Alignment at the ESRF

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1. Introduction

The ESRF Survey and Alignment group is responsible for the installation, control and periodic realignment of the accelerators and experiments which produce high quality x-rays used by scientists from Europe and around the world. Alignment tolerances are typically less than one millimetre and often in the order of several micrometers. The group is composed of one engineer, five highly trained survey technicians, one electronic and one computer technician. This team is fortified during peak periods by technicians from an external survey company.

The ESRF Survey and Alignment group has had the honour of hosting the Sixth International Workshop on Accelerator Alignment IWAA99 for which this paper has been prepared. On this occasion, an oral presentation, several posters and a guided visit were made outlining a number of our activities at the ESRF. This somewhat eclectic paper summarises these different presentations.

First an overview and comparative study of the main large-scale survey instrumentation and methods used by the group is made. Secondly a discussion of long term deformation on the ESRF site is presented. This is followed by presentation of the methods used in the realignment of the various machines. Two important aspects of our work, beamline and front-end alignment, and the so-called machine exotic devices are briefly discussed. Finally, the ESRF calibration bench is presented.

2. Survey and Instrumentation

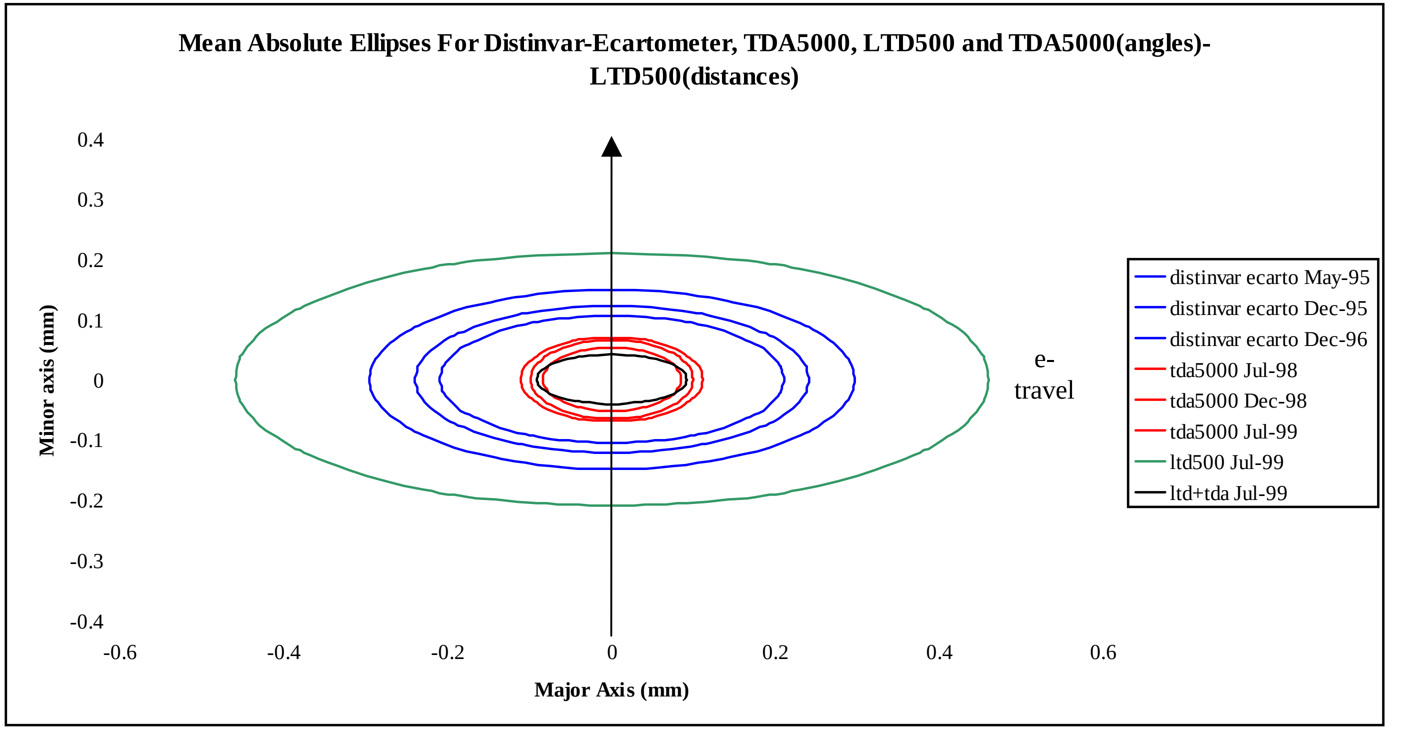
Until recently, all planimetric measurements were made with two instruments developed at CERN, the distinvar and the ecartometer. These two instruments are very precise but are time consuming and require special skills to use correctly. A typical survey of the ESRF Storage Ring takes up to 50 man-days to complete. Shutdown periods when surveys can be made at the ESRF have become shorter and shorter. During these periods many activities including those of the alignment group must be performed in parallel. The Survey and Alignment group activities are rarely compatible with those of the other groups working in the tunnels. For these reasons a viable alternative to the distinvar/ecartometer pair was pursued.

