IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

THE 19 GeV e^+- e^- STORAGE RING PETRA

The PETRA-Project Group *
presented by G.-A. Voss

Introduction

On July 15, 1978 the first electron beam was stored in the new electron-positron storage ring PETRA.** More than nine months earlier than originally scheduled, this event concluded a construction period of 2 years and 8 months since the authorization of the project. The fast construction rate was accomplished even though the project was severely limited in manpower and money: One of the conditions for authorization was that DESY would not hire new staff for designing and building this large storage ring; and of the 98 million DM authorized for the construction of PETRA, only some 80% have been appropriated so far. PETRA was built by a project group formed from members of many different DESY experimental and machine groups while much of the original program at DESY was carried on. (The upgrading of the peak energy of the DORIS storage ring from 3.5 GeV to 5.1 GeV fell into this period).Design and construction of PETRA was helped by friendly collaboration with other laboratories, particularly CERN,SLAC,Cornell Univ., TH.Aachen and GSI Darmstadt.

The 2.3 km PETRA tunnel and the 6 experimental halls were built around the existing DESY laboratory in a cut-and-fill construction, Fig.1. A view of the periodic machine structure is shown in Fig.2 .

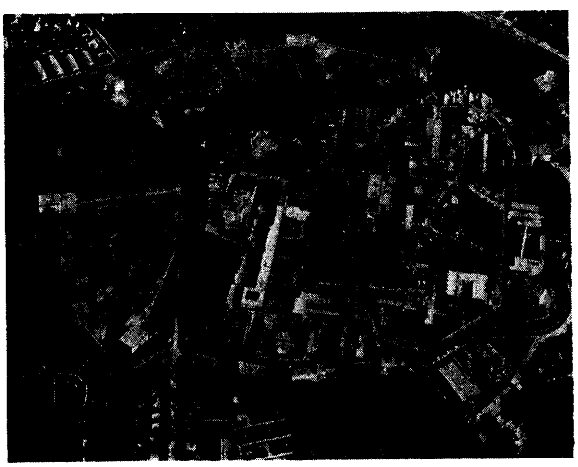

Fig. 1 Air view of the PETRA construction

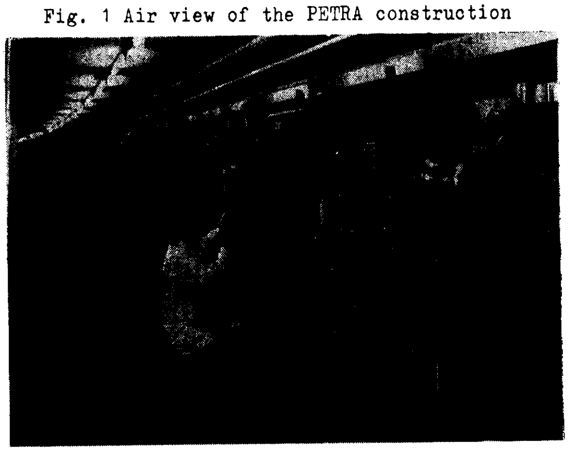

Fig. 2 Periodic machine structure

PETRA has four short straight sections (Fig.3) already equipped for experiments, two long straight sections with halls for future experiments, and two long straight sections now equipped with 32 rf accelerating units (Fig.4) that are driven by four transmitters at a total power of 4.5 MW.

