Surveying and Alignment Concept for the

Bonn Electron Stretcher Accelerator (ELSA)

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1. Introduction

The Bonn 2.5 GeV Electron Synchrotron which started operation in 1967 allowed research works in elementary particle physics. A small part of the operation time was given to users of synchrotron radiation, too. Most of the medium energy physics experiments, however, were working at reduced machine intensity because of accidental coincidence rate problems at the beam duty cycle of 5%.

Nearly two years ago the Bonn ELectron Stretcher Accelerator ELSA came into operation. It is the first continuous beam machine which provides electron beams between 0.5 and 3.5 GeV.

The Bonn accelerator assembly consists basically of three parts (Fig. 2):

1. In the Linac the electrons get a pre acceleration and gains an energy of 100 MeV.
2. As a booster for the stretcher serves the 2.5 GeV Synchrotron.
3. In connection with the crucial increase of the beam duty cycle this new accelerator ELSA allows a new generation of experiments with multiparticle final states (ALTHOFF et al. 1982), for instance.

Fig. 1 shows the structure and the layout of the ELSA-ring. The main part of ELSA is arranged into a concrete tunnel 5.5m below the ground surface (Fig. 2) while the particle physics has to be carried out in the existing experimental areas at the 2.5 GeV synchrotron and in the hall of the former 500 MeV synchrotron (closed down in 1984).

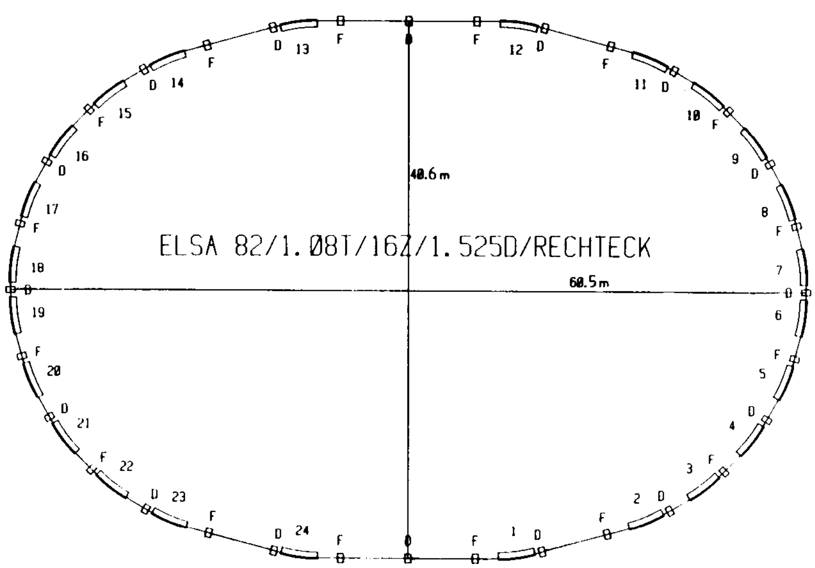

Fig. 1: Lattice of the ELectron Stretcher Accelerator (ELSA)

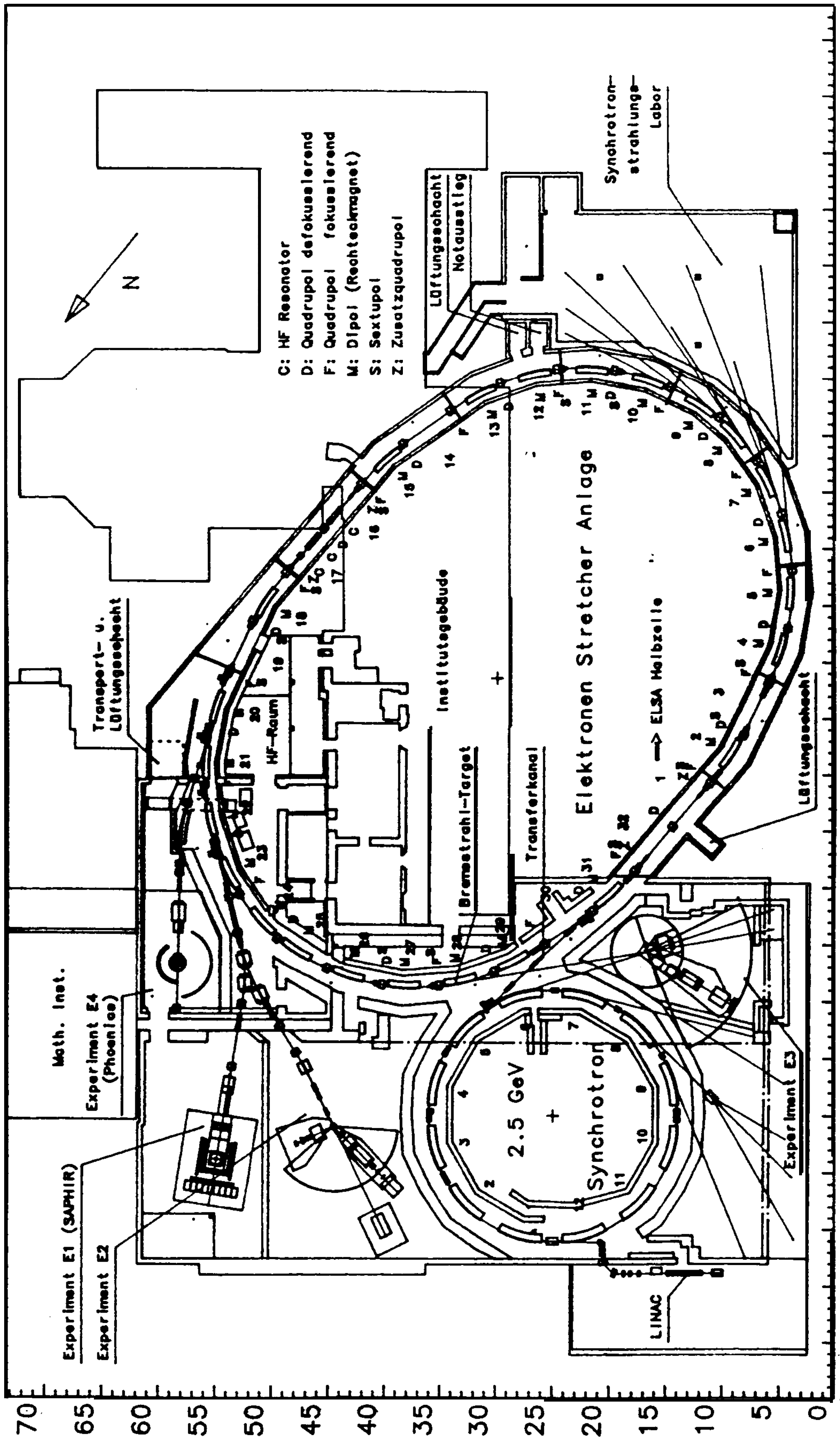

Fig. 2: Layout of the Bonn accelerator assembly

The ELSA ring is so configurated that the injected electrons per cycle will cover a distance of about 164.4 m. The stretcher accelerator shows in comparison with the 2.5 GeV ring a seperated function structure (Fig. 2), that means there are separated magnet components forming the closed orbit especially 24 main dipole magnets for the beam deflection and 32 main quadrupole magnets for beam focussing.

2. Accuracy requirements for adjustment the ELSA magnets

The assignment was to position the beforementioned magnet components with an high accuracy shown in Schedule 1. They were determined on the base of model calculations. The data related to the coordinate system S_b which slipped along the theoretical beam line opposite to the earth fixed system S_E (Fig. 3). Deviations from these requirements exercise an influence on the characteristic of the stretcher ring and the quality of the electron beam.

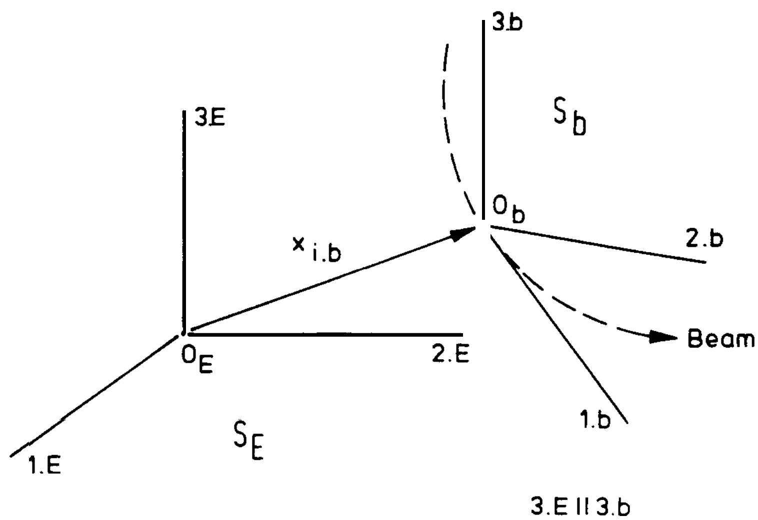

Fig. 3: Local coordinate system S_b in which axis 1.b shows in beam direction (in the area of the drifting length) resp. pointed tangential to the beam (in the area of the dipole magnets)

Element	Degree of accuracy σ of the linear deviation in direction of	rotary deviation relating to
Dipole magnet	Axis 1.b: ± 0.5 mm Axis 2.b: ± 1.0 mm Axis 3.b: ± 1.0 mm	Axis 1.b: < 2 mrad Axis 2.b: < 2 mrad Axis 3.b: ± 0.5 mrad
Quadrupole magnet	Axis 1.b: < 3 mm Axis 2.b: ± 0.2 mm Axis 3.b: ± 0.2 mm	Axis 1.b: ± 0.3 mrad Axis 2.b: ± 0.3 mrad Axis 3.b: ± 0.3 mrad

Schedule 1: Grouping the accuracy requirements

These specifications correspond to the criteria of accuracy which LÖFFLER (1982) gives for the storage rings of DESY/Hamburg. Schedule 1 shows that the positioning of the quadrupoles generally were more critical than those of the dipoles. That is small wonder because the quadrupole were comparable to lenses in geometric optics. Therefore the electrons should "see" a magnetic field of 0 Tesla when they pass a quadrupole. This case is given for the axis of the magnet otherwise the electrons will find a magnetic field which grows up with 0.01 T/mm linear with the distance from this axis.

3. Measuring concept

Concerning with the explanations of Ch.2 a surveying and alignment concept had been developed to position the ELSA magnets in height and plane. The measurements of the heights were ensued with geometric levelling. On the occasion different levels were used within the scope of the measuring works, for example the precise bubble level WILD N3 or the compensator level KERN GK-2A. Two specialities of the N3 are, that it is free of magnetic field influences and can be used in high precision levelling with short distances. In the following only the plane measurements will be described. Three basic requirements were important for the surveying and alignment concept:

1. To know the "optical" properties of an accelerator exactly it is necessary to get informations about the magnetical properties of a magnet element like the quality of the magnetic field, position of the magnetic axis etc. Therefore a magnetic field measurement of all magnets have to be done. This demand was not followed at the Bonn Physical Institute, rather a sample of 5 elements per type of magnets got an magnetic field investigation (KRAUSS 1986, ZIMMER 1986). Also no connections were found to the geodetic reference marks at the top of the magnet elements.

2. The mechanical dimension of the quadrupole lengths (in direction of axis 1.b) can be measured very bad because the assembling of the four magnet sectors shows tolerances til l-2 mm and the influences to the magnetic field is unknown. In this connection another important condition was that the quadrupoles weren't moveable in direction of axis 1.b.