There were two main criteria for (a) replacement instrument(s). The precision in the measurements had to be equivalent to that of the distinvar/ecartometer pair and there had to be a substantial gain in time. We were prepared to have a slight loss in precision for the gain in time. Two potential alternative technologies were investigated. The first was a motorised theodolite (Leica TDA5000) with automatic target recognition (ATR). The second was a laser tracker (Leica LTD500).

	Distances			Angles		Offsets		Time	Precision	
	Number of Surveys	Number of Measures	Standard Deviation	Number of Measures	Standard Deviation	Number of Measures	Standard Deviation	Days	dR direction perpendicular to beam	dL direction along beam
			(mm)		(grad * 10-4)		(mm)	(man days)	(mm)	(mm)
Distinvar / Ecartometer	3	1054	0.137			1004	0.073	50	**0.125**	**0.249**
TDA5000 motorised Theodolite with ATR	3	1629	0.165	1616	3.213			8	**0.062**	**0.098**
LTD500 Laser Tracker	1	1015	0.018	1015	13.300			12	**0.210**	**0.461**

Table 1 above showing results of the distinvar/ecartometer, tda5000 and LTD500 surveys.

Figure 1 at right showing mean absolute error ellipses for the distinvar/ecartometer, tda5000 and LTD500 surveys.



The results of the comparative surveys were surprising. Most surprising and unexpected is that the LTD500 laser tracker results are the worst of the three instrument configurations compared.

There is a clear explanation for this. The angular precision of the laser tracker is approximately 13 dmg (40 arc seconds) whereas the angular precision of the TDA5000 theodolite is approximately 3 dmg (10 arc seconds). Apparently the remarkable distance precision of the laser tracker (18 µm) is insufficient in the ESRF context to offset its comparatively poor performance in angular precision. As an exercise, a calculation was made with the laser tracker distances and TDA5000 angles. These results, although better, are not remarkably different from those of the TDA5000 alone. This demonstrates the importance of angles in a narrow circular accelerator tunnel such as the ESRF. Recall that for the ESRF at least, the most sensitive direction to alignment is in the radial sense or the direction perpendicular to the travel of the beam. Because of the confines of the tunnel and the network configuration, this direction is the most sensitive to angle measurements. The direction along the travel of the beam is most sensitive to distances. Consequently the remarkable distance precision of the laser tracker is poorly adapted in this particular configuration. The distance precision of the TDA5000 is adequate.

