A NEW STANDARD METHOD FOR THE SURVEYING AND ALIGNMENT OF BEAMLINE FACILITIES AT GSI

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1. INTRODUCTION

The GSI institute of heavy ion research is financed by the country of Germany and the federal state of Hessen. Founded in 1969, the main emphasis of the institue's work is the research of the characteristics of atomic nuclei. The Universal Linear Accelerator UNILAC was built first and in 1987 new facilities were added to the setup. Today the GSI consists of the following beam-line modules:

- Universal Linear Accelerator UNILAC — Length: 120 m
- Heavy Ion Synchrotron SIS — Circumference: 216 m
- Fragment Seperator FRS — Length: 70 m
- Experimental Storage Ring ESR — Circumference: 108 m
- Experimental Caves (A,B,C, M, ...)

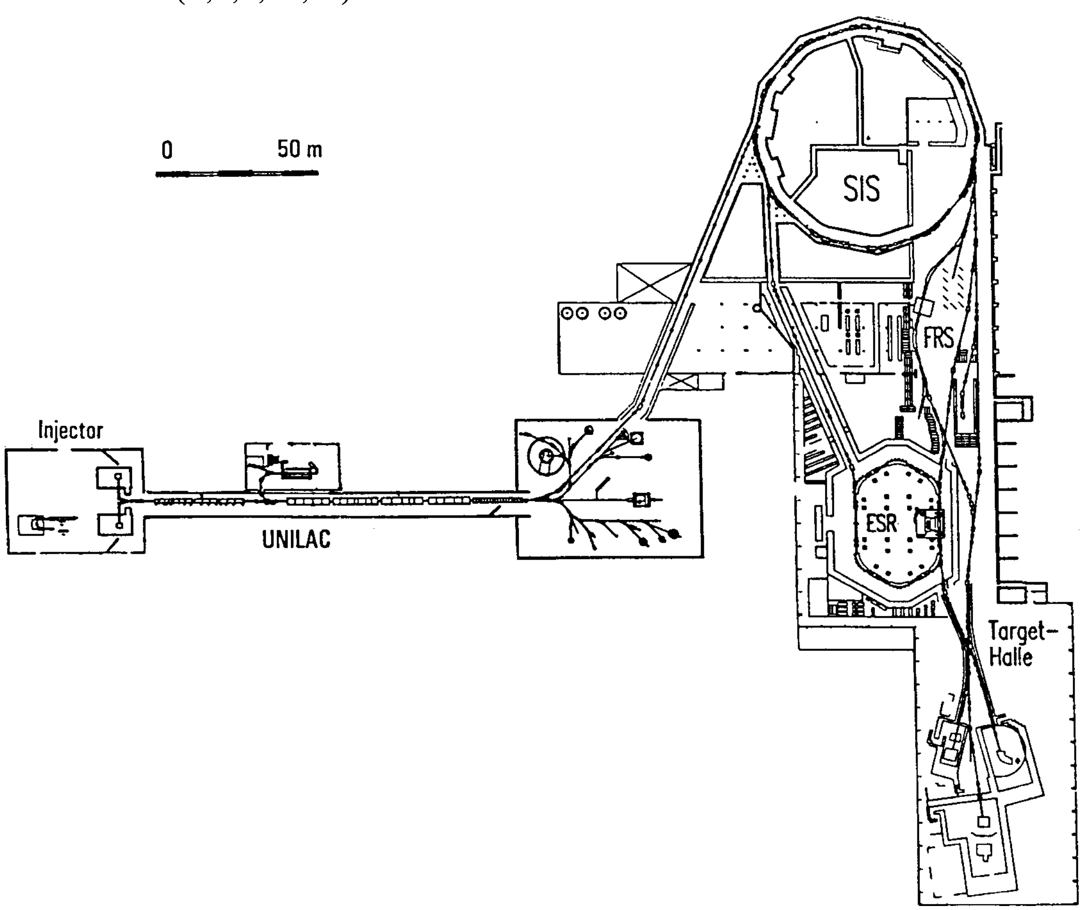

Fig. 1: GSI Accelerator Facilities and Experimental Areas

The GSI accelerators allow acceleration of all atomic nuclei up to Uranium to an energy of 20 MeV/u. The latest success has been the discovery of the fundamental elements 110 and 111 in November/December of 1994. GSI is planning to start a small medical center for the treatment of cancer tumours based on heavy ion radiation in 1996.

From 1986 to 1991 Mr. Ingobert Schmadel carried out all survey and alignment tasks at the GSI. In 1991 he set up his own company, Metronom, a service company for industrial measurements. Since 1991 Metronom has been partner to the GSI for all high-precision surveying tasks, namely developing concepts, surveying experiments and aligning components (in total about 350 components must repeatedly be aligned).

2. THE FIRST ALIGNMENT CONCEPT

Previous alignment tasks were solved by measuring fixed reference networks defined by concrete pillars or monuments. After the coordination of reference points, the components were aligned using the intersection method. The sensor equipment consisted of the laser range finder Kern ME5000, the ECDS System (Kern E2i theodolites), scale-bars, Wild N3 and other tools for levelling and tilt measurements.

No special software structure was used for processing the measurement data. Each step in the data reduction and preprocessing up to the least square adjustment were carried out with no special hand-in-hand working programs. The adjustment was done with the program PANDA (GEOTEC).

Another important point of interest was the fiducialization of components. Most components are equipped with screws, which are building supports for mobile plates. In the past, the alignment staff had to fit out the components with mobile plates before they could start their measurements. This was extremely time-intensive and precision and reliability was dependent on the degree of care the staff put into their work. For more details see [1] and [2].

Unfortunately, surveying experts were not consulted right from the start of the project; the conditions they had to cope with when they started working were thus very unsatisfactory.

3. STATUS OF ALIGNMENT

The first alignments of the Synchrotron SIS and the Experimental Storage Ring ESR were carried out in 1990 and 1991; to date no realignment has been performed. But now, five years later, a realignment is necessary, as due to the settlement of the ground the components have moved off there original positions. The changes in height have been detected by annual settlement and deformation measurements. Ground movements of up to 3 mm have been determined.

In the case of the SIS, the curve in ground settlements is declining. No more concrete blocks for radiation protection have been added to the building and the height of the accelerator building is now stable; the right time for realigning the components has been reached.

The ESR is under reconstruction and when the new installation is finished, a realignment will be necessary. In addition to this the entire ring, built on separate foundations, has been tilted by ground movements. Differences in height of up to 2.5 mm between two towards points have been determined.

The same problems apply to other parts of the accelerator, so the GSI has to check the positioning of all of their accelerator components. Unfortunately, the method used for the first alignment can not be used anymore, because most of the lines of sight are interrupted by cables, walls and other installations such as pumps or electronic devices. Furthermore, the survey procedures would take too long. The original process of alignment, e.g. installing and handling of the mobile plates, the setup of the instrumentation (including orientation measurements), alignment without special software, etc. was too time-consuming and toilsome.

In 1993 Metronom started working on a new alignment concept for the GSI's accelerators. The aim of the concept was to improve the whole strategy of surveying and alignment and had to meet the following requirements:

- No use of concrete pillars (to improve flexibility)
- No mobile plates (to improve reliability and to put an end to climbing on components!)
- No use of ECDS (personnel reduction of one operator)
- No special solutions for individual parts of the accelerators (one method for all)
- No measuring heights of 3.5 m (to avoid the dangerous use of ladders and to speed up the procedure)
- No data-processing with special "expert system programs" without defined user-shells
- No mixture of different centering supports (Kern, Taylor-Hobson, specific solutions)

4. THE TASA CONCEPT

4.1 Basic Philosophy

Taking the requirements mentioned above into account, Metronom has developed the TASA Concept. TASA stands for Tacheometric Accelerator Surveying and Alignment and is based on the new generation of high-precision total stations.

The basic principle of positioning components by polar measurements is neither a new nor an inventive idea. This method has been used by CERN and DESY for several years, but the exclusive use of only one sensor for all measurements, combined with a comprehensive installation of new consoles and software produces a very flexible method.

In the past, the unhomogeneous precision of angle and distance measurements has been compensated by special configurations. Normally there is a difference in the requirements for accuracy in longitudinal and transversal (resp. radial) direction. A typical accuracy for longitudinal alignments is about 0.5 mm, whereas a transversal alignment has to achieve a precision of 0.1 mm and is much more critical. Polar measurements can be used if the precision of the distance measurements affect the longitudinal direction and the precision of angle measurements affect much more the transversal direction. Consequently, the lines of sight, or rather the distance measurements have to follow the beam-line to meet the specifications.

4.2 Total Station

In 1993 the decision was made to use the total station Leica TC2002 for surveying and alignment. At this time, a precision of 0.4 mm for distance measurements was expected and this precision has determined the development of the concept. The latest tests on and calibrations of a new and specially selected TC2002 have confirmed that this was the right decision. Up to a distance of 25 m the TC2002 reaches a standard deviation of 0.06 mm (!) and a maximum residual of 0.15 mm for distance measurements in comparison to interferometer measurements.

Due to the extremely high accuracy of distances measured by the TC2002, the instrument can be used for the determination of the reference network instead of the ME5000. Furthermore, it is possible to reduce the requirements on the configuration (parallel to the beam-line), as the influence of the distance accuracy is less critical. In order to reach the high precision of distance measurements it is necessary to take the changes of atmosphere into consideration, which will be consequently done by using an electronical sensor to record the actual temperature, pressure and humidity. Another condition is the employment of high-grade triple-prisms, especially calibrated to the distance-meter.

4.3 Fiducial Points

One feature included in the TASA Concept, has been the replacement of all mobile plates by fixed consoles. In the past, the fiducialization was done by fixing plates to the top of each component. The fiducial points were signalized by Taylor-Hobson spheres. Before a component was installed on site into the beam-line, the mobile plates were adjusted in accordance with the beam line and by taking the magnetic deviations of the component into account. Previously, the fiducial points were always on the top of the component in a fixed position and the surveying and alignment process had to be able to align the component using the above fiducial points. In many cases this was very painstaking. For example, the height of the beam-line of the ESR is about 2 m above the floor; in addition to this, the height of the fiducial points above the beam-line is about 1 m. Consequently, all measurements had to be carried out at a height of at least 3 m.

An immense advantage of the new fixed consoles, welded onto every component, is that they can be positioned to locations where they can be easily measured, simply by taking measuring conditions (lines of sight, heights of stands, error-figures, configuration, etc.) into consideration.

Each component will be equipped with two fixed consoles (e.g. on the side) carrying a support for a Taylor-Hobson sphere and a socket for an inclinometer. After the installation of the new consoles a transfer measurement will be required to determine the nominal positions of the new fiducial points. For this measurement the ECDS System will be used. Based on the nominal coordinates of the new fiducial points the alignment of a component can be done using the TASA Concept.

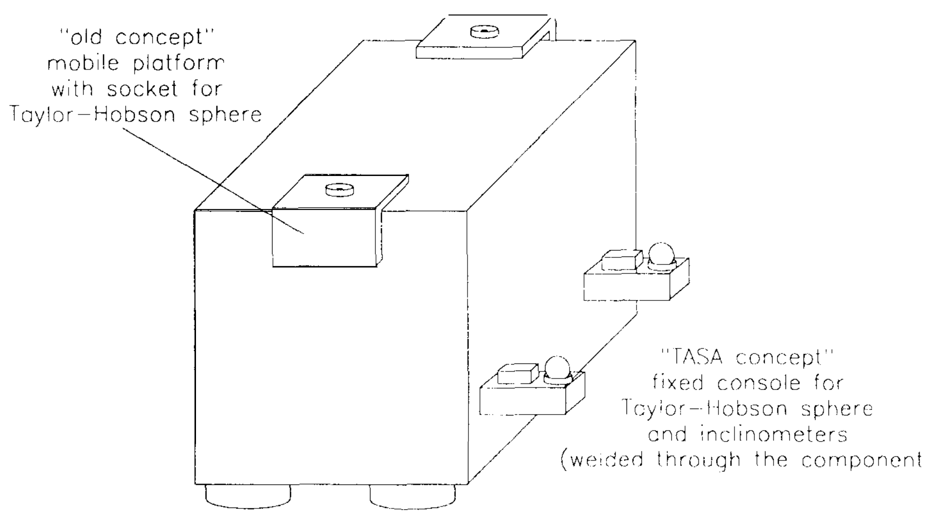

Fig. 2: Fiducialization

4.4 Tilt Measurements

The inclinometers are necessary to control the roll (transversal tilt) of the component; the pitch (longitudinal tilt) will be controlled by the difference in height of the two fiducial marks. In previous alignments the tilts were controlled by conventional levelling or analog inclinometers fixed directly to the fin of the magnets. The TASA consoles provide three little spheres (welded on screws) with which an electronic inclinometer (coupled through a V-prism) can be fixed to the consoles. This makes the operation of tilt measurements extremely comfortable.