3. For precise distance measurements there (normally) were available to the author only the KERN 1m-invar base rod or steel rods with a maximum length of 4.05 m. Later it was possible to use the MEKOMETER 5000 of the RWTH Aachen.

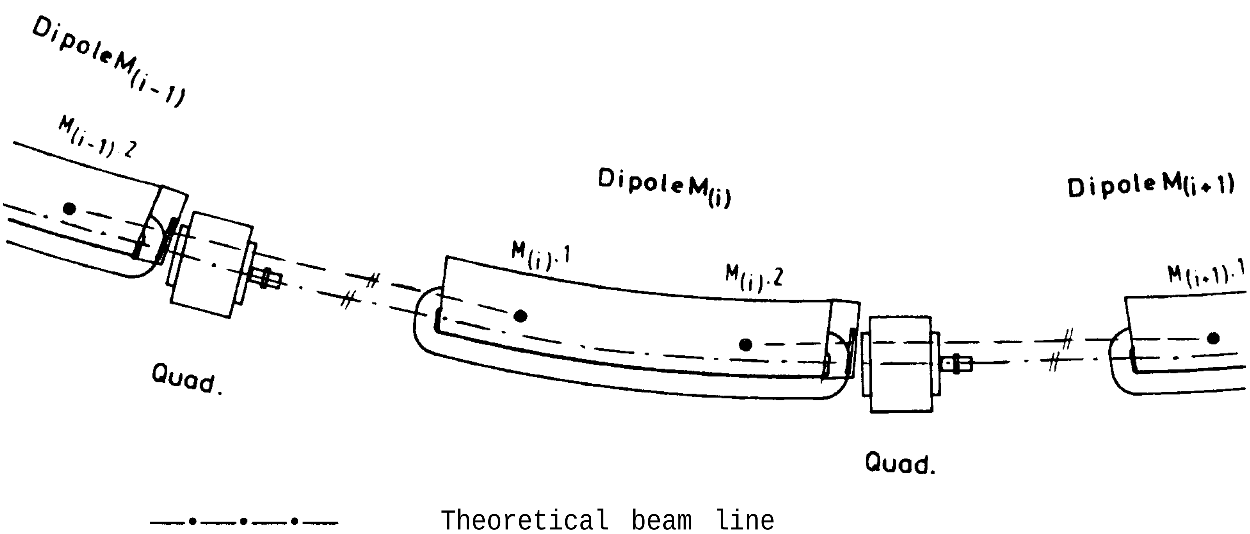

Fig. 4.a: Adjustment of the quadrupole from the connetion line $M_{(i)}.2$-$M_{(i+1)}.1$

Therefore the strategy in quadrupole adjusting was to align each element between two dipols (SCHAUEKTE 1989). Fig. 4a presents the concept assuming the reference points $M_{(i)}$.2 and $M_{(i+1)}$.1 at the top of the dipoles were placed in their computed position. In this case the quadrupole axis is placed parallel to the connection line $M_{(i)}$.2- $M_{(i+1)}$.1. Compared to the requirements of Schedule 1 the dipoles had to be positioned with a lower accuracy than the quadrupoles. When the lower accuracy were adhered you will obtain the situation in Fig. 4b. Getting small deviations q_1 and q_2 (the nominal values were obtained in connection with transformation calculations) a special device is mounted in respect to the reference planes at the top of the quadrupoles. The mechanical construction of this device guarantees that the targets $Q_{(j)}$.1 and $Q_{(j)}$.2 come into a parallel position relating to the nominal beam line.

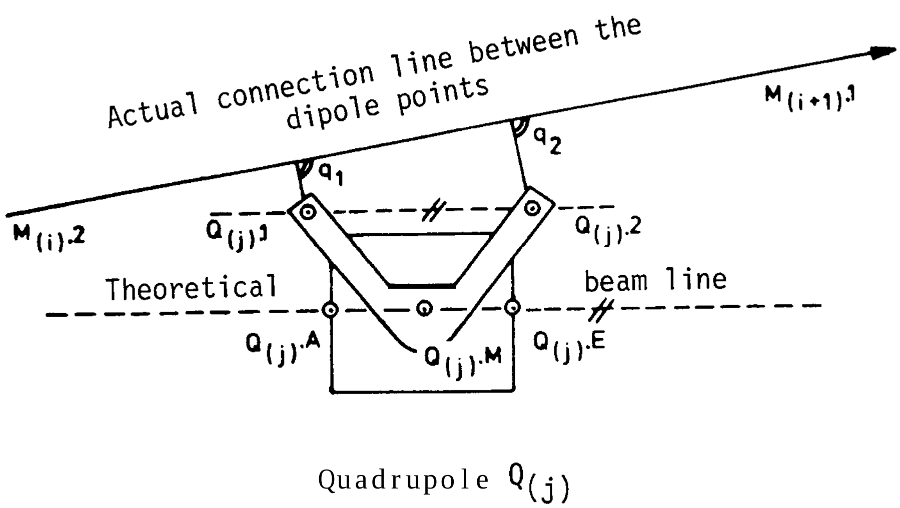

Fig. 4.b: Adjustment of the quadrupole from the connection line $M_{(i)}$.2-$M_{(i+1)}$.1

But the positions of the reference points $M_{(i)}$.2 and $M_{(i+1)}$.1 must be well known with a better or same precision as this is valid for the quadrupol adjustment. For that a narrow ring network in the ELSA-tunnel (Fig. 5) was measured, at which also marked points at the tunnel floor were used besides the reference points at the dipoles. The measurements ensued with a theodolite WILD T2000S, a KERN Mekometer 5000 and a KERN 1m-invar base rod.

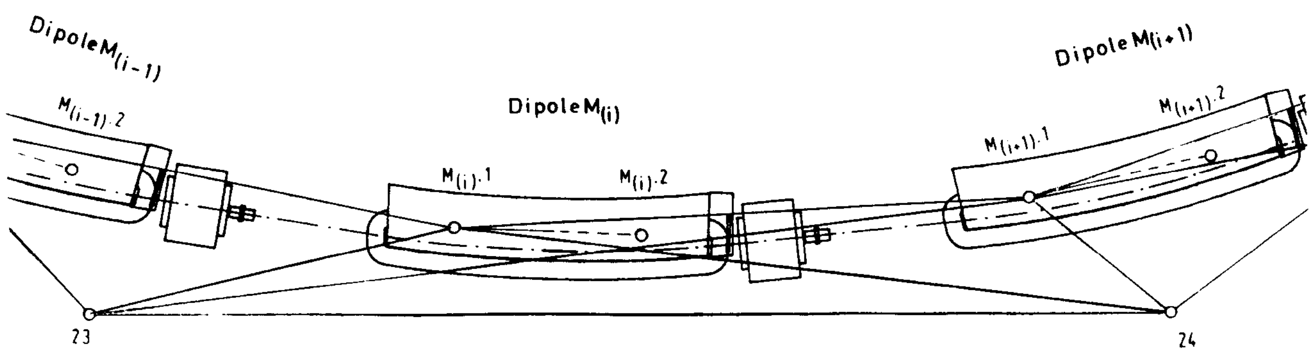

Fig. **5** : Section of the ring network

4. Results of the adjustments

Schedule 2 contains the results of a 2D-adjustment calculated with the PAN program (GEOTEC 1985). It shows that in the whole the handicaps of Schedule 1 were accomplished:

1. the coordinate differences dy, dx (refered to the local ELSA coordinate system) give an information over the pre-adjustment of the dipoles;
2. the standard deviations sy, sx give an information relating to the accuracy of the measured point positions.

Dipol point	Y [m]	X [m]	dy [MM]	dx [MM]	sy [MM]	sx [MM]
10.1	1089.6339	1015.6744	0.45	-0.55	0.09	0.11
11.1	1090.7711	1020.6387	0.24	-0.29	0.09	0.10
12.1	1090.5849	1025.7283	0.14	-0.59	0.10	0.15
13.1	1089.0879	1030.5971	0.35	0.00	0.10	0.12
15.1	1083.4697	1039.1434	-0.15	0.04	0.11	0.11
18.1	1071.0407	1050.0325	0.16	0.16	0.10	0.11
20.1	1061.9012	1054.6259	0.07	0.40	0.11	0.10
21.1	1056.9369	1055.7632	-0.28	0.16	0.10	0.08
22.1	1051.8477	1055.5767	-0.27	-0.34	0.10	0.08
23.1	1046.9791	1054.0797	-0.06	-0.02	0.09	0.08

Schedule 2: Extraction of the 2D-adjustment results

After carrying out the adjustment of the quadrupoles in a separate control measurement their actual positions were investigated in respect to the nominal positions. For that purpose a ring polygon was measured over the quadrupole points $Q_{(j)}$.M. The results were shown in Fig. 7.

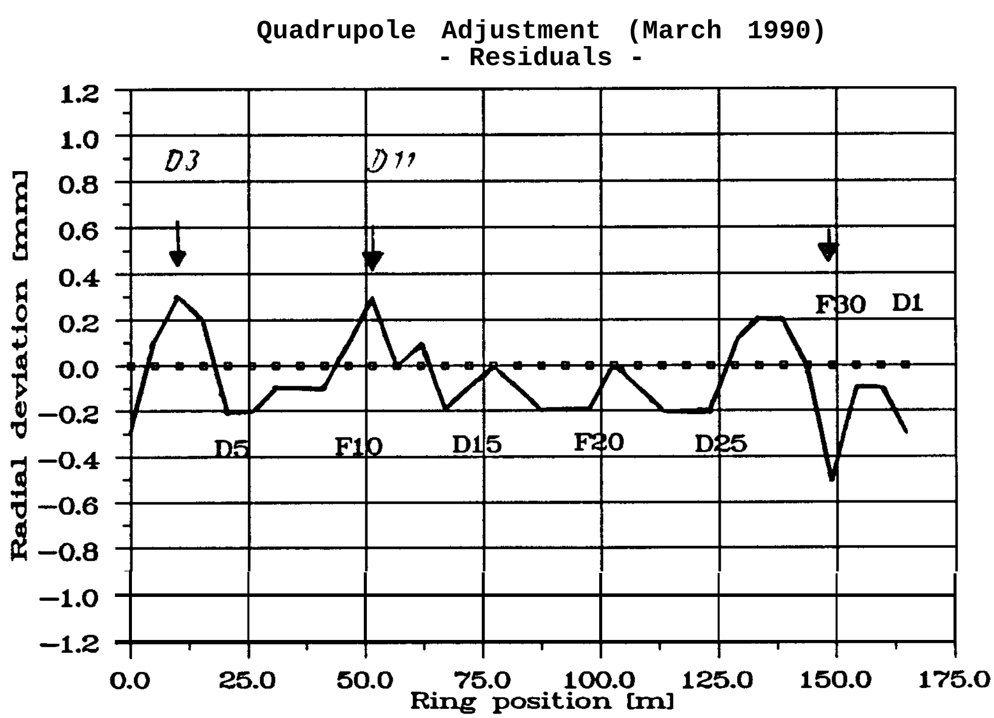

Fig. 7: Residuals of the control measurement

When you leave out of consideration the difference at quadrupole D3, D11 and F30 generally all deviation were ≤ 0.2 mm. You will find pausible interpretations for these differences. For example Quadrupole F30 is built up in the area of the injection beam line where a lot of impairments like air turbulences, barriers near the line of sighting etc. will influence the single line of the ring polygon. In these cases only a (redundant) measuring method (for example shown in Fig. 7) gives sufficient informations whether single observations will be outliers.

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