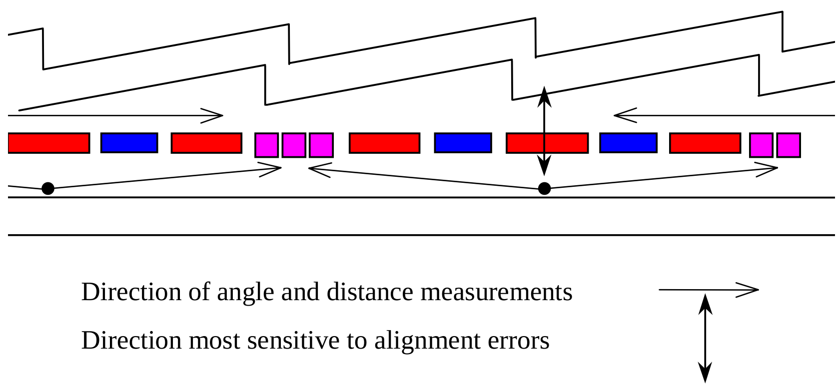
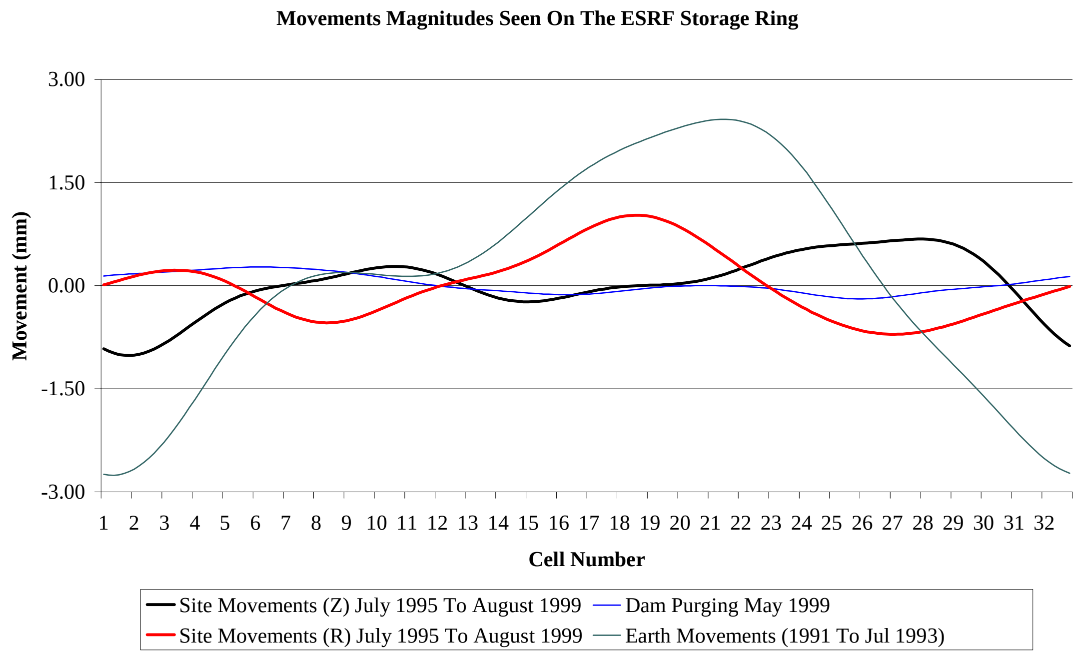


Figure 2 ESRF machine layout showing directions of angle and distance measurements and the direction most sensitive to alignment errors.

3. Site Deformation

A study using planimetric and altimetric data gathered at the ESRF over several years was made in an attempt to identify long term deformation signatures. Several trends were identified.

There are two distinct types of deformation movements observed on the ESRF machine and site. The first are due to obvious events such as fluvial deposition and removal in the adjacent Drac and Isère rivers, earth works, construction and systematic movements at the tunnel floor joints etc.... This list is not exhaustive and there are events for which there is no obvious explanation. These events can be long term, unidirectional, seasonal, diurnal or



