Alignment At The ESRF

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ABSTRACT

The ESRF Storage Ring requires a very high standard of alignment quality to guarantee maximum beam longevity. One important part of the ESRF Storage Ring alignment strategy is the Hydrostatic Levelling System (HLS). This system monitors the evolution of the machine in the vertical (H) direction. Coupled with servo controlled jacks, it permits the rapid realignment of the machine as soon as significant alignment deterioration is recorded. The results of the ESRF Booster and Storage Ring alignment, and the HLS are presented in this paper.

INTRODUCTION

The design specification of the ESRF Storage Ring requires that the radial deviations (dR) and vertical deviations (dH) of the sensitive elements (quadrupoles) at a given point of its circumference not exceed 0.10 mm. The deviation in the tilts of the magnets from the horizontal plane must not exceed 0.10 mrad. The tolerance in absolute positioning of the magnets around the ring is ± 3 mm in R and H. These tight tolerances have dictated the methodology and alignment philosophy of the ESRF Alignment and Geodesy Group (ALGE). In particular, careful choices have been made with the instruments used for the alignment and monitoring of the machine.

GENERAL COMMENTS ON ALIGNMENT AT THE ESRF

All survey work at the ESRF is made on networks of monuments with high precision instruments. The survey network can be broken down into three levels. At the first level, a network of exterior concrete pillars is positioned around the site. These pillars serve as the backbone of all civil engineering and alignment activities at the ESRF. At the second level, a network of concrete pillars and articulated wall brackets is located in the Booster and Storage Ring tunnels. Additionally, a network of removable metal tripods is located around the Experimental Hall. The third level network consists of the elements themselves (quadrupoles, sextupoles, dipoles etc...) that must be positioned. Today the ESRF survey network comprises nearly 2000 points at these three levels.

The ESRF chose the Distinvar and Ecartometer for all high precision alignment work. Although they are now 20 years old, they are still the only instruments available that can measure relatively short distances quickly, reliably and with a precision of less than 0.05 mm. For all prealignment work and long distance measurements, the Wild DI2000 distancemeter is used. Angles are measured with the Wild T3000 theodolite. All of these instruments are connected to lap-top computers. The CERN sphere and socket, based on the standard 3.5 inch Taylor Hobson sphere was chosen as the survey monument at the ESRF.

ALIGNMENT OF THE ESRF BOOSTER AND STORAGE RINGS

For alignment purposes the ESRF Booster Ring is composed of 78 quadrupoles and 66 dipoles. The 66 dipoles, paired with 66 quadrupoles, are supported on girders. The 12 remaining quadrupoles are have independent supports. Other important components of the Booster are aligned relative to these elements. The objective of the Alignment and Geodesy Group was to align the Booster Ring magnets with a relative precision of 0.3 mm in R and H, and 0.5 mm in S, the direction along the travel of the beam. The absolute accuracies in R and H are ± 2 mm.

To best achieve the objectives set out above, the alignment was made in three steps. The quadrupoles and dipoles were aligned on the 66 girders in the modulator hall where the alignment team could work in relative comfort. These girders and the 12 individual quadrupoles were then transported and prealigned in the tunnel. Finally, all of the Booster elements were correctly positioned and smoothed. Smoothing is the process of minimizing the relative positional errors of adjacent elements. The final alignment was made in two tours of the tunnel. First every second element was correctly positioned using its neighbors as reference. The process was repeated with the remaining elements in the second tour. This method of 'leapfrogging' was very successful. After three weeks of commissioning, no additional magnet movements were required.

Booster Girder Alignment		
	Objective	Achieved
dR	0.30 mm	0.08 mm
dH	0.30 mm	0.04 mm
dS	0.30 mm	0.18 mm

Fig. 1 Standard deviations of the relative precisions of the alignment of quadrupoles and dipoles on the Booster Ring girders.

Final Alignment Results For The ESRF Booster				
	Absolute		Relative	
	Objective	Achieved	Objective	Achieved
dR	2 mm	0.67 mm	0.3 mm	0.16 mm
dH	2 mm	0.31 mm	0.3 mm	0.08 mm
dS	2 mm	0.12 mm	0.5 mm	0.12 mm

Fig. 2 Standard deviations of the absolute and relative precisions in the final alignment of the 66 girders and 12 individual quadrupoles in the Booster tunnel.

The alignment activities in the installation of the ESRF Booster Ring began with the first general survey of the external and tunnel networks in October 1990 and ended with the final smoothing of the machine in August 1991. It required 2900 man hours of field survey work.

For alignment purposes, the ESRF Storage Ring is composed of 64 G10-G30 type girders, 32 G20 type girders and 64 dipoles. Each G10-G30 type girder supports three quadrupoles and two sextupoles. The G20 type girders support four quadrupoles and three sextupoles. Other important Storage Ring elements are positioned relative to the girders and dipoles. The objective of the Alignment and Geodesy group was to position the 320 quadrupoles and 224 sextupoles on the girders at a relative precision of 0.03 mm in R and H, 0.20 mm in S, and 0.10 mrad in tilt. The relative positional error tolerance between neighboring girders is 0.10 mm for R and H. The absolute positional error around the ring in R and H is ± 3 mm.

The alignment of the Storage Ring was made in five steps. First the quadrupoles and sextupoles were prealigned on the G10, G20 and G30 girders. The girders then passed to the 'Micro' Girder Alignment Laboratory (µGAL) where the final alignment of the magnets was made. Next each girder was transported and installed in the tunnel. The dipoles and girders were then positioned in the tunnel in a process requiring three iterations to achieve the final alignment of the machine.

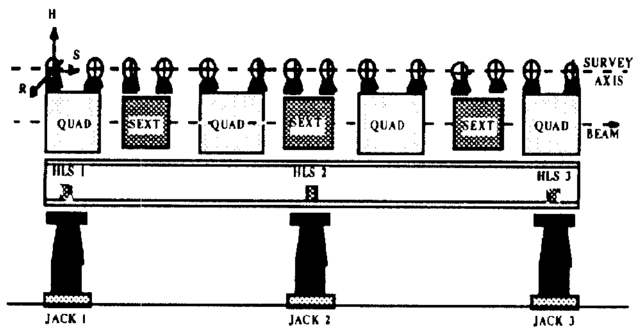


Fig. 3 Schematic drawing of a typical Storage Ring G20 girder showing the position of the quadrupoles (QUAD), the sextupoles (SEXT), the HLS vessels, the servo controlled jacks and the survey reference axis.

To facilitate the introduction of the vacuum vessels before the final alignment of the girders, the quadrupoles and sextupoles were prealigned at a precision of ± 0.5 mm. After the vacuum vessels were installed, the girders passed to the alignment laboratory µGAL. The relative comfort provided by a laboratory saved considerable time and improved the positional accuracy of the magnets on the girders. The girders were then transported to the Storage Ring tunnel.

Alignment Of G10, G20 And G30 Girders			
	Objective	Achieved	
		µGAL	Tunnel
dR	0.03 mm	0.02 mm	0.03 mm
dH	0.03 mm	0.02 mm	0.02 mm
dS	0.20 mm	0.06 mm	0.08 mm
dT	0.10 mrad	0.03 mrad	0.10 mrad

Fig. 4 Standard deviations of the relative precisions of the alignment of quadrupoles and sextupoles on the Storage Ring girders in the µGAL laboratory and after transport to the tunnel by carrier and crane.

The final alignment and smoothing of the Storage Ring machine was made in three steps. In the first step, all of the girders were prealigned at ± 2 mm. The second iteration used the results of a machine survey to minimize the relative positional errors between adjacent girders. This was followed by a general survey of the external, the tunnel and machine networks. The results of this survey determined the movements that were required for the final smoothing of the machine.

The alignment activities in the Storage Ring began with the installation of the tunnel pillar and wall bracket network in October 1990 and ended with the final smoothing of the machine in February 1992. This alignment required approximately 14000 man hours of field survey work.

Final Alignment Results For The ESRF Storage Ring				
	Absolute		Relative	
	Objective	Achieved	Objective	Achieved
dR	± 3 mm	-1.31 mm	0.10 mm	0.10 mm
dH	± 3 mm	2.75 mm	0.10 mm	0.05 mm

Fig. 5 Absolute and relative precisions in the final alignment of 96 girders in the Storage Ring tunnel

THE ESRF HYDROSTATIC LEVELLING SYSTEM (HLS)

The ESRF is situated on the confluence of the Drac and Isere rivers in Grenoble France. This location is geologically unstable. Tests made during 6 months in 1989 indicate that differential ground settlement will be in the order of 1.5 mm/km/year. These results indicate that the Storage Ring would require regular monthly shutdowns for realignment to maintain the 0.10 mm alignment tolerance in H.

The solution provided by the ESRF Alignment and Geodesy Group is the Hydrostatic Levelling System (HLS) coupled with servo controlled jacks. This system provides a real time continuous monitoring of the sensitive Storage Ring elements. It has an instrumental resolution greater than 0.1 µm and an precision in height difference measurements (dH) better than 5 µm. With the servo controlled jacks, the misalignment of the machine as a result of differential ground settlement can be corrected at a tiny fraction of the cost in time and manpower of a traditional realignment by surveyors. The system also gives a result far superior to the traditional methods. The HLS has been patented by the ESRF.

The HLS is based on the principle of communicating vessels. Fluid, which will always seek a level of equal potential or height, is allowed to flow freely by means of pipework around the Storage Ring. The surface of the fluid is the reference. Height differences (dH) are measured between a capacitive sensor mounted above the HLS vessel, and the fluid surface.

Water has been selected as the HLS reference fluid because it is safe, inexpensive, and is a good conductor of electricity. However, water has a relatively large coefficient of dilation (2 µm/°C/cm). Corrections for the temperature difference between vessels and the height of the column of water in the vessel must be made. The capacitive sensor is not in contact with the surface of the water so corrosion and mineral salt deposition present no problems. The measure is a pseudo-distance of integration which eliminates problems with dust and vibrations on the surface of the water. The effect of the meniscus on the water's surface is eliminated when all of the vessels are the same size and the fluid is homogeneous. It is clear that if differences in pressure between HLS vessels cannot be avoided, a first order theoretical correction, based on pressure observations taken at each point, must be applied to the measures. However, the solution adopted by the ESRF is to maintain the system under an equal pressure by connecting each vessel with its neighbors by an air system. Experience has shown that variations in pressure between vessels separated by a cumulative 40 meters of pipe are not detectable.

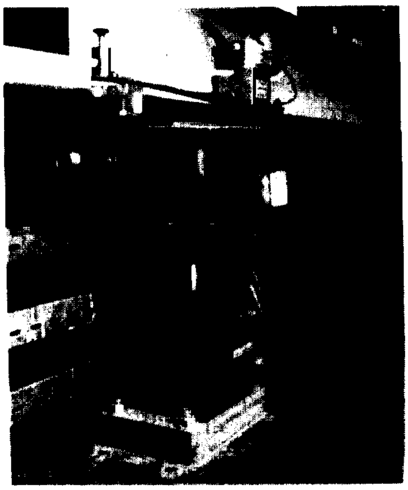
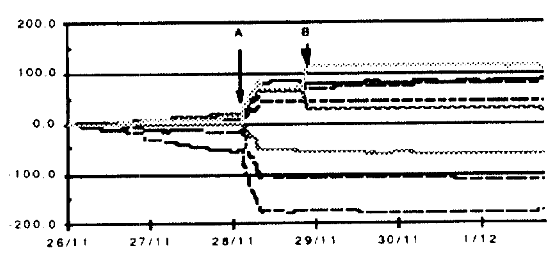


Fig. 6 HLS vessel and servo controlled jack installed in the Storage Ring tunnel.

The precision and reliability of the system is made possible by the connection of the HLS output signal (0-10 V) to a high resolution analog/digital card. A differential output signal avoids errors resulting from electrical parasites. Data acquisition by the analog/digital interface has been developed by the ESRF Computer Group. Corrections for the non-linearity of the sensor output over the range of 2.5 mm (0 - 10 V), and temperature differences between vessels (normally third degree polynomial curves) are provided in real time by the computer.

The installation of the HLS in the Storage Ring has just recently been completed. However, measurements were taken in Cell No. 5 during several weeks from November 1991 to January 1992. The graphs below show measures taken during one week in December 1991. It is clear that even though the temperature in the Storage Ring fluctuates considerably, the dH measures remain stable. The markers A and B show the effect on the level of Cell 5 when the roof beams were installed over the tunnel. Without the HLS, this alignment deterioration would have gone undetected.



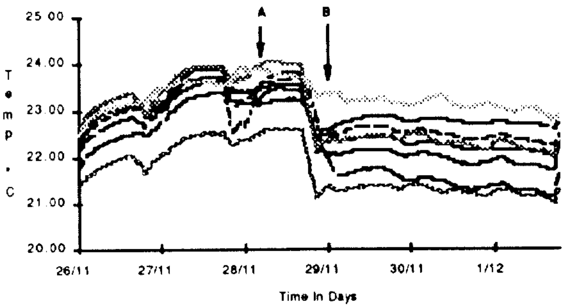


Fig. 7 HLS dH and temperature fluctuations in Storage Ring Cell No. 5 during one week in December 1991. A and B indicate when parts of the Storage Ring roof were installed.

CONCLUDING REMARKS

The final alignment of the ESRF Booster and Storage Rings is superior to the design specification tolerances. It is now the job of the ESRF Alignment and Geodesy Group to maintain the alignment of the machine over the years to come. The Hydrostatic Levelling System and the servo controlled jacks will be a very important part of the alignment strategy.

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