4.5 Pillars

The new fiducial points allow different measuring conditions. Heavy and high concrete monuments can be replaced by mobile pillars. DESY has developed a system of mobile pillars which can be installed for a measuring period. Based on DESY's positive experience with these pillars GSI has also adopted this system. The DESY pillar consists of a tube of steel or aluminum of 1.5-1.7 m in length. The pillar is inserted into a special socket fixed to the floor. The measuring point is the midpoint of a Taylor-Hobson sphere put into a socket on the top of the pillar. For further information see [4].

4.6 The Centering Method

Furthermore, the centering of the instrumentation has been changed from the Kern centering method to one based on Taylor-Hobson spheres, using an adaptor - created by DESY - between the Kern support and the Taylor-Hobson socket. Consequently, the Taylor-Hobson sphere is the only target for all angle and distance measurements; no other prisms or targets are required.

4.7 The Software

Another important element is the data processing which is involved in the alignment procedure. To improve the alignment strategy it is imperative that different computer programs are used. The GSI has decided to develop a complete new software package for the different tasks of surveying and alignment. This package should be programmed to enable unskilled employees to operate it and should support all steps of the procedure. For further information, see the contribution "Wirth H., Moritz G.: The Most Flexible Instrumentation for Surveying and Alignment - a High Precision Total Station Controlled by Modem Software", published in the proceedings of this workshop.

5. SCENARIO OF TASA ALIGNMENT

- Unique transfer measurements from "top-points" to "side-points" to establish new nominal coordinates
- Installation of all reference points through mobile pillars
- Carrying out of reference network measurements with redundant angle and distance measurements (originally planned with E2 and ME5000, now only TC2002)
- Least square adjustment of the network
- Tacheometric alignment of the components using the TC2002, an electronic atmosphere sensor and two inclinometers
- To control the alignment, all fiducial points will be determined a second time using a different reference point

6. TASA AT THE EXPERIMENTAL STORAGE RING ESR

The Experimental Storage Ring will be the first area of the GSI accelerators to be realigned. As an example, the transfer of the concept from theory to practice will be shown. The ESR consists of the following components:

24 dipole-segments (4 segments build one 60°-dipole)
20 quadrupoles
8 sextupoles
24 special devices (septa, solenoids, electron-cooler, kicker, inflectors, etc.)

Table 1: Assumed requirements for the alignment of ESR components:

Component	longitudinal [mm]	transversal [mm]	vertical [mm]	pitch [mrad]	yaw [mrad]
dipol	0.5	0.3	0.3	0.1	0.1
septa	0.5	0.2	0.3	0.1	0.1
quadrupole	0.5	0.1	0.1	0.1	0.1
sextupole	0.5	0.1	0.1	0.1	0.1

A network of 14 pillars will be installed in order to construct a stable network and to place a basis for all alignments at the user's disposal. Unfortunately it is no longer possible to measure diagonals, as all lines of sight are lost. The only way to build a safe and reliable network configuration is to measure overlapping transverses (fig. 3). Simulation calculations have shown that the requirements of the precision and reliability for the reference and magnet points can be met.

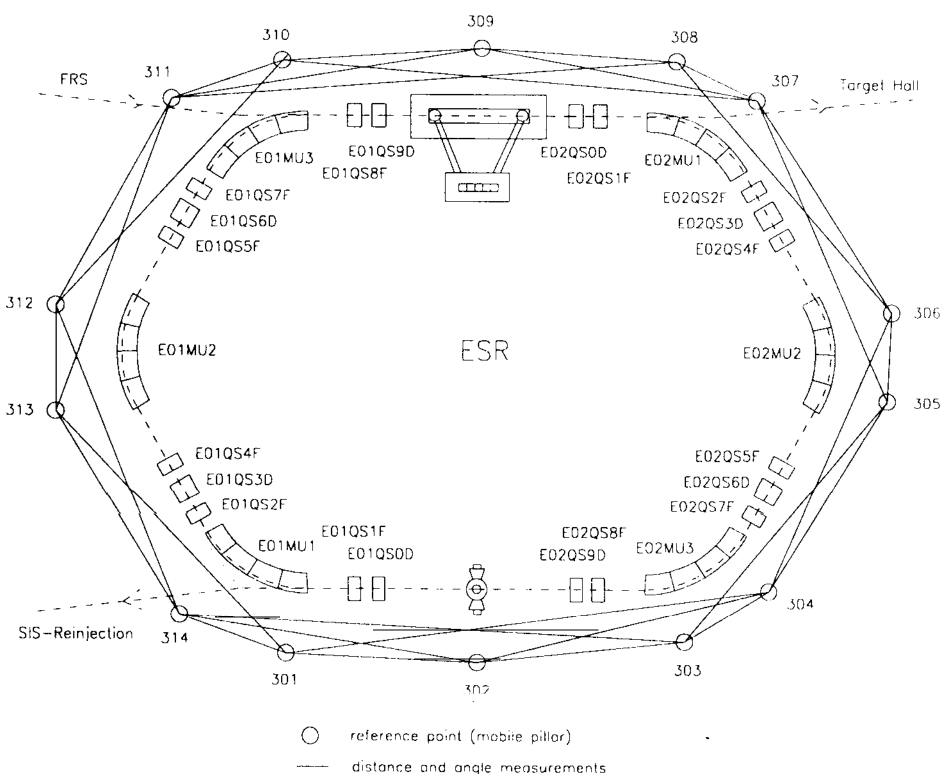

Fig. 3: The ESR reference network

Based on an estimated accuracy of 0.4 mm for distance measurements and 0.3 mgon for angle measurements the concept for the ring alignment was created. The idea of the first concept was to align the dipoles with the intersection method based on two reference stations at each corner of the ring to cope with the required accuracy in a beam direction of 0.2 mm. The design acknowledged that the distance accuracy permits configurations where the distances directly affect the transversal or radial direction by planning lines of sight parallel to the beam-line (fig. 4). Due to this, the transversal positioning will be greatly affected by the precision of angle measurements.

After the latest calibration of the new TC2002 the concept was revised. With an accuracy of 0.1 mm for distances, it will be possible to abandon the idea of using the intersection method for the dipole alignment. All components can be positioned using the same method; that is the final aim of the new concept.

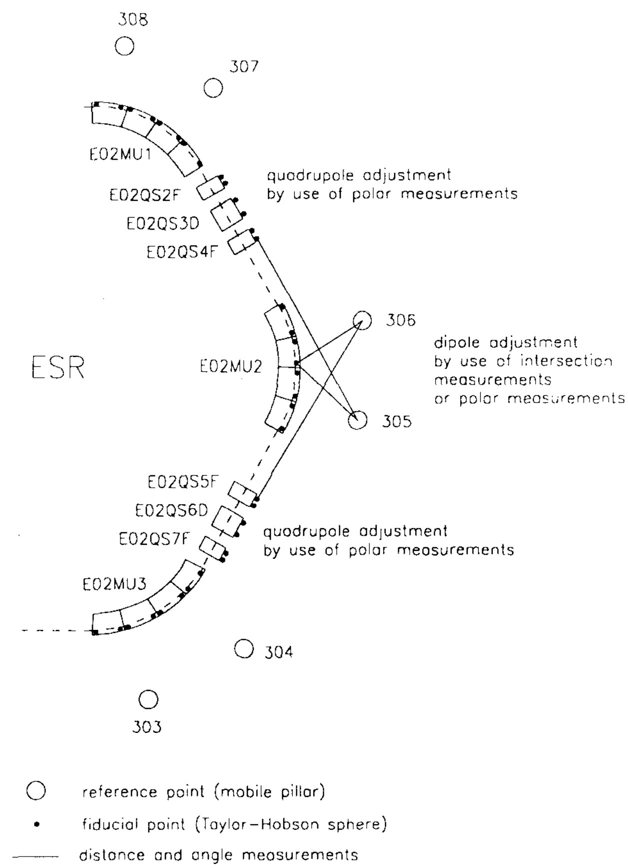

Fig. 4: Alignment setup for ESR components

The new dipoles and septa consoles were welded onto the top comer of each component. In this case an installation on the sides of the magnets was not possible, because other beam-line components (e.g. inflector magnets) are positioned in front of the dipoles and the sides are hidden. The quadrupoles, sextupoles and other components were equipped with consoles on their sides. The transfer measurement to determine new nominal coordinates is now being carried out. The pillars will be installed in November 1995 and the realignment of the ESR will take place at the end of the year.

7. CONCLUSION

The TASA Concept can be used for all alignments of the different GSI accelerators. For all accelerators a special investigation was carried out to check if it is possible to position a new pillar system and to install new consoles on the components. The free positioning of ficucial points makes it possible to use polar measurements for all components. This is an enormous advantage and a step forward for alignment procedures at GSI. Furthermore, use of a total station as opposed to the ECDS System means that one operator less is needed.

Although an older method existed and was practiced, the GSI has decided to abandon their alignment concept for a newer system. The time necessary for the alignment of an accelerator can be decreased by up to 50% using modem instrumentation and software.

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