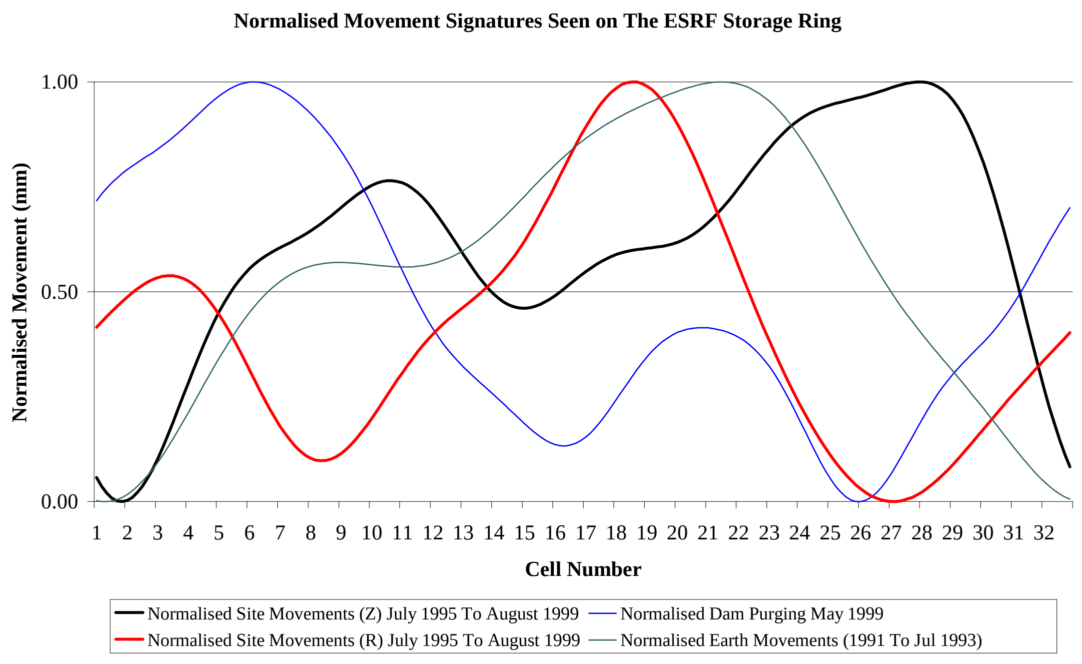


Figure 3 Magnitude and normalized graphs of the five most identifiable ESRF deformation signatures.

unique. Their magnitude ranges between 200 µm to several millimetres. The second type of observed deformation movements are typically small (magnitude less than 200 µm). For the purpose of this discussion, they are considered to be random and caused by mechanical and thermal stresses. These movements are not discussed further in this paper.

Five movement signatures have been identified on the Storage Ring. The first and by far the largest was due to the landscaping earthworks made on the site during the autumn of 1992 and spring of 1993. In parallel the central building was constructed. These movements are clearly identified in the zones centred on cells 2 and 21.

The second clear signature is the removal (and intrinsically the build-up) of sediment in the adjacent Drac and Isère rivers. These movements are observed using the Hydrostatic Levelling System (HLS). They occur over several days during which the St Egreve dam, located approximately 3 km down river of the ESRF, opens its floodgates to remove sediment build up in the riverbeds. It is not clear exactly how much of the deposited material is removed during this operation. However, not all accumulated sediment is removed. Typical overall movements are in the order of ±300 µm. The maximums are observed in the zones centred in cell 17 (Drac) and cell 26 (Isère). There is a counter movement centred in cell 6. Note that for the sake of coherence, the dam purging signature is given as the negative of what is observed. We observe a net upward movement due to the removal of sediment. Clearly, the sediment build up has a net downward effect. This sign reversal is made so that this effect is expressed in the same manner as the other long-term deformation signatures.

Two other important movement signatures are the accumulated (since 1993) long term vertical and horizontal distortion of the machine. They appear inversely correlated. The vertical deformations are minimum (i.e. negative with respect to the mean) in the zones centred in cell 2 and to a lesser extent cell 15, and maximum (i.e. positive with respect to the mean) in the zones centred on cells 11 and 27. The horizontal deformations are minimum (i.e. negative with respect to the mean) in cells 8 and 27 and maximum (i.e. positive with respect to the mean) in cell 19 and to a lesser extent cell 4. The net result is an upward movement approximately perpendicular to the rivers and an elongation in the direction very roughly parallel to them. The analogy to this movement would be an upside down saddle.

These net movements are difficult to explain and are probably the result of several effects, most of which we have not identified. They are not related to a site rebound after landscaping activities of 1992-1993, nor are they to the beamline hutch construction. The deformations do appear to be related to the rivers. However, this relation is not as one would expect it to be. Logically, the continual long-term sediment build up in the river bottom would induce downward motion in these zones. We observe the contrary. The dam purging signature that is positive (i.e. the net build up of sediment causing a downward movement) underscores and supports this contradiction.

There is a clear long term sinking towards the center of the Storage Ring. This sinking appears to be centred along an axis linking the TL2 and TL1 injection zones. There is a considerable mass of civil engineering works in these two areas. It is worth noting that the axis of maximum horizontal movement is roughly parallel to the TL2-TL1 axis and the maximum vertical movement axis is perpendicular to it.