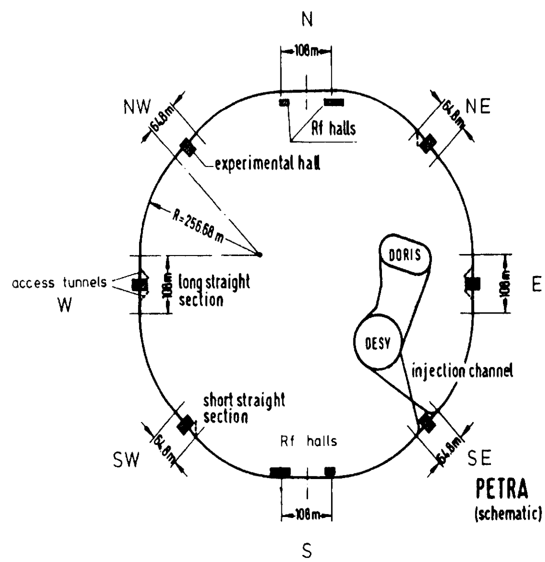

Fig.3 PETRA schematic

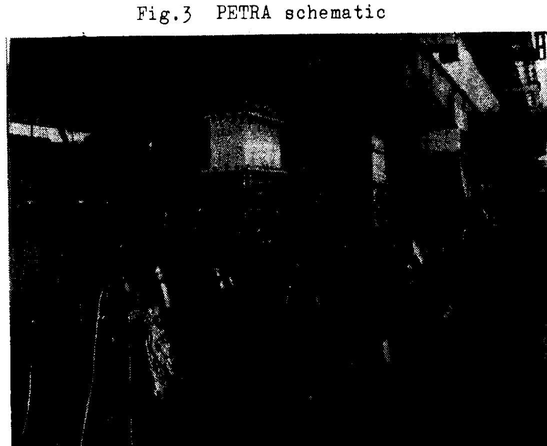

Fig.4 Rf cavity section

*W.Bothe,E.Dasskowski,D.Degèle,C.Dehne,A.Febel, H.Frese,H.Gerke,G.Hemmie,G.Hochweller,K.Holm,G.Horlitz,H.Kaiser,J.Kewisch,D.Kohaupt,R.Kose,J.Kouptsidis,W.Krechlock,W.Kriens,A.Krolzig,H.Kumpfert, M.Leneke,F.Loeffler,J.Mais,H.Musfeldt,H.Narciss, H.Nesemann,S.Pätzold,R.Pamperin,F.Peters,J.Peters, H.Pingel,A.Piwinski,W.Radloff,J.Rosbach,R.Rossmanith,F.Schwickert,K.Steffen,D.Trines,G.A.Voss, H.Wagner,K.Wille,S.Wolff,A.Wrulich,H.Wümpelmann

** PETRA has been described in several papers (1) (2)(3)(4) to which the reader may be referred.

Deutsches Elektronen-Synchrotron,DESY
Notkestr. 85 2000 Hamburg 52, Germany

0018-9499/79/0600-2970$00.75 © 1979 IEEE

The Commissioning of PETRA

On July 15,1978, electrons of 5 GeV energy were injected into the storage ring, and after several hours of component adjustment, were stably stored. During this first trial no sextupole circuits were energized and adjustment of quadrupole circuits was extremely critical. On July 18, after chromatic corrections had been applied and a coarse first turn orbit adjustment had been done, storage conditions had greatly improved. Two days later, on July 20, accumulation through repeated injection was observed and an average single bunch electron current of 3 mA was obtained (the maximum design single bunch current is 20 mA). At the end of July an electron beam was accelerated from the injection energy of 5 GeV to an energy of 11.11 GeV by ramping up all magnet currents. No major difficulties were encountered. At that time this energy was limited by the available rf accelerating voltage: Only two of four 1.2 MW transmitters and 16 of 64 accelerating cavities had been installed. But even those few could not be run up to full power because of insufficient vacuum conditions.

For positron injection the storage ring DORIS is needed as an intermediate positron accumulator(5). Until the end of August 1978 DORIS was used for investigating the Y and Y'-resonances, and until the beginning of September was not available for PETRA operation. By the middle of September first luminosity measurements at 2x5 GeV had been made. Values up $2\cdot10^{29}$ $cm^{-2}s^{-1}$ were observed. As part of the machine program various optics adjustments were tried out. Also the dependence of bunch length on bunch current was investigated.

The largest observed average single bunch current was 5 mA at that time. It was limited by a vertical single bunch instability. Since effects in the resonators were suspected, the decision was made to short-circuit 12 of the 16 installed rf cavities during a shutdown in October. This shutdown was also used to install 3 large particle detectors at three interaction points. But after resuming operation it was found that shortening the 12 accelerating units had made no observable effect on the current limit. With the remaining 4 active units, the maximum energy was 2 x 8.5 GeV, and most of the subsequent machine and physics runs were done at that energy. At the beginning of November it was discovered that the current limit was strongly influenced by the value of beta functions near the interaction regions. Increasing the vertical beta value from 15 cm to 100 cm at the interaction points and thereby decreasing the maximum beta values at the adjacent quadrupoles from 450m to 100m allowed an increase of the single bunch currents to 18 mA, which is 90% of the design value. It was also verified that, at higher energy, the desired 15 cm beta value at the interaction points could be restored without current loss by a subsequent change of optics.

Towards the end of the year, machine studies concentrated on investigation of beam-beam interactions. Luminosities of about $10^{30}cm^{-2}\ s^{-1}$ at 2 x 8.5 GeV were observed.

Time was given to the 3 experimental groups for checking out their detectors, which are shown in Figs. 5,6 and 7, and first high energy physics runs were made. By the end of January, three high energy physics papers had been published giving values for the multihadron production cross sections at center of mass energies of 13 and 17 GeV, analysis of the jet structures at high energies, new limits for the validity of q.e.d. and describing first observations of hadron production by photon-photon collisions.

Fig. 5 PLUTO detector during assembly

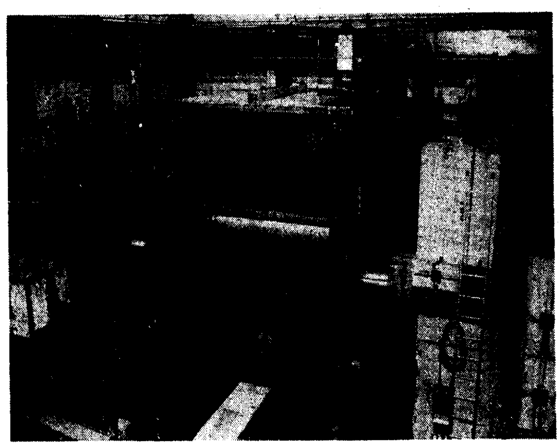

Fig. 6 TASSO detector during assembly

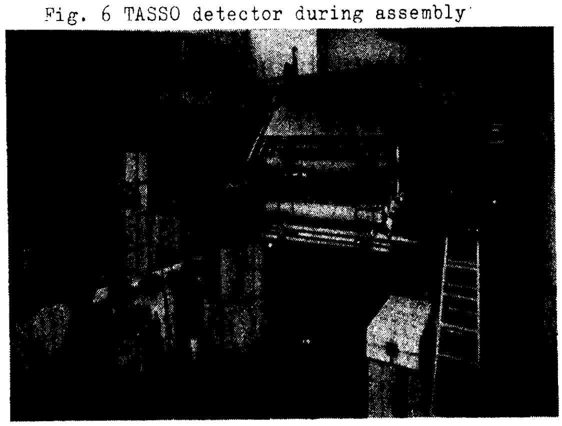

Fig. 7 MARK J detector during assembly

At the beginning of February PETRA was shut down for 4 weeks. During this period the new accumulation storage ring PIA (6) was installed, which after its commissioning later in 1979 will free DORIS for colliding beam physics again. Also the shorts in the 12 accelerating units were removed and another 16 units were installed. This together with the commissioning of the other 2 transmitters increased the available rf voltage to 70% of the design value and the maximum beam energy to more than 17 GeV. The fourth experimental detector was also installed during this shutdown, and 4 interaction regions are now equipped with particle detectors for colliding beam physics.

After resuming operation in the first week of March, single beam energies of 14 GeV were reached in PETRA.

Performance of machine optics

In order to obtain maximum luminosity in the space charge limited region it is important to maintain the maximum possible beam emittance at all energies. This can be accomplished in PETRA by varying the beam optics. Three different tunes have been tried out and found to work satisfactorily. All three tunes had values of the beta function at the interaction points of β_z = 15cm and β_x = 2.5m, but the focussing conditions in the normal structure were very different: The Q values varied between 17 and 25 and consequently the beam emittance changed by a factor of 10. In all three tunes the stable beam acceptance was found to be larger than the minimum desired value of 10 π mm mrad. The observed beam acceptances, on the other hand, were considerably smaller than the values predicted by tracking programs (7).

When the values of the beta functions at the interaction points were varied from β_z = 15cm to β_z = 100 cm and β_x = 2.5 m to β_x = 12.5 m a large increase in machine acceptance was observed. As a result of this it was decided to use a beam optics with large beta values at the interaction points for injection and to change the beta values subsequently.

Another method for emittance control is the variation of damping partition. This can easily be done by a small change in orbit radius through variation of the rf frequency. Fig. 8 shows the observed bunch dimensions as functions of acceleration frequency. This control of beam emittance was successfully used in the colliding beam physics runs: While the beams slowly decayed,

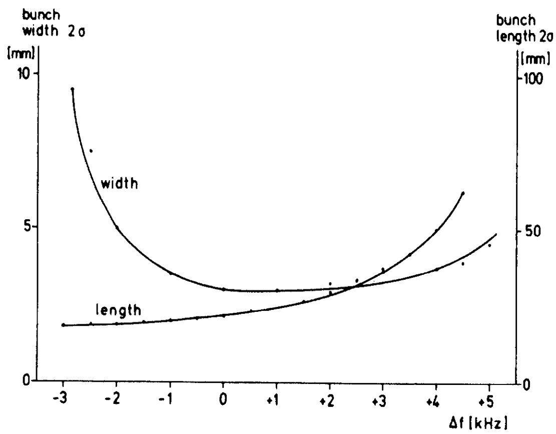

Fig.8 Bunch dimensions as functions of acceleration frequency

beam sizes could be readjusted so as to stay close to the space charge limit.

Orbit corrections for a new optical tune are typically made on the first turn, using the 112 beam position monitors and 32 screens which can be moved into the beam. The resulting orbits typically have position errors of Δx_{rms} = 6 mm. Initial application of a subsequent correction program using the orbit measurements of the stored beam reduced these values to Δx_{rms} = 2.9 mm. Work continues on further improving this correction method.

Single bunch phenomena

As already mentioned, the present current limit of 18 mA/bunch seems to be given by a vertical instability of a new kind: When approaching the limit, the bunch height increases, and then the beam blows up statistically. This is not a standard head tail instability of fundamental or higher modes, since it seems to be unaffected by chromaticity and transverse feedback systems. But it is clearly a single bunch phenomenon since smaller bunches in neighbouring buckets are unaffected. Current limits are strongly influenced by the beta function values close to the interaction points. But with values as high as 18 mA these instabilities do not limit the performance of PETRA at present.

Bunch length measurements with a fast photo diode show a surprizingly small dependance on single bunch current (8). At the injection energy of 6.5 GeV the bunch length typically increases from 3.6cm at small currents to 6.9 cm at 18 mA. Although at bunch lengths of W_{fwhh} = 6.9 cm peak currents are larger than 450 Amp, overheating of vacuum components due to higher mode excitation has not been observed in any part of the structure.

Integral measurements of losses due to higher mode excitation show that these agree with expectations. A 7 mA bunch loses an energy of about 500 KeV/turn due to this effect (9).

A more detailed paper on single bunch phenomena will be found in these proceedings (8).

Injection performance

Injection into PETRA is from the DESY synchrotron at energies of 6.5 GeV. Single bunches of electrons are preaccelerated in the 50 MeV linac I and subsequently accelerated in DESY. Positrons are produced in pulse trains of 30 bunches and preaccelerated to 400 MeV in linac II. After acceleration in DESY to an energy of 2.2 GeV they are stored and accumulated in the storage ring DORIS. Single bunches with up to 10^{10} positrons/bunch are then ejected from DORIS at the rate of 1 to 2 Hz and reinjected in DESY. After acceleration to 6.5 GeV these single bunches are injected into PETRA. The intermediate storage in DORIS increases positron injection rates by a factor of 150 as compared to direct injection from linac II via DESY (5). Both electron and positron injection can be done in a pulse sharing sequence. The present positron injection rates in PETRA are 2.5 mA/min (1 mA = $4.8 \cdot 10^{10}$ particle/bunch), the electron injection rates are up to 10 mA/min.

In the original PETRA proposal it was assumed that between PETRA injection sequences DORIS would be available for colliding beam physics. But since the operation of DORIS at the presently most desirable energy of 2 x 5 GeV is rather complex and makes such a scheme difficult, a special intermediate storage ring PIA is under construction(6). After commissioning of this new small ring in the summer 1979, DORIS will be completely freed of the PETRA injection task.

Vacuum

Although the PETRA vacuum system was not baked out or gas discharge cleaned in situ, the vacuum improved rapidly over the last few months and reached an average pressure of about $2 \cdot 10^{-9}$ mbar while the beam life correspondingly increased to 10 hours. At 8.5 GeV, the pressure increase due to synchrotron radiation improved from $3 \cdot 10^{-9}$ mbar in October 1978 to $3 \cdot 10^{-10}$ mbar/mA in Feb.1979.

Beam-beam interaction and luminosity measurements

In the original proposal it was assumed that Q-shifts in both planes due to beam-beam interaction up to values of .06 would eventually be possible. The largest tune shifts per interaction point observed so far were .025 in the vertical plane and .03 in the horizontal plane, and work so far has been done with only two bunches in each beam instead of four. Consequently the luminosity which has been reached so far is still smaller than the design values: At 2x5 GeV the largest luminosity observed was about $2 \cdot 10^{29}$ cm^{-2}sec^{-1}. At 2x8.5 GeV, values of about 10^{30} cm^{-2} sec^{-1} were reached. For this, bunch currents of 2 to 3 mA were required, far less than the single bunch current capability of the machine allows.

The space charge limit manifested itself in a vertical blow-up of the weaker of the two currents resulting in a lower specific luminosity or in a reduced life time. The conditions which lead to such a beam-beam effect are still not well understood: There have been many instances where the space charge limits were even lower than the above mentioned numbers. A special paper with more detailed information on beam-beam observations in PETRA has been submitted to this conference (10).

Conclusion

With the exception of the observed space charge limits, PETRA corresponds in almost all other respects to expectations. Single bunch current limits and life times are already close to design values. Higher order mode losses are small and quite acceptable. The bunch lengthening effect has been surprisingly small. Conditions for colliding beam experiments - so far performed at center of mass energies of 13 and 17 GeV - seem to be satisfactory.

Acknowledgements

The authors are aware and gratefully acknowledge that many of their colleagues at DESY, at other laboratories and industry have essentially contributed to the PETRA project. Among the collaborating laboratories, they particularly thank the helpful groups at CERN, SLAC, Cornell Univ., TH. Aachen and GSI Darmstadt. They also acknowledge with pleasure the valuable contributions of H. Wiedemann during the initial design phase and of S. Kheifets and E. Messerschmid during later phases of the PETRA development.

References

(1) PETRA Proposal, DESY, November 1974

(2) PETRA Proposal, updated version DESY, Feb.1976

(3) G.A.Voss "The Electron-Positron Storage Ring PETRA, Plans and Status" IEEE Trans.Nucl.Sci. NS-24 No.3, 1842(1977)

(4) G.A.Voss "PETRA - Status Report", Proc. of the 10th Int.Conf. on High Energy Accelerators, Protvino (1977), p. 448

(5) A.Febel et al."PETRA-Injection-System", Proc. of the 10th Int. Conf. on High Energy Accelerators, Protvino (1977), p. 464

(6) A.Febel, G.Hemmie "PIA, The Positron Accumulator for the PETRA Injection", in these proceedings

(7) S.Kheifets, E.Messerschmid "Katalog von PETRA-Optiken" Int.Bericht DESY PET-77/18 Dec.1978

(8) R.D.Kohaupt "Single Beam Instabilities in PETRA" in these Proceedings

(9) M.Bassetti et al. "First Measurement of Parasitic Mode Losses in PETRA" DESY 79/07 January 1979

(10) A.Piwinski "Observation of Beam-Beam Effects in PETRA" in these Proceedings.