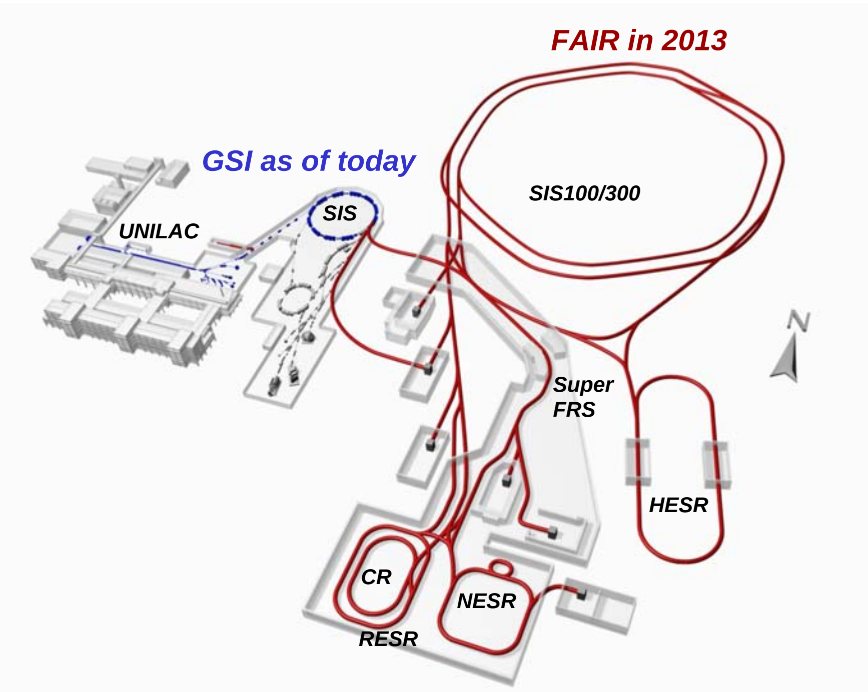
A HIGH-PRECISION SURVEY AND ALIGNMENT SYSTEM IN INACCESSIBLE, HIGH-RADIATION AREAS OF FAIR: FUNDAMENTAL IDEAS

Ina Pschorn, GSI, Planckstr. 1, 64291 Darmstadt, Germany
Andreas Marbs, i3mainz, Holzstr. 36, 55116 Mainz, Germany

1. INTRODUCTION

After commissioning of FAIR – a new Facility of Antiproton and Ion Research, which had been proposed by the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt / Germany and received the support of the German Ministry for Education and Research in February 2003 – personnel admittance to specific areas for routine maintenance, and consequently for survey and alignment, will not longer be possible due to the very high radiation level.

This high-radiation environment as well as the stretched, non-linear geometry of a magnet sequence with dimensions up to 50 m prohibits the use of well-established stationary monitoring systems. Thus, a new concept for an automated, remote-controlled surveying and alignment system has to be designed. Preliminary ideas could be paraphrased as *alignment on the fly*. That means combining photogrammetric elements on a movable mechanical device with complex evaluation software and remotely controlled positioning elements.



Improvements
- *Primary beam intensities: Factor 100 – 1000*
- *Secondary beam intensities for radioactive nuclei: up to a factor 10000*
- *Ion energy: Factor 15*

Special Properties
- *Intensive cooled radioactive ion beams*
- *Cooled Antiproton beams with up to 15 GeV*
- *Internal targets for experiments of high luminosity in rings*

New Technologies
- *Fast pulsed superconducting magnets*
- *Electron cooling at high ion beam intensities and energies*
- *Fast stochastic cooling*

Fig. 1: Present and future facilities of GSI

2. THE GSI FUTURE PROJECT "FAIR"

Main item of FAIR, the intended new accelerator facility at GSI site, is the new large dual superconducting synchrotron SIS 100/300 with a currently planned circumference of 1190 m. The two separate accelerator rings will be installed in the same tunnel, which will be built below ground for reasons of ecology and radiation protection. The other associated storage rings and experimental plants will be arranged above ground [1]. An overview of the existing machines, which will partly serve as an injector, and the future facility is given in figure 1.

The operation of any high-energy accelerator with its target and experimental facilities provokes radiation, especially at sites of beam loss or deliberately production of radionuclides. Thus for FAIR an adequate shielding by concrete walls with a thickness of up to 9 m is designed to protect people and environment from exposure. During operation there will be no access to the accelerator. In periods of shutdown usually most parts of the facility can be entered for maintenance work – sometimes only after an appropriate waiting time.

However, in several locations a high level of neutron production and activation can be expected such a kind, that - even in periods the accelerator is switched off - personnel will be exposed to a radiation dose which exceeds the permissible dose rate around a multiple, due to the activation of the tunnel walls and accelerator components. This will be true particularly in the areas of the superconducting fragment separator (Super-FRS, see figure 2) and the antiproton target. These areas are expected to remain inaccessible for personnel even for usual shutdown service activities, once initial installation and commissioning took place. Concerning future survey and realignment tasks these circumstances prohibit the use of well-established stationary monitoring systems or classic measurement systems like total station or laser tracker. The basic necessity for using automated, remote systems for position control and realignment within these zones is therefore obvious.

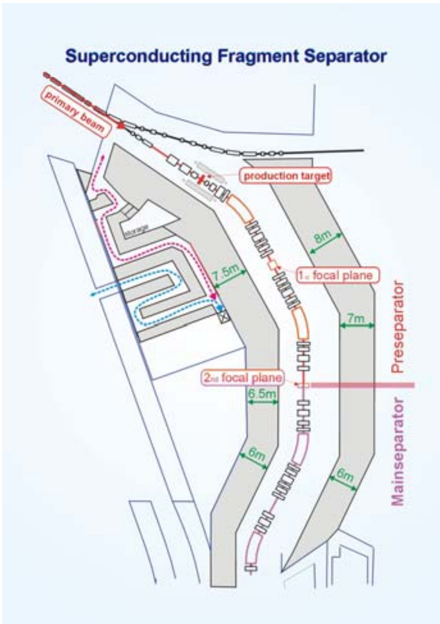


Fig. 2: Preliminary plan of Super-FRS with shielding walls and entrance labyrinth [3]

3. "RALF" – REMOTE ALIGNMENT ON THE FLY

A recently started R&D project that is called **RALF** (**R**emote **AL**ignment on the **F**ly) deals with the conceptual work on an approach for a high-precision survey and alignment system in inaccessible, high-radiation areas. Thus the fundamental ability of surveying and - if necessary - adjustment of the machine (e.g. Super-FRS with its nonlinear beamline containing target area, dipoles and focusing components) is to be preserved, in spite of the already mentioned limited access after some operating time in accordance with safety regulations and radiation protection requirements.

3.1. Requirements

The new measurement system has to meet following requirements:

- No access of human personnel
- Great demands on accuracy (some 1/10 mm)
- Very fast data acquisition
- Automated, remotely controlled adjustment of accelerator components
- Handling a nonlinear beamline with a length up to several decameter

The method will not be used as a permanent monitoring system but for regularly determination of the actual condition of the machine geometry.

3.2. Basic concept – Photogrammetric solution

Fundamental ideas are based on a photogrammetric solution: close-range photogrammetry is the only non-contact geodetic measurement technique that works without human impact on the object and accomplishes flexible measurement and monitoring tasks with highest accuracies. Since being field-tested for many years in industrial applications, photogrammetry also seems to be a suitable method for alignment tasks in inaccessible areas of FAIR. Photogrammetric methods in power plants [2] and remote systems for precise machine adjustment have been successfully adopted in the past. Even though differences between individual demands do not allow a simple transfer of existing solutions to the present problem at GSI, a successful application of remote monitoring and adjustment devices appears to be realistic.

The authors' approach for survey and alignment of accelerator components in inaccessible areas of FAIR is based on a number of high-precision digital cameras, which are installed on an automated guided vehicle system. This movable mechanical device will be driven along the considered beamline, and is equipped with one or more inclinometers to get additional information about orientation (see fig. 3). Number and arrangement of cameras are still not known since no final layout and with this no final constructional design are available so far. Geometric parameters are essential for estimation of achievable accuracy; for alignment of accelerator magnets typically some tenth of millimeter are required. Hence no detailed simulations have been computed yet.

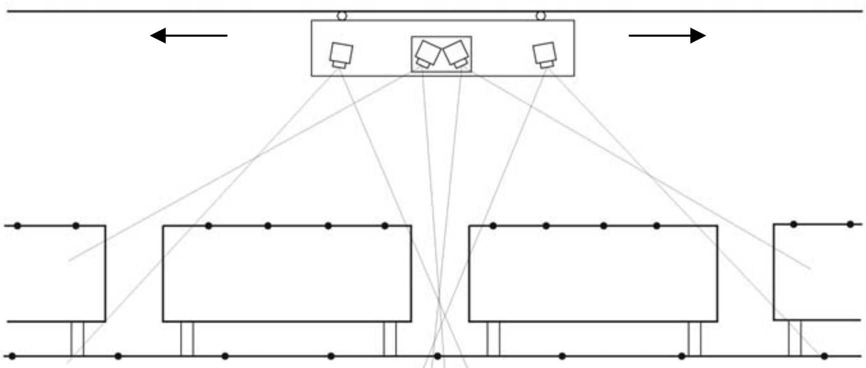


Fig. 3: Rough concept of the proposed surveying and alignment system RALF

It is intended to have a special room for the camera carriage, where the system is protected from neutron and gamma radiation to the greatest possible extent. This room is not only supposed to be a storage room for the camera system but also a place for calibration, maintenance and repair.

Photogrammetric targets have to be fixed on the accelerator components. In order to be able to adjust the magnetic axes of the classical magnets, the targets have to be fiducialized, e.g. with laser trackers as it is accomplished at GSI already for several years. Since superconducting magnets, operating at temperatures of 4K, will be used at FAIR too, appropriate procedures for relating the effective magnetic axis of a non-accessible component to (photogrammetric) reference marks outside the cryostat have to be developed in close collaboration with the magnetic measurement group [1]. In addition to appropriate fiducials on the magnets, a number of tie-points have to be distributed in entire object space to guarantee a stable photogrammetric network along the beamline. For the purpose of checking the inner orientation of the cameras and in order to scale the network, calibrated scale bars have to be placed in object space as well.

3.3. Measuring scenario

As a first conception an alignment procedure with RALF might work as follows: The remote-controlled camera carriage leaves its storage room via tracks (which are mounted on the floor or on the ceiling) and enters the activated area along the beam line. In any case the accelerator has to be switched off during the observations to prevent the camera chips from serious damage by neutron radiation, which appears when the accelerator is in use.

As seen in figure 3 it is planned to capture at least two neighboring components in one shot synchronously. The image data together with the measured tilt angles are sent to a computer, where it is stored for later analysis and processing. After first stop for data acquisition the system moves on to the next magnet and connects it to the previously surveyed. This has to be repeated until all necessary components are captured. Then the camera system moves back to its storage room.

After finishing the data acquisition the images are analyzed in a fully automated process. The photogrammetric targets are detected, identified and measured. A bundle adjustment is carried out to obtain adjusted object coordinates of the fiducial points. A comparison to the nominals results in correction values for the alignment of the accelerator components that is completed by using remotely controlled positioning elements. Finally another camera run can be performed to check the quality of remote alignment.

3.4. Technical challenges and problems

During planning of RALF several serious challenges have to be faced. Below, a loose collection of problems, constraints, open questions and keywords are listed which have to be considered in the future:

- Influence of **gamma and neutron radiation** on CCD or CMOS chips
- Additional arrangements for **camera protection** (if required)
- **Self diagnosis** of camera system

- Adequate camera configuration versus **limited space** in accelerator tunnels
- **Full remote control** of camera system and adjustment devices
- Camera vehicle: **mode of drive**
- **Length of beamline** up to 50 meters
- Relative **accuracy** below 0.1 mm
- Link to the **adjacent machines**
- **Lack of information** about environmental conditions (radiation intensity, size and shape of buildings and tunnels, type and size of accelerator components...)
- **Extra room** for storage, protection and calibration of the camera system
- **Temperature** gradients
- **Appropriate fiducialization** of (superconducting) magnets
- **Vibrations** caused by movement of the camera carriage and their influence on camera geometry
- **Data transfer** camera – computer – adjustment devices
- Automatic positioning elements: **radiation tolerance**
- ...

3.5. First research

Since the project started some weeks before, only a rough concept can be presented at this early stage of planning. First research in the areas of geometric stability of cameras, accuracy of image measurement and considerations on net configuration resulted in valuable experiences for the future work which have been incorporated into the basic concept.

3.5.1. Camera tests

Up to now two different high-resolution digital cameras have been tested at the facilities of i3mainz: the SVS4020 B/W CCD camera by SVS-Vistek GmbH (Fig. 4) and the CSB4000F B/W CMOS camera by Tokyo Electronic Industry Co. Ltd. (Teli). Both cameras feature a 4 Mega Pixel sensor and are well suited for imaging applications like industrial metrology.

	SVS4020 B/W CCD Camera by SVS-Vistek GmbH	**CSB4000F B/W CMOS Camera by Teli**
Resolution	2048 x 2048	2048 x 2048
Pixel size	7,4 µm	6,0 µm
Image device (diagonal)	21,5 mm	17,4 mm
External dimensions	50 x 50 x 45 mm	54 x 43 x 94,5 mm
Lens mount	M42-, C-Mount	C-Mount
Interface	CameraLink™	FireWire IEEE1394
Prices (approx.)	7.000,- €	4.400,- €

Table 1: Camera characteristics

The 4 Mega Pixel cameras were selected consciously, due to lower costs compared to ultra-high-resolution sensors; a substantial criterion, since an array of a still unknown number of cameras is to be used.

