments.

In parallel the diagnostic systems were steadily improved allowing quantitative measurements and interpretation to be made.

MAJOR SYSTEMS

The basic parameters of DESY III described in Ref.1 have not changed. In the following sections we highlight only some features of major components and their operation.

Magnet Power Supplies. DESY III has a single main dipole - and four quadrupole circuits. A number of normal orientated and twisted multipoles (quadrupoles, sextupoles and octupoles) for compensation of transverse resonance- driving terms at injection energy are installed. These multipoles will be individually DC - powered. The ratings of the supplies will be found empirically by exploring the tune diagram. The quadrupoles are excited by chopper controlled supplies. In order to avoid phase space dilution at injection from LINAC III and transfer to PETRA II the specified relative dipole field variation from cycle to cycle is $\pm 2\times10^{-4}$ at injection and $\pm 2.2\times10^{-5}$ at ejection.

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Fig.1 shows the circuitry of the dipole power supply. This was built in house. The injection field is controlled by the small power supply SPS connected in series to the two main power supplies MPS. These latter are bypassed at injection via free wheeling diodes FWD. The current ripple is suppressed by an active filter AF.
All five power supply excitations are determined by digital controllers which are driven by excitation tables with 18000 entries arbitrary each. This enables input of smooth excitation curves using 4th order polynominals and the application of corrections for eddy current effects and magnet saturation. This has turned out to be an important feature.

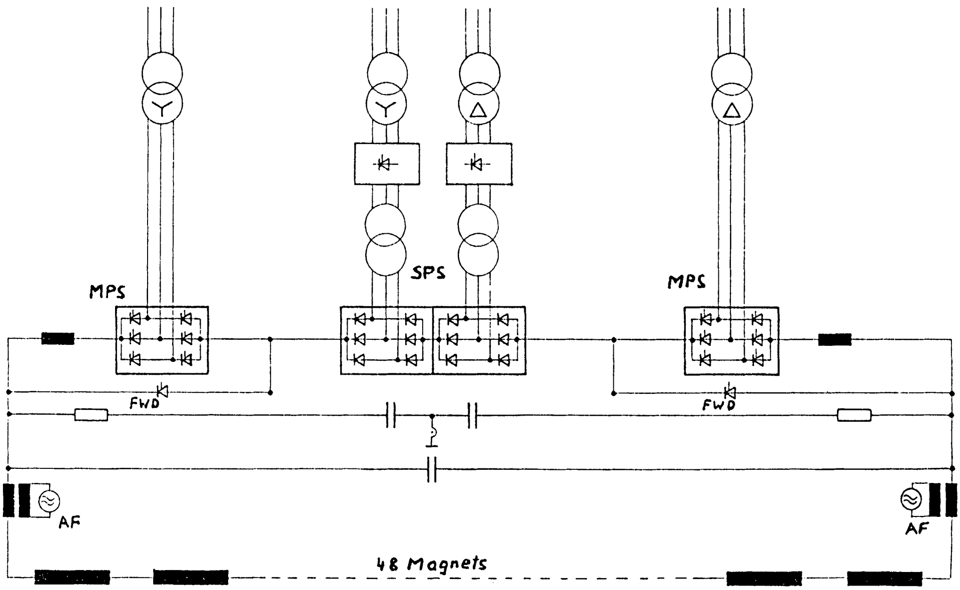


FIGURE 1 Dipole power supply circuit

Vacuum. The average pressure of the vacuum system is present $\sim 10^{-8}$ mbar. This leads to $\sim$.5 s beam lifetime at injection energy. In order to avoid circumferential eddy currents the beam pipe is cut into several insulated sections by inserting capton foils between flanges. These flanges are bypassed with low rf impedance in order to avoid discontinuities for the mirror beam current. In 1990 the capton foils will be replaced by ceramic gaps. This should give significant reduction of the vacuum pressure.

Injection. Multiturn injection is performed using an orbit bump that deflects the beam onto a stripping foil of Al_2O_3 where the newly injected H^- particles are converted and added to the existing stored beam, thus increasing the phase space density of the stored beam. After accumulation of about 10 turns ($\sim 30\mu s$) the orbit bump is rapidly turned off, taking the beam off the stripping foil within $20\mu s$. In order to get sufficiently small emittance growth during particle penetration the foil thickness has to be less than 1200 Å (Ref.2). These aluminum oxide foils were fabricated in house using the same technique which was formerly developed at Rutherford Lab (Ref.3). After injection and accumulation the rf voltage is adiabatically increased for optimal bucket forming and longitudinal capture.

RF System.The accelerating voltage of $20KV$ at peak maximum is delivered by a ferrite loaded cavity of CERN-PS type. A tuning loop which controls the phase angle between the grid voltage and the anode voltage of the final stage drives the biasing current between $150A$ and $2000A$, covering the frequency range of $3.2Mhz$ to $10.3Mhz$. The whole system including the rf-waveform generator, which modulates the rf-amplitude is computer controlled.

The rf frequency is controlled by a commercial VCO which is locked to a digital synthesizer of high frequency stability ($\frac{\Delta f}{f} = 10^{-8}$).
The synthesizer frequency is defined by a digital frequency table consisting of 360,000 entries which describes the appropriate change in frequency during the ramp including empirically optimized radial beam position bumps. This frequency table as well as the current table for the magnet current supplies are generated by an ATARI PC that allows the basic function parameters to be changed.

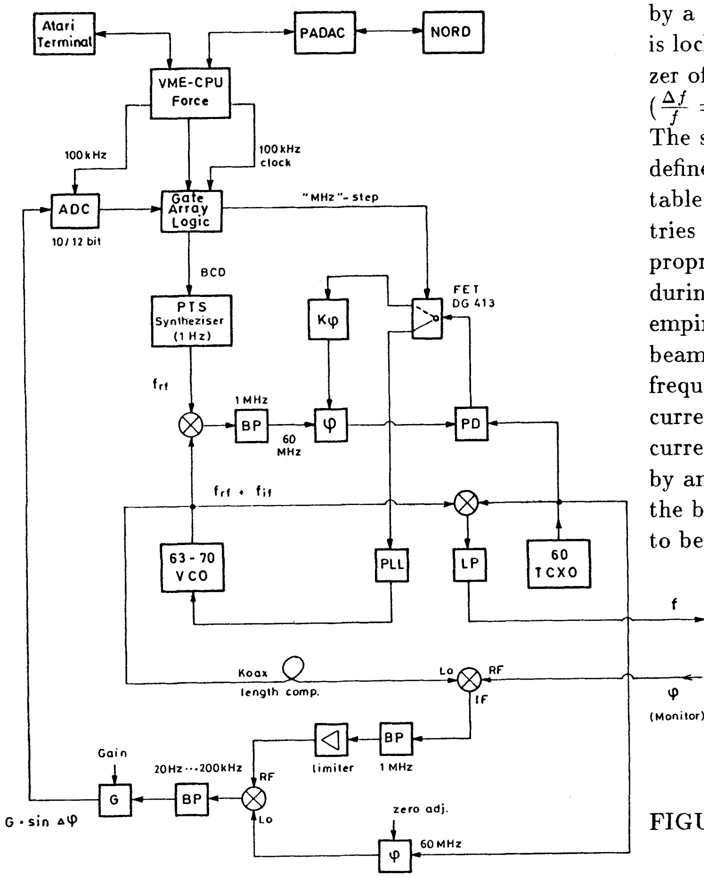


FIGURE 2 Low level rf system circuit

Correction Elements. The vertical orbit can be corrected by individually DC powered vertical deflecting magnets which are separated by nearly 90 degrees in phase. The rating of the supplies allows the injection orbit to be swept over the full vertical aperture and they are controlled by the NORD computer either singly or combined in order to form local bumps.
The horizontal correction is performed using backleg coils on the 24 main dipoles as well as 8 discrete deflecting magnets. The induced voltage from energy ramping in the backleg windings is compensated by additional return windings on each dipole magnet. These 24 return windings are connected in parallel and thus carry the sum of all 24 power supply currents. The sum of all kicks produced by the backleg coils is automatically zero and thus the energy of the machine is not changed whatever the correction current distribution might be. For comparison see Ref. 4.

INSTRUMENTATION.

We shall concentrate only on the most important hardware that controls the tracking of powersupplies, the tunes, the beam intensity, -position and -profile.

Tracking. Because of the different transfer function step responses of the dipole and the quadrupole power supply circuits, a fourth order polynomial function between flat bottom and the linear rise of the guide field had to be chosen in order to match the boundary conditions. The ratio of the current signals of the quadrupoles and the dipole are monitored on an oscilloscope. At present these signals fluctuate within $\pm 1 \times 10^{-3}$. This gives sufficiently stable tunes.

Tune Measurement. Coherent transverse oscillations are excited by extra vertical and horizontal deflecting kickers once per ramp period. The beam response is monitored using a four quadrant wide band stripline monitor. The lower cutoff frequency of about 1 MHz requires the beam to be rf modulated. A revolution clock samples the signal into a fast 12 bit transient recorder which takes 1 to 3 ms transfer time. The stored data are then transfered via IEC bus into a PC equipped with a FFT processor which analyzes the data and finally diplays the spectrum on the terminal. Special electronic equipment takes care of keeping the sample triggers centered on the bunches.

Beam Position Monitors. Four quadrant magnetic ring core monitors are used to measure beam position horizontally and vertically. They are based on former development of pickup monitors (Ref.5). The wide band frequency response of 50 KHz to 20 MHz overlaps the whole range of bunch frequency (3 to 10 MHz). 32 monitors are installed and evenly distributed around the ring. Each monitor has three output signals, derived from the four quadrants; a sum signal and two difference signals for horizontal and vertical beam position. Both horizontal and vertical difference signals are divided by the sum signals and yield to analogue signals which are proportional to the beam position during the ramp. It is planned to digitize the signals and to do further processing via the NORD control system.

Intensity Monitors. Beside the 32 intensity monitors that are used to buildup the quotient for position measurements special intensity monitors installed: A DC current monitor with about $100\mu s$ step response for current measurement of unbunched beams and two monitors of type similar to the position monitors but with lower cutoff frequency in order to measure beam current during injection and before bunching appears.

Profile Monitors. Two types of profile monitors are installed in DESYIII; residual gas ionisation monitors which allow continuous monitoring of the beam size with a resolution of better than $1mm$, and wire scanners. The wire scanner drives a $7 - 35\mu$ carbon wire with a velocity of 1 ms^{-1} through the beam. Scattered protons are then detected in a scintillator with a photomultiplier tube. The resolution is better than 0.5 mm. In the horizontal and vertical plane one rest gas ionisation monitor and one wire scanner have been installed.

BEAM PERFORMANCE.

Measurement of the coherent betatron tunes at injection as a function of quadrupole strengths has confirmed the expected average envelope parameters. Measurement throughout the acceleration cycle with the quadrupole demand currents strictly scaled to that of the dipole shows a variation of $\Delta Q \sim \pm 0.02$. Although outside the specified tolerance, there is flexibility available in the ramp functions to empirically correct this behaviour.
Closed orbit correction is performed with DC powered magnets and becomes ineffective at high energy. Figure 3 is a plot of the vertical orbit at full energy as measured by the BPM system. It is clear that a re-alignment of the ring, already foreseen for early 1990, may be beneficial.

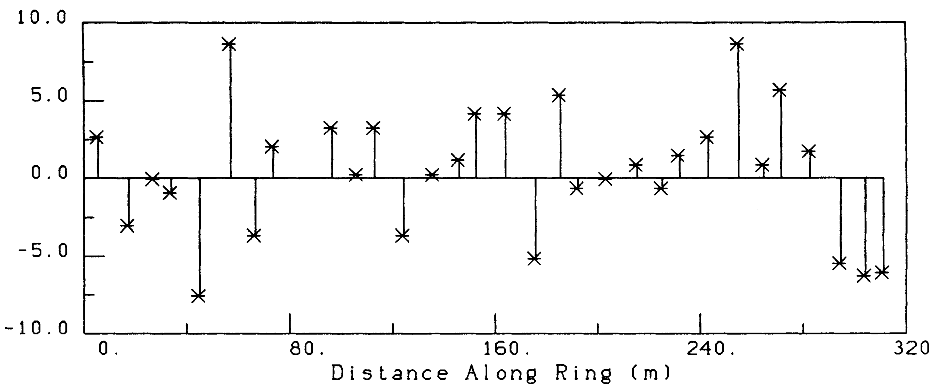
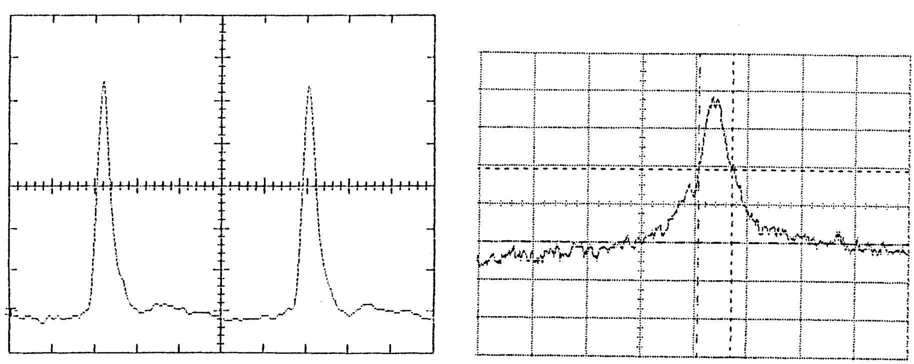


FIGURE 3 Vertical orbit displacements (mm) at full energy

Figure 4 shows typical signals obtained from the resistive wall monitor and the residual gas ionisation monitor showing the longitudinal bunch and radial beam profiles respectively at peak energy.



(a) 20ns/div (b) 6.8mm/div

FIGURE 4 Longitudinal (a) and radial (b) profiles at full energy

We may measure the synchrotron frequency at flat top by applying a non-adiabatic rf frequency shift, with reduced phase loop gain, and observing the response of a radial BPM where there is finite dispersion. Such a response is shown in Figure 5.
By deriving the beam momentum from the rf frequency and nominal circumference and assuming gaussion distributions in all dimensions, we may estimate transverse and longitudinal emittances containing 90 % of the particles together with the lattice transition energy. This yields ϵ_l =0.14eVs, ϵ_x=2.3.10^{-6}m and γ_t=10.2. The emittances are a factor of 1.5 and 2 respectively greater than design but are adequate for initial tests of transfer to PETRA II. The transition energy is somewhat above that predicted. However measurements of synchrotron frequency versus quadrupole strength have confirmed the expected differential behaviour.

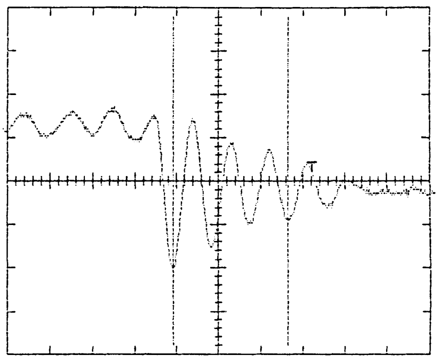


FIGURE 5 BPM radial response to an abrupt rf frequency shift

Injection of a chopped linac beam of duration $\leq 2\mu$s allows observation of BPM analog signals and was used to detect the build up of a coherent radial oscillation and coincident intensity loss, which have been observed to occur some 120μs after injection at which time the injection bump turn-off should be complete. As yet the cause has not been established. A comprehensive series of experiments was made where the injected current was varied and the beam survival recorded over the whole acceleration cycle. Whilst overall transmission of a single injected turn (1.5×10^{11} protons) is some 25%, that for 9 turns is only 4%. The early, intensity independent, loss of around 20% may be attributed to input beam mismatch and the coherent oscillation noted above. During the 10 ms flat bottom, when the rf voltage is raised to trap the coasting beam, we observe lifetimes which decrease with increasing beam intensity. In the subsequent smooth 200 ms early acceleration phase the lifetimes are once more independent of the remaining intensity and thereafter the losses are essentially zero. A full interpretation of this data has not, as yet, been made.

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