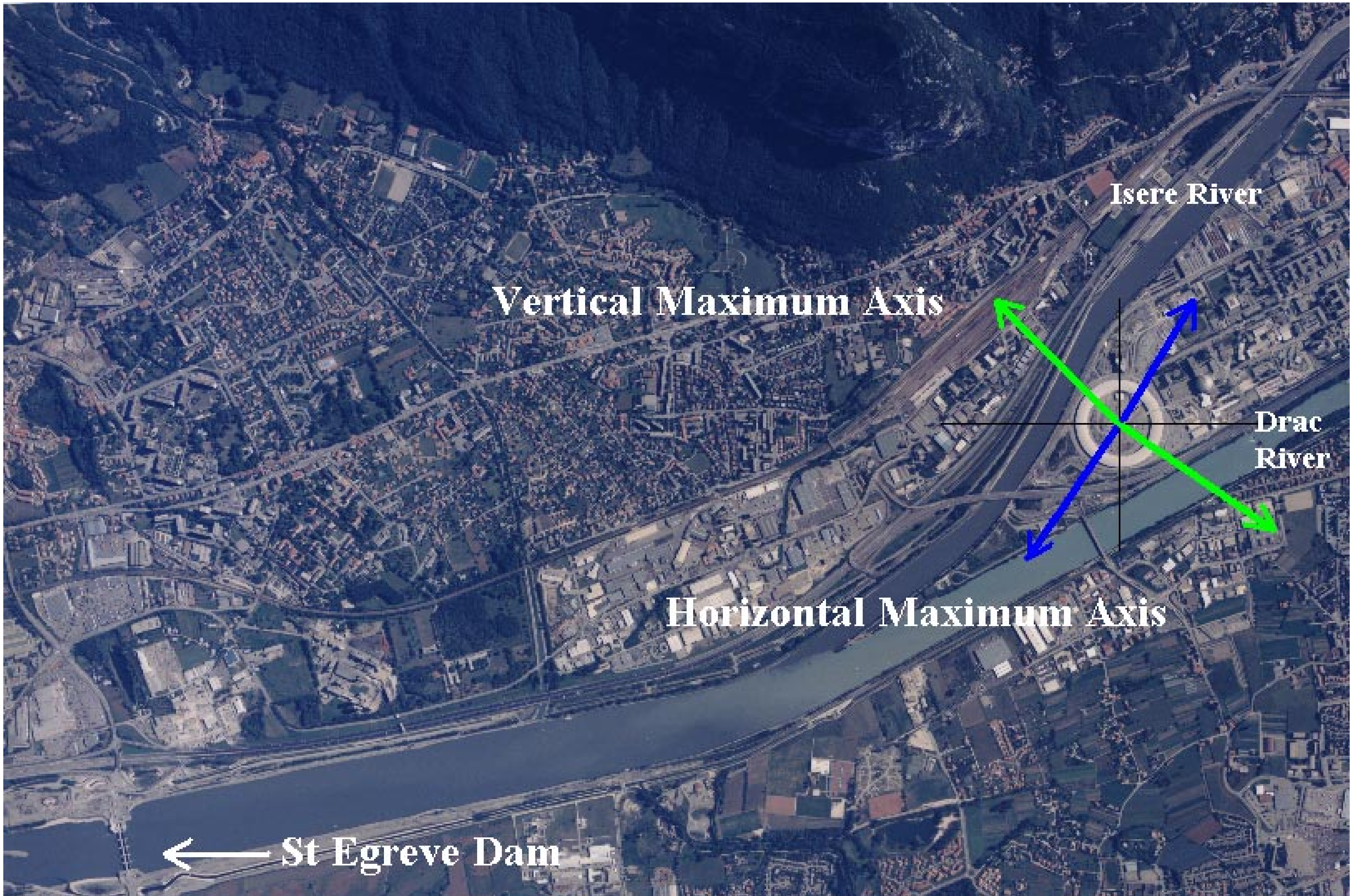


Figure 4 Photograph of the ESRF site showing the maximum vertical and horizontal movement. Note that the vertical maximum is contrary to what would normally be expected. Logically, sediment build-up causes a net downward motion. We observe this indirectly when the St Egreve dam opens its floodgates to purