

THE MOST FLEXIBLE INSTRUMENTATION FOR SURVEYING AND ALIGNMENT - A HIGH PRECISION TOTAL STATION CONTROLLED BY MODERN SOFTWARE

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1. INTRODUCTION

For the surveying and alignment of the GSI beam-lines the Metronom company has developed the TASA Concept. The main aim of this development was the use of only one strategy for all accelerator alignments. The solution consists of the use of high-precision polar measurements combined with a complete assembly of new fiducial points. Furthermore, the installation of the new concept has prompted the GSI to modernize its surveying and alignment software. This paper aims to give an overview of the different sensors and the software package. The theory behind the concept is described in "TASA - A New Standard Method for the Surveying and Alignment of beam-line Facilities at the GSI", published in the proceedings to this workshop.

2. TASA HARDWARE

2.1 The High-Precision Total Station Leica TC2002

The use of polar measurements is a very simple way of determining three-dimensional coordinates. It is frequently used in several geodetic applications and there have been many attempts to establish this method for industrial measurements (e.g. Total Stations, 3D-Lasertracker). The polar method has also been used for accelerator alignments, but all concepts have to take the often unsatisfying precision of the range-finder into account.

LEICA offers the TC2002 as a high-precision total station in combination with reflective foils and software based on ECDS Modules as the PCMS System for industrial measurement applications. The instrument consists of a theodolite (T2000) and a concentrically integrated range-finder (D12002). In the general specifications for this total station, LEICA defines an accuracy for the distances of 1 mm + 1 ppm, but the distance sensor provides much more. LEICA is able to select tuned instruments during their fabrication and to deliver very powerful sensors with an accuracy of about ten times better than their specification.

After the GSI had acquired a TC2002 in July of 1995, they commissioned the Technical University of Aachen with the calibration. The accuracy of distances between 2 m and 25 m was inspected by comparing the TC's readings to "true" distances (measured by a laser interferometer) at an interval of 25 cm. The test proves excellent tuning of the system. No cycle error was detectable and the only correction for the sensor/prism system was a offset. Figure 1 shows the residuals to a fitting curve. The standard deviation for the distances was calculated as 0.06 mm !

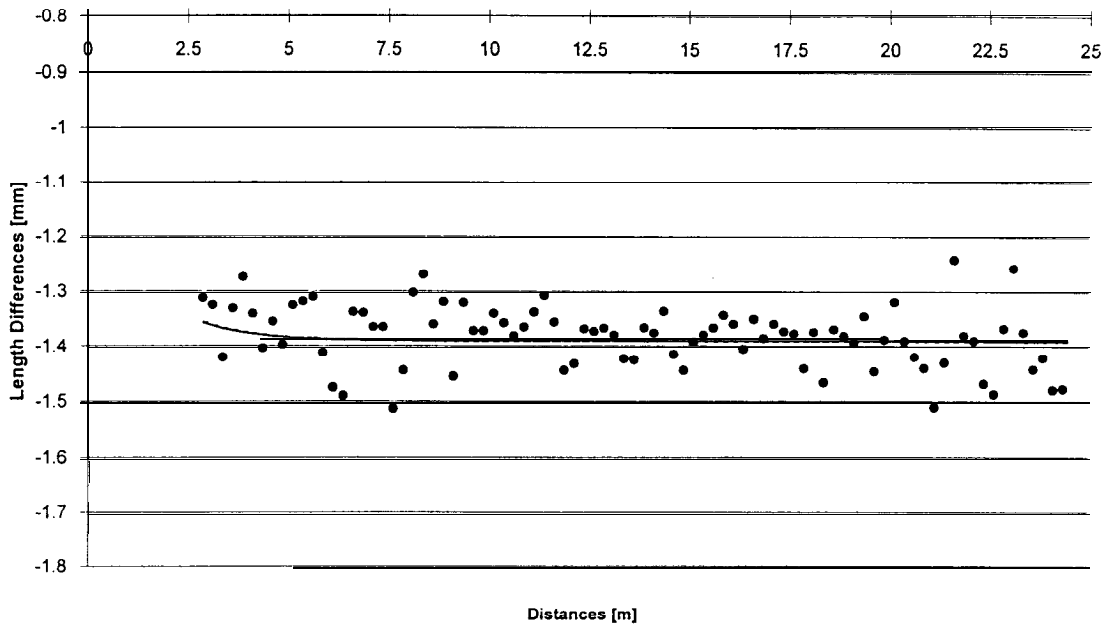


Fig. 1: TC2002 Versus Interferometer Distances

To achieve the same accuracy on site as in the laboratory, it is necessary to heed the following points:

- Each sensor/prism constellation must be calibrated separately
- Variations in the atmosphere must be determined
- The alignment of the prism to the sensor must be within a certain limited range

2.2 Targets

The indicated precision can not be obtained using reflex foils; upgraded triple prisms must be used. To simplify the prisms setup and to merge the reflectors with the centering method, they must be integrated to Taylor-Hobson spheres. This has been done by DESY and other institutes to enable measurements using the ME5000 laser range-finder. The prism is adjusted to the spherical center to eliminate the offset of the reflector.

The advantage of this solution is the missing offset of the prism, but it is not possible to measure horizontal and vertical angles within the same aiming. For this a conventional Taylor-Hobson target with concentric circles (or other marks) is needed, adjusted to the exact midpoint of the sphere.

To enable polar measurements on “one shot”, Metronom has developed a device based on a Taylor-Hobson sphere (made by Brunson) and a Leica standard prism. The installed prism is mounted on a xyz-support to simplify the process of alignment to the spherical center. The prism provides concentric circles on its entrance plane like the original Taylor-Hobson sphere. In contrast to the ME5000 target, the prism is adjusted without considering the offset value. The adjustment of the aiming mark to the midpoint of the sphere is more important, as an additional offset can be compensated automatically within the computation.

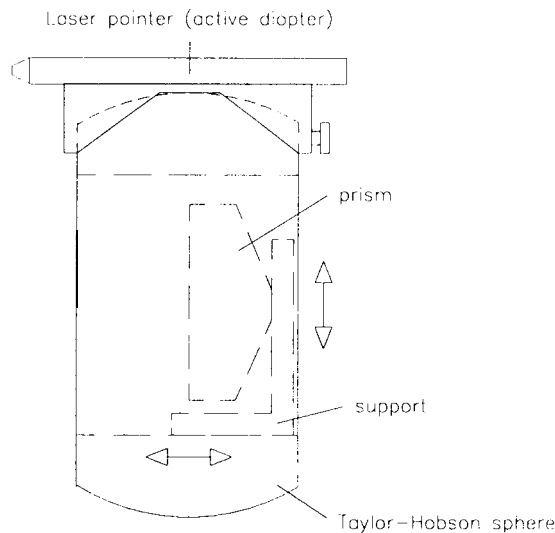


Fig. 2: Sideview of the Reflector Unit

2.3 Registration of the Atmosphere

The atmosphere is determined using electronic sensors. Metronom has installed two sensors on a portable support to measure the temperature, pressure and humidity of the air. The sensors are directly connected to the computer and they are queried with every distance measurement.

Table 1: Atmosphere Sensors Used

Sensor	Name	Precision
Temperature	VAISALA HMP231	0.1°C
Air Pressure	VAISALA PTB201A	0.25 hPa
Humidity	VAISALA PTB201A	1 %

2.4 Inclinometers

Two fiducial points (beam-in, beam-out) are mounted on every component. The components are aligned while setting the fiducial points to their nominal coordinates and by levelling, i.e. by tilt correction. The longitudinal tilt (pitch) can be evaluated from the heights of the fiducial points; the tilt rectangular to the beam (roll) must be measured separately. To improve the levelling system it is advisable to use electronic sensors. While realising of the TASA Concept, Metronom established sensors made by Lucas Schaevitz (Switzerland) with a measuring range of $\pm 1^\circ$ ($=17.45$ mrad) and a precision of 0.03 mrad (depending on the absolute tilt). The advantages of the Schaevitz LSOC-inclinometers are their small size, robustness, wide working range and good precision.

To determine possible twists in components the transversal tilts are measured twice. This is supported by the TASA consoles, which carry socket screws, to attach the inclinometers at equal and repeatable positions. To allow simultaneous measurements of both tilts, two sensors must be employed. In order to query the sensors electronically they are connected with the computer through a power supply.

2.5 The Sensor System

To align components online it is necessary to connect all sensors to the computer. Fortunately, it is possible to address the sensors separately, so no special bus system is required. Optional it is possible to support a second screen, placed near by the component, to show the alignment staff the actual residuals and values of movement.

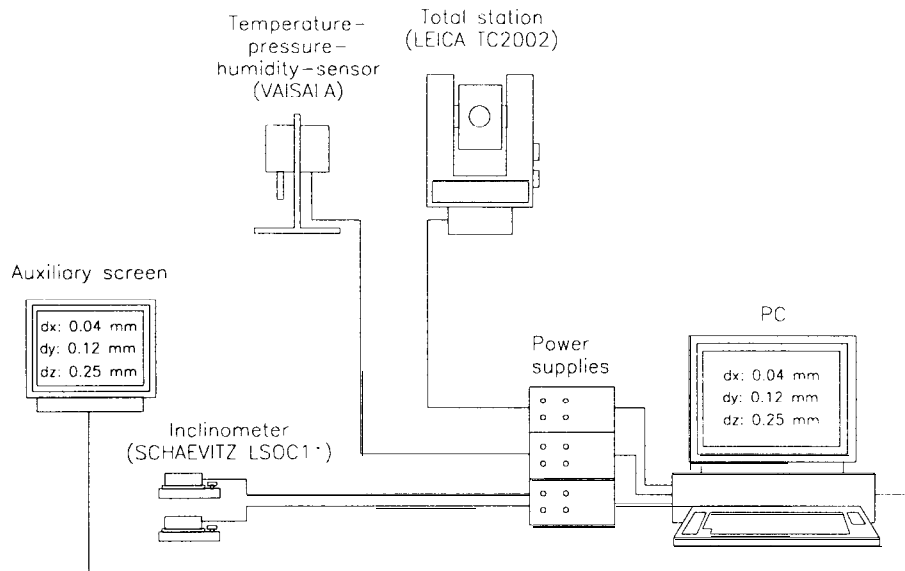


Fig.3: Sensor Configuration

2.6 Computer

No special hardware is required to operate the system. A modem PC, capable of running MS-Windows, is a standard in computing today. For TASA measurements, Metronom prefers the use of a handheld-computer like the new HUSKY-FC-486, as it is protected against humidity, dust and mechanical shocks. Furthermore, the FC-486 supports MS-Windows using PEN technology rather than a mouse or trackball.

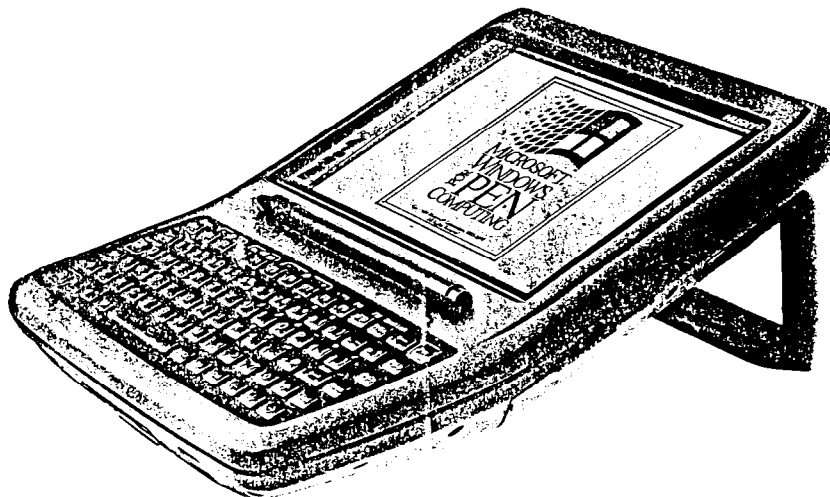


Fig.4: HUSKY FC-486

3. TASA SOFTWARE

The TASA Concept is a new alignment method including hardware and software. During a complete alignment procedure a lot of data must be handled. Until the TASA Concept was realized no special software structure was used. The GSI decided to commission Metronom with the development of a new software package to come up with a solution specially designed for polar alignments based on the described hardware. The different programs should be user-friendly and able to be operated by unskilled employees, flexible and suitable for hand-in-hand work. To meet these requirements Metronom has developed programs which run under MS-Windows. The operating system allows event-driven programming and supports the design and the use of software with standard user-shells (general look and feel).

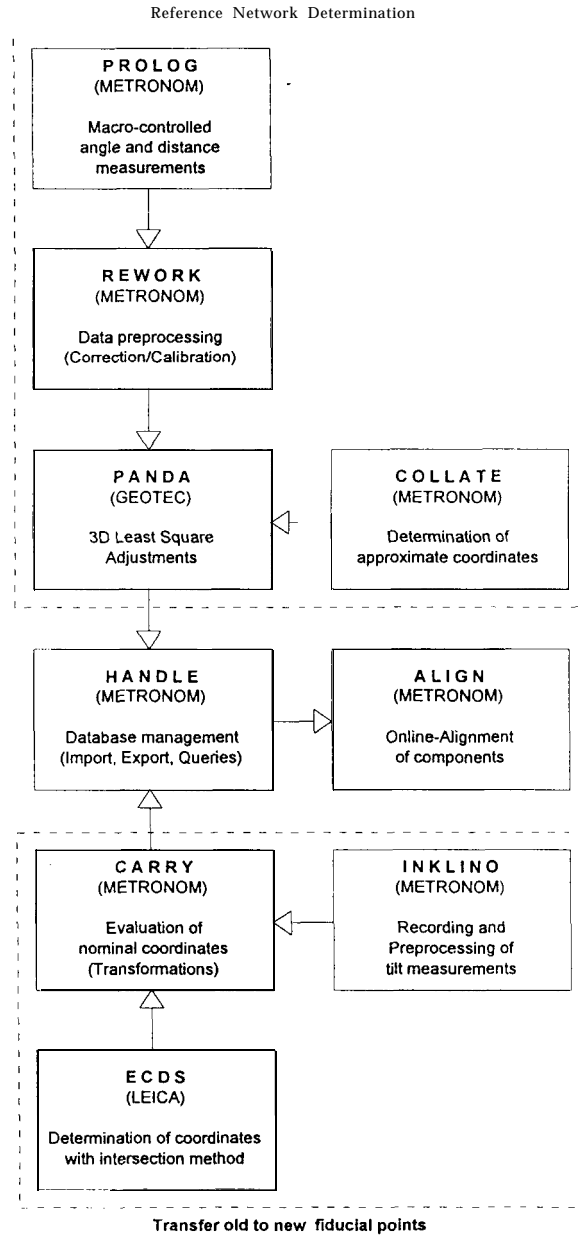


Fig.5: TASA Software Structure

Figure 5 shows the software-structure of 7 programs realised by the TASA Concept. The following descriptions give an overview of the features of the different programs.

- **INKLINO (Tilt Measurements)**

INKLINO is a program for tilt measurements with electronic inclinometers. It is possible to display online the readings of two sensors in a single or tracking mode simultaneously and to store the data into a file. The stored readings are corrected by systematic corrections (e.g. offsets, bias, etc.). For alignments a virtual analog needle can be displayed to improve the recognition of the tilt's value and sign.

The tilt measurements can be analysed with the same program. For this purpose there is a module for data reduction and statistical evaluations (average value, median, standard deviation, etc.).

- **CARRY (Transformation Program)**

The program CARRY has been specifically designed for the GSI. It is a transformation program for the calculation of nominal coordinates of new fiducial points. Input data is the tilt (roll) of a component (determined using INKLINO), a set of 3D coordinates for the "old" and "new" fiducial points in a horizontal coordinate system (determined using ECDS) and a set of nominal coordinates for the "old" fiducial points (calculated by the GSI). Output data is the nominal coordinates of the "new" fiducial points.

