A HISTORICAL FIRST
ON ACCELERATOR ALIGNMENT
ALTIMETRIC ALIGNMENT OF SR IN TWO HOURS (HLS/JACKS)
PLANIMETRIC ALIGNMENT OF SR IN FOUR HOURS (DR,DS PLATES)

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1. INTRODUCTION

In 1987, the ESRF paved the way for a new ambitious accelerator alignment to satisfy demanding and as yet unachieved design specifications. This consists of a permanent realignment of the magnetic elements distributed over the 1 km circumference of the storage ring to an absolute horizontal plane with a precision of ± 1mm. Relative alignment precision is specified at ± 0.1mm between two adjacent elements (DZ). Realignment operations are performed in less than one day.

We thus aim to achieve the same tolerances on radial positioning of elements (DR) with a lesser tolerance for positioning as per the curved X axis (DS).

We estimated that relative movements over 1 km would be of the order of 1.2 mm/year on the geologically homogeneous sub-soil of the Grenoble site. This led us to schedule monthly realignments to satisfy specifications. (The estimation was based on information recorded on the scientific polygon over a 15 year period and consolidated by a specific ESRF study made between 1987 and 1988).

Experience has shown that for a machine located in the horizontal plane, radial displacement amplitude is a factor of four inferior to displacement amplitude in the vertical plane.

This led us to make the following choice :

- Separation of measurement systems and displacements both in the vertical and horizontal planes;
- Continuous control of movements and corrective displacements controlled by a computer in the vertical plane (HLS/Jacks : monthly realignment goal);
- Traditional planimetric measurement campaign (distinvar and ecartometer) realignment using 0.01 mm graduated vernier (DR,DS) (annual realignment goal).

Today, after the Washington PAC publication, we shall present the result of the first SR realignment which took place on January 10, 1993. In so far as altimetric and radial correction are concerned, these results are ten times better than initially foreseen in the specifications, thus enabling the affirmation that it is possible to realign a 1km circumference storage ring in less than one day.

An absolute precision of ± 0.1 mm/km and relative precision from one girder to another superior to 10 μm in DZ were obtained in two hours. An absolute precision of ± 0.5 mm and a relative precision of ± 0.06 mm in DR were obtained in four hours.

2. Z ALIGNMENT OF SR

2.1. Description of the System

From a geometric point of view the ESRF storage ring is composed of 544 sensitive elements distributed on 96 girders of an average weight of 6 tons. Each girder is supported on three jacks and equipped with three HLS located immediately above.

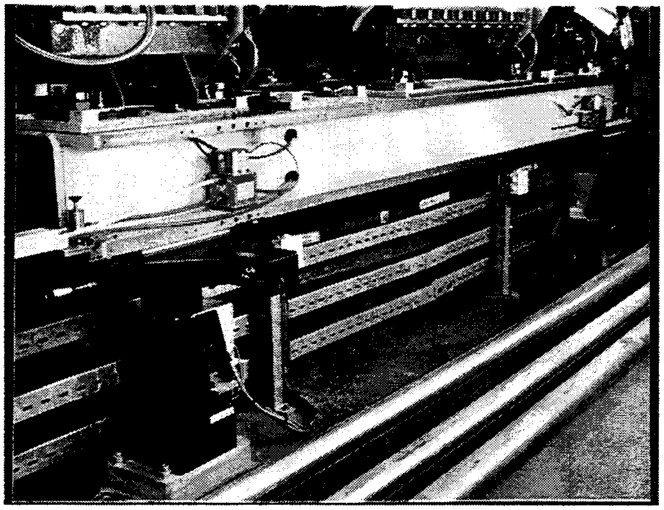

Fig.1 One of the 96 girder supports for the ESRF storage ring quadrupole and sextupole magnets.

2.1.1 Hydrostatic Levelling System (HLS)

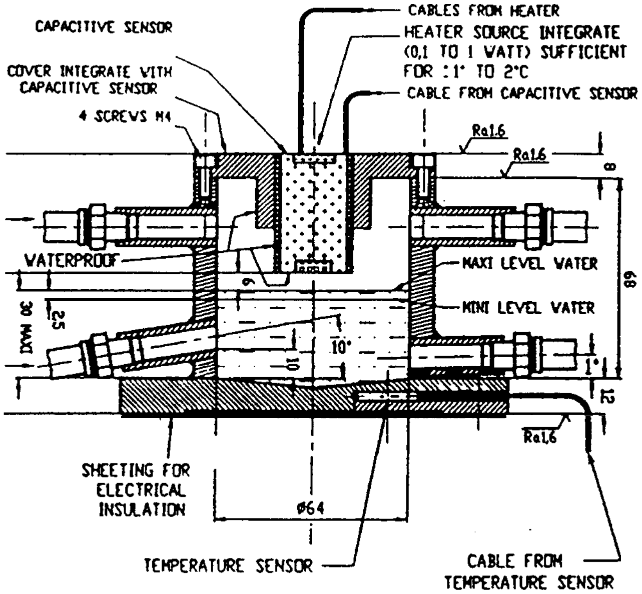

Fig. 2 Cross section drawing of HLS vessel

The HLS (Fig. 2) is a measuring instrument based on the principle of communicating vessels. The 288 instruments are interconnected along the circumference of the storage ring by a fluid filled tube which determines the reference plane and an air filled tube which guarantees pressure stability along the network. The design of the capacitive monitoring device was based on high tech satellite developments made by ONERA[1]. This device has a measurement range of 2500 µm, analog resolution inferior to 2 µm and digital resolution inferior to 0.1 µm.

In 1989 once laboratory tests confirmed that each of the "Hydrostatic Levelling System" and jack prototypes were capable of achieving the desired results, the series production of the 300 each of HLS[2] and Jacks necessary to align the ESRF storage ring was launched.

From April 1991 thru January 1992, the installation of girders in local mode was made in record time, to which the HLS made a significant contribution. During the so called storage ring "Commissioning Phase" (running from January 92 through June 92) the software was written, installed all equipment connected to the control room.

The pipes which connect the HLS vessels are made of high radiation resistant (20 Mrem) transparent material of 8/10 mm internal/external diameter.

2.1.2 Accurate Jacks Servo-Controlled

The servo-controlled jack (Fig. 3) is a high precision screw jack, withstanding a nominal load of 3 tons, and with a 40 mm displacement capacity (correction estimate over a 20 year period) and resolution under loading of 0.2 µm.

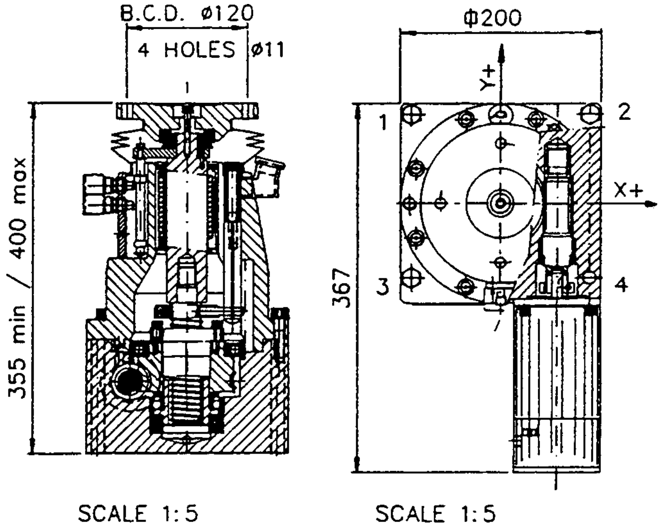

Fig. 3 Cross section of a micrometric screw jack used on the ESRF storage ring

The acquisition and control system consists of G64 modules for analog/digital transformation of a 16 byte signal, a VME type transfer bus and an HP type computer operating on UNIX. The acquisition of signals emitted by the 288 HLS on an HP 900/800 work station takes 15 seconds. Transmitting instructions to the 288 jacks takes about two hours, this is due to the procedures and security systems which are operational at present. The intrinsic speed of the system could be 15 minutes.

2.2. January 10, 1993 - A World First !

The first realignment operation required an extremely careful preparation. This was carried out during machine commissioning, we performed a series of monthly filling tests. This test required 60 hours thermal stability in the tunnel. During the first 12 hours we checked the status of the machine prior to testing (< 5 µm / 12h / 288 HLS). The following 36 hours were

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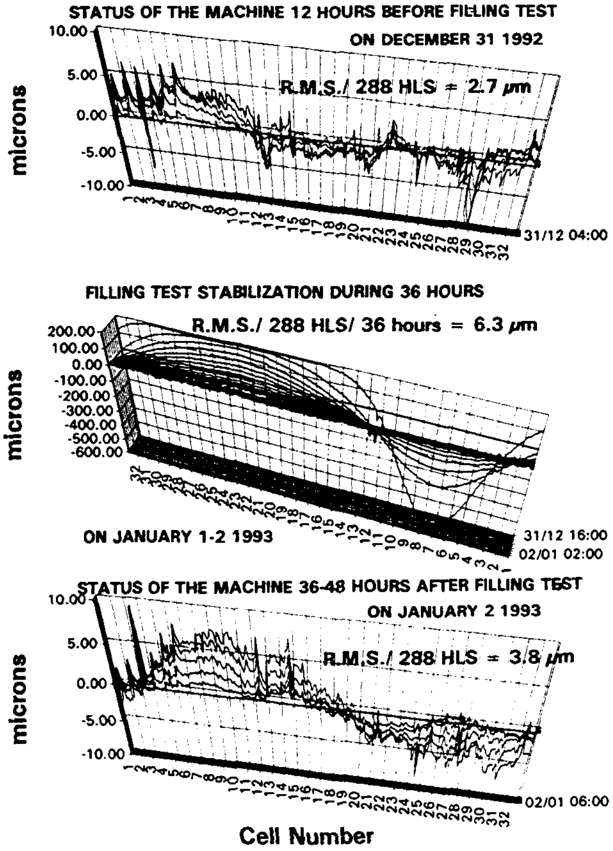
[1] ONERA Office National Etudes et Recherches Spatiales Aéonautiques (Palaiseau, France).

[2] FOGALE-NANOTECH Manufacturer of HLS, (190 Parc Georges-Besse, 30000 Nimes, France).

devoted to checking the adjustment of the mean plane before and after filling < 10 µm /36 h / 288 HLS. The last 12 hours were spent checking the stability of the machine after testing (Fig. 4).


STATUS OF THE MACHINE 12 HOURS BEFORE FILLING TEST ON DECEMBER 31 1992

FILLING TEST STABILIZATION DURING 36 HOURS ON JANUARY 1-2 1993

STATUS OF THE MACHINE 36-48 HOURS AFTER FILLING TEST ON JANUARY 2 1993

Fig. 4 Precision and stability time of HLS network on ESRF storage ring

We were only able to perform these tests during the long weekends when the machine was shutdown. During the January 10 campaign, we performed such tests before and after the realignment operation in order to guarantee optimal safety conditions.

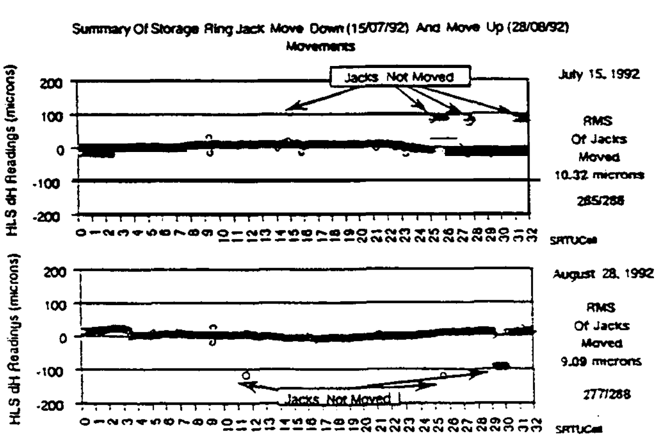

Summary Of Storage Ring Jack Move Down (15/07/92) And Move Up (28/08/92) Movements

Fig. 5 Curves showing reliability and precision of HLS/jack couples
during two commissioning tests

The organization of commissioning of jacks was more complex as confronted with the legitimate reticence of the Operation Team to jeopardize parameters painstakingly achieved over a period of several months. Nevertheless two preliminary tests were performed on July 27 and August 27, 1992 during the summer shutdown period. These tests were a uniform displacement of ± 100 mm. They attained a success rate of 92% and 96% respectively and enabled correction of defects, essentially linked to connection problems (absence of cables or motor cards).

In view of the large amplitude of displacements to be carried out (± 1.5 mm) due to numerous earth works, we decided to split the hydraulic network into sixteen sectors, composed of two cells each. This was done for two major reasons :

- to prevent loss of signal during adjustments, maximum HLS amplitude being 2500 µm;
- to reduce stabilization time to about two hours instead of thirty six for the whole network.

First of all the even then the odd numbered cells of each pair were moved. These operations each took one hour.

The passage of the machine from its position illustrated at the top of Fig. 6 to that illustrated at the bottom of Fig. 6 takes two hours. The curve in the middle of Fig. 6 indicates the differences between orders given to the jacks and the readings recorded by the HLS system.

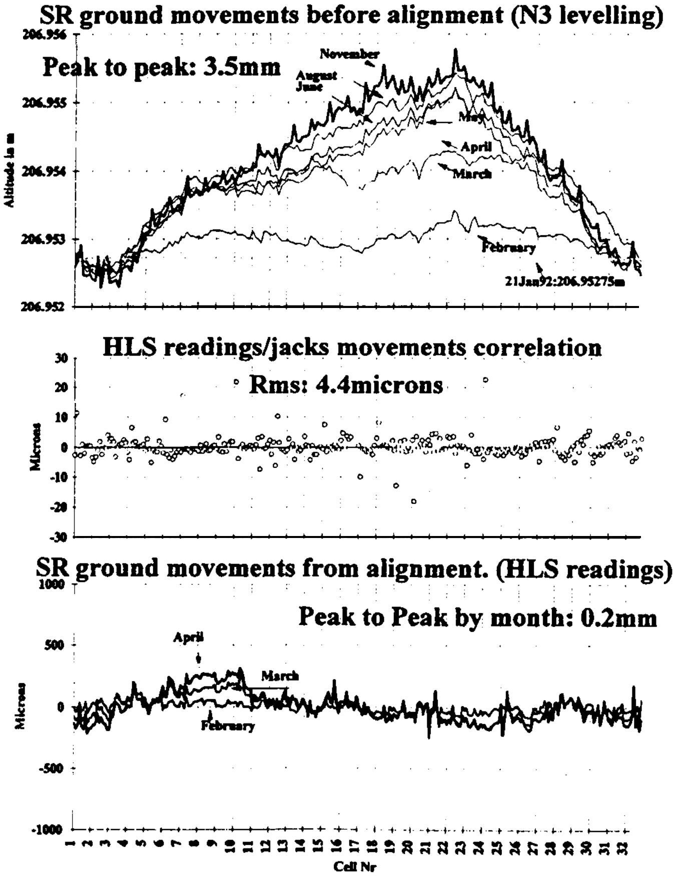


Fig. 6 Status and altimetric evolution of the storage ring
before, during and after the January 10, 1993 realignment campaign

The RMS value of the jack/HLS pair is 4.7 µm and we obtained a 100% success rate on the 288 displacements during this historic alignment operation performed on January 10, 1993.

3. R ALIGNMENT OF SR

3.1. Description of the System

Each girder is equipped with three displacement plates located on the heads of the jacks. The adjustment tool is based on the Vee-Flat-Cone system.

Displacement caused by dilatation is possible along the beam axis as this has no effect on the orbit and is oriented in relation to the trajectory of the particles (Cone-Vee). The median plate is entirely free (Flat).

These plates are equipped with 56 balls enabling displacement of five tons of equipment with an effort inferior to one kilogram on the displacement screw equipped with a graduated vernier to 1/100th of a mm. Displacement precision is less than 10% of its value, i.e. 0.03 mm for a displacement of 0.3 mm.