Fig. 4: Industrial camera SVS4020 (SVS-Vistek GmbH)

i3mainz runs a photogrammetric test field for camera calibration. This test field was used to analyze the geometric stability of the tested cameras. It consists of a large number of retro targets, distributed on a wall and two meters in front of it. In addition six photogrammetric scale bars are arranged in different positions (horizontal, vertical, diagonal) to guarantee homogenous accuracies in all directions. The test field was captured several times by a block of convergent images, arranged in three stripes (see figure 5). Up to 30 images were taken per image block, including images where the camera was rotated by 90°, 180° and 270° around the optical axis to determine principle point coordinates and other camera parameters. With the help of bundle adjustment software the inner orientation parameters and RMS values of object points, image points and scales have been observed at different configurations. As a result of the camera tests the following conclusions can be drawn:

- SVS camera seems to be more accurate and more stable than Teli (which corresponds to the prices of the cameras)
- Accuracy of image measurement using retro targets: 1/25 – 1/30 pixel (SVS-Vistek) and 1/15 – 1/20 pixel (Teli) respectively
- Relative accuracies of 1:40.000 or better should be realistic (0,25 mm accuracy at 10 m object size)

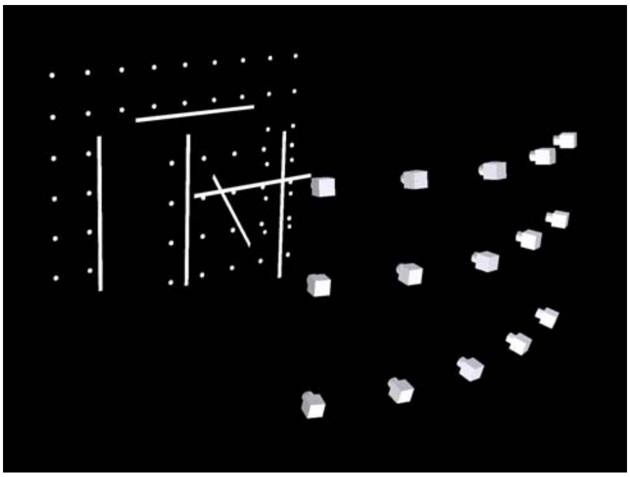


Fig. 5: Test field and camera positions

It should be noted, that no investigations considering influence of gamma or neutron radiation on camera chips have been carried out so far, which could significantly worsen the image measurement accuracy due to noise and might lead to long time damage of the camera chips.

3.5.2. Net configuration

Network simulations with CAP bundle adjustment software have been carried out recently during research at a similar project. These investigations resulted in valuable experiences considering network design at stretched objects and influence of additional observations on object point accuracy. For example it was analyzed, how a robust mechanical connection of two or more cameras (additional observation: relative orientation) can improve object point accuracy. In addition the influences of known camera parameters (out of prior calibration) and the number and arrangement of scale bars in object space have been analyzed. Further research will be focused on network simulations at the facilities of FAIR to obtain information about size and design of the future camera system.

4. OUTLOOK

Next months' work will concentrate on the photogrammetric network design and the arrangement of the camera system. Moreover it is fundamental to investigate the influence of the radiation on CCD/CMOS chips and thus on camera images. Among the definition of requirements on camera technology, creating necessary algorithms for image analysis, fixing general conditions for measurement setup and thus for the building design, serious investigations on automated, remotely controllable adjustment devices, which are suitable for these environmental conditions, have to be made.

A time frame of three years is planned for conceptual work on a final solution for RALF. After terminating the project the conclusion will help to configure and to build the required infrastructure for the measurement system.
The research project started in June, 2004 in co-operation with i3mainz, Institute for Spatial Information and Surveying Technology, Mainz/Germany, and will shortly be implemented into NUSTAR project [4], funded by the sixth European framework program for research and technological development (EU FP6) .

5. REFERENCES

[1] I. Pschorn, “The GSI Future Project: an International Accelerator Facility for Beams of Ions and Antiprotons”, 7th IWAA 2002, Nov. 11-17, 2002
[2] Da Ruan, Paolo F. Fantoni (ed.), “Power plant surveillance and diagnostics: Applied research with artificial intelligence”, Springer, 2002
[3] G. Fehrenbacher et al, "Shielding design for the future FAIR project", GSI Scientific report 2003
[4] M. Winkler, "New rare isotope facility Super-FRS", NUSTAR Annual meeting, Feb. 19-21, 2004