- **PROLOG (Reference Network Measurements)**

This program is the most conventional one, as it supports all kinds of measurements using geodetic instrumentation. This program allows angle and distance measurements using Leica sensors (e.g. TC2002, T3000, E2, ME5000, etc.). It is possible to measure sets of angles and distances (including atmospheric parameters) and to store the readings in a file. The most important feature of PROLOG is a macro function for defining measuring macros. Normally the operator knows the exact numbers of stations and targets, so he can put them into the program before he starts working on site. The macro automatically reads the stored numbers and tells the operator which target he has to aim at. The recording of the readings can be released with a button on the instrument, so it is not necessary for the operator to interact directly with the computer.

- **REWORK (Data Preprocessing)**

REWORK prepares the data, recorded with PROLOG, for the least square adjustment process. All kinds of corrections are calculated in order to eliminate systematic errors (e.g. evaluation of two-face angle measurements sets, calibration of distances, atmospheric corrections, vertical offsets, etc.).

- **COLLATE (Approximation of Coordinates)**

The calculation of a least square solution needs proximate coordinates. COLLATE is able to evaluate proximate coordinates and to create a input file for the adjustment program PANDA.

- **HANDLE (Database Management)**

The database management program HANDLE is the heart of the TASA software package, as it is the central data store. The user is able to create all files necessary for the operation of other TASA programs using import and export functions. The data is stored in a relational database, so the operator has the advantages of sorting, selecting or defining special data queries to create dynasets. HANDLE supports a special user-shell to improve the data access and to allow operators with no database skills to work with a relational database without any knowledge of the internal administration procedures.

- **ALIGN (Online Alignment)**

The program ALIGN combines the features of a data acquisition, preprocessing and evaluation program. This module supports functions for the tacheometric online alignment of components using a TC2002, electronic atmosphere and tilt sensors. The evaluated actual coordinates of the fiducial points of the component (beam-in, beam-out) are compared with their nominal values. Based on the coordinate differences and a set of coordinates for the alignment supports of the component, the program calculates shifts for the support screws. The program displays these values in a table, which can be transmitted to a second screen placed close by the alignment staff.

The following screen shots give an overview of the design of the software. The use of standard control elements (e.g. menu structures, buttons, function keys, option boxes, list boxes, online help, etc.) enables the user to operate the programs without participating in a lengthy training course (intuitive use).