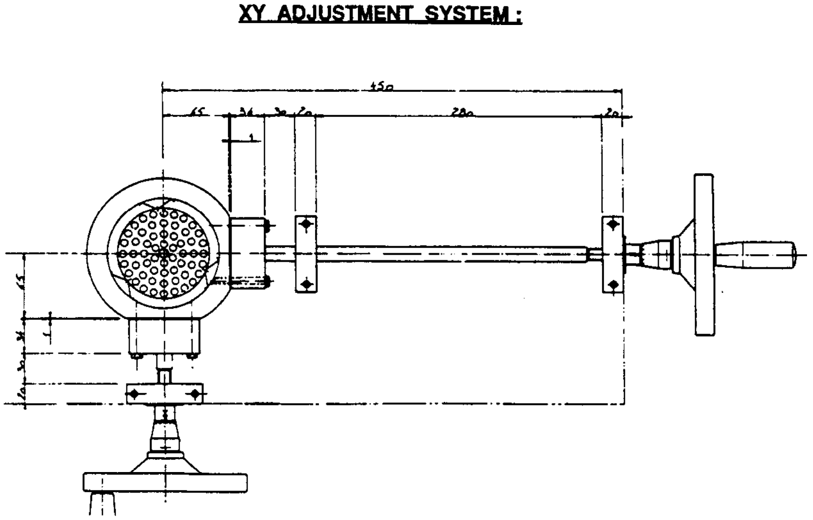


Fig. 7 Layout diagram of a DR,DS plate

3.2. Record Alignment on December 28, 1992

In order not to confuse the reader with the type of performance achieved, it should be noted that performance was not achieved on the measurement-alignment tandem but only on alignment itself.

In fact it took two teams a whole week to perform measurements on the machine elements and to make the calculations necessary to the realignment operation.

The displacement operation of the 192 DR plates took one person four hours to perform.

It then took two teams one week to perform control measurements on the machine elements. This operation was performed two months later due to planning constraints on machine operation.

The top curve represents the radial position of the machine before alignment, the theoretical smoothed curve is superposed, minimising displacements; *(RMS = 0.18 mm and 1.23 mm peak to peak).*

The lower curve represents the radial position of the machine two months after alignment with the theoretical smoothed curve superposed *(RMS = 0.06 mm and 0.37 mm peak to peak).*

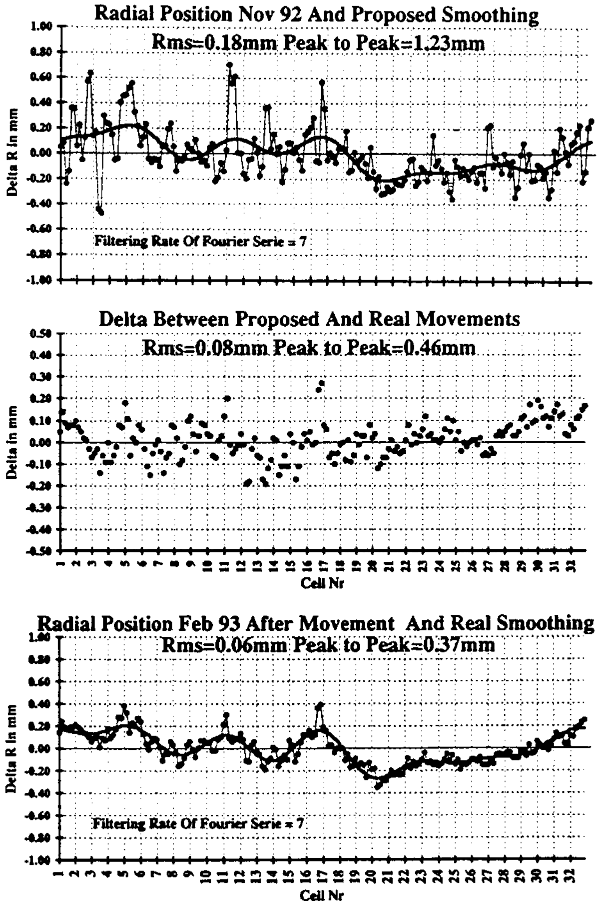


Fig. 8 Situation and planimetric evolution of the SR before and after the alignment operation on 12/28/92.

The median curve represents the difference between displacements and those recorded two months later.

Results are corrected by displacements which inevitably took place during the two month period and consequently are even better than those obtained the day after the alignment operation.

4. GENERAL CONCLUSION

Radial displacements recorded during the first year confirmed the initial hypothesis concerning the expected muliplicative factor between two radial and vertical displacements. The reliability of displacements performed by DR, DS plates designed by the ESRF Design Office enable a radial adjustment of the girders independent of any measuring instrument. The manual solution was retained for the supports of the ESRF storage ring and offered excellent quality price and precision in view of the absence of a planimetric reference comparable to that of gravity in the vertical plane.

Displacements recorded since the January realignment confirm the 1988 estimates concerning differential settlements over one month (Fig. 6 bottom).

The success of the HLS/jack pair recorded in January 1993 attests to the feasibility of a monthly realignment enabling the ESRF accelerator to be maintained in an absolute horizontal plane of ± 1 mm and adjacent equipment to a value inferior to 10 µm during realignment.

When taking account the 1993 - 1994 beamline installation program, it would appear that the optimal realignment schedule will be every four to six months (the next will take place in July 1993). Differential settlement recorded in zones 6 to 13 correspond to beamlines which will be installed this year. In years to come the frequency of realignment campaigns during steady state operation will be monthly. This will guarantee Users on all beamlines with a beam stability of ± 0.1 mm around the whole circumference of the ring. Recent HLS connections set up between the machine and recently installed beamlines have given a promising insight to a whole range of new possibilities for control in experimental areas.

At present, automation of radial displacements for circular accelerators is not a necessity for financial reasons and due to the lack of an absolute reference, the same does not apply to beamlines. We are therefore closely following developments at CERN in the field of wire alignments associated with the HLS which should, in the near future, offer a bi-directional global solution to numerous rectilinear alignment problems.

We believe that these results demonstrate the coherence of our presentation made at Stanford in 1989, concerning a new generation of alignment techniques for the 90s. The bi-directional controlled solution (DZ, DR) should become a reality over the next two years and why not look to a three dimensional solution (DX, DY, DZ) before the end of the Century ?

5. ACKNOWLEDGEMENTS

The results obtained are the fruit of a sound 4 year collaboration between the ESRF survey team and the contractor SINTEGRA. We also acknowledge the contribution of trainees and staff employed on time-limited contracts. Our thanks also go to the present team shown on the photo for the hard work they put in to accomplishing these results and their future efforts towards the success of beamline installation.

Fig. 9 Survey and Alignment team, June 1993 (ESRF & SINTEGRA)

6. REFERENCES

[1] Gelman M., Le nivellement hydrostatique, ESGT, (1981).

[2] Roux D., Conception d'un système de contrôle altimétrique automatique et permanent pour le projet ESRF. ALGE-87-03, Octobre 1987, (1987).

[3] Roux D., Alignment and Geodesy for the ESRF project, Proceedings of the first international workshop on accelerator alignment, July 31-August 2, 1989, Stanford Linear Accelerator Center, Stanford University, USA (1989).

[4] Martin D. & Roux D., Real Time Altimetric Control By A Hydrostatic Levelling System, Second International Workshop On Accelerator Alignment, September 10-12, 1990, Deutshes Elektronen Synchrotron, DESY, Germany, (1990).

[5] Martin D., Alignment At The ESRF EPAC 92, Berlin, Germany (1992).

[6] Roux D., Determination Of The Accuracy Of An HLS Network. TS/WR/ALGE/92-22b, (1992).

[7] Martin D. & Roux D., Dimensional Control of The Experimental Hall (1992).

[8] Löffler F., Dobers T., Neubauer G, High Precision Levelling System For The HERA-Detectors And Interactions Quadrupoles. DESY, Hamburg, Germany (1992).

[9] Roux D., A New Alignment Design, Application of ESRF Storage Ring. SEE, Paris, France (1992).

[10] Roux D., The Hydrostatic Levelling System (HLS)/Servo Controlled Precision Jacks. A New Generation Altimetric Alignment and Control System. PAC, Washington, USA, (1993).