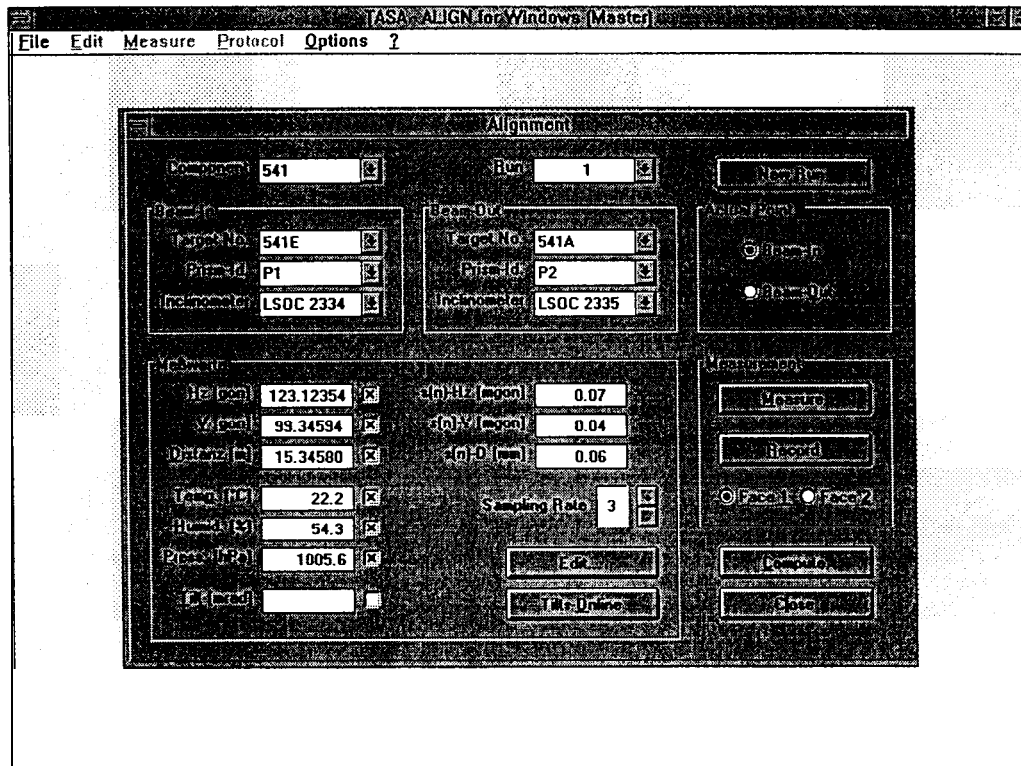


Fig. 6: Screen shot of the Data Capture Module of ALIGN

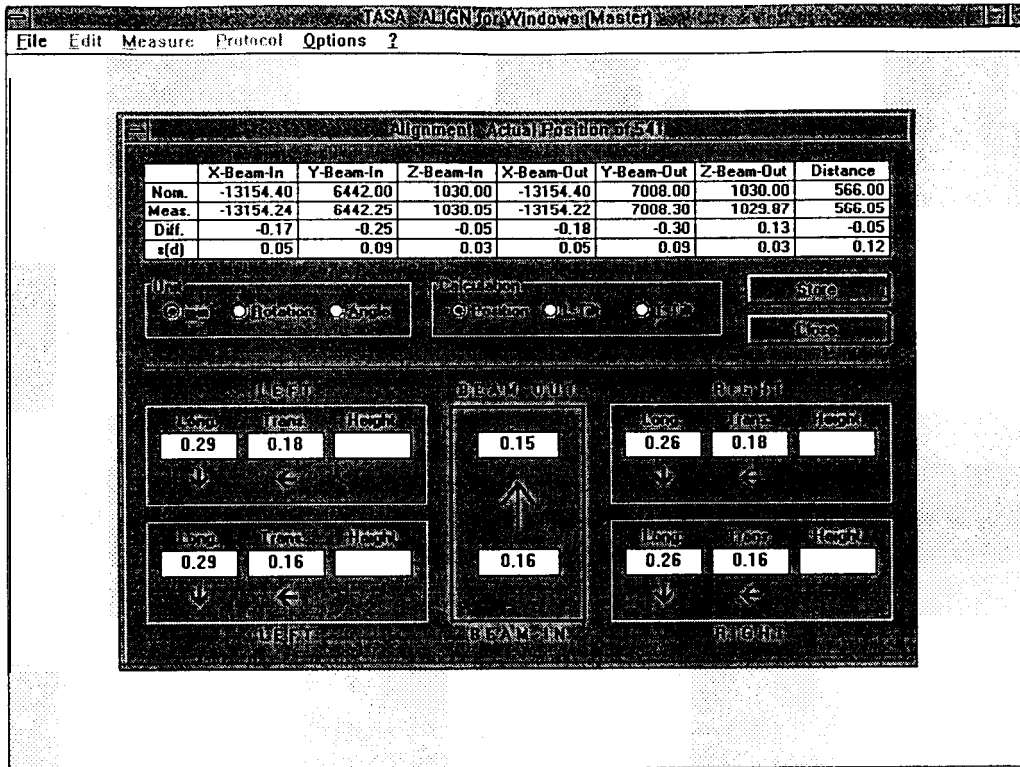


Fig. 6: Screen shot of the Alignment Evaluation Module of ALIGN

4. CONCLUSION

The GSI has no surveying staff of its own. Surveying and alignment tasks are carried out by service companies. With the TASA software the GSI is not dependent on special experts and individual solutions. For the operating of the programs the user must be skilled in geodetic methods, but not necessarily in accelerator alignment methods.

The realisation of the TASA Concept for all of the GSI accelerators is not yet finished. The first accelerator (ESR) is momentarily being prepared for a realignment at the end of 1995. Metronom and the GSI intend developing the entire system to a commercial product as an alignment method for small and midsize accelerator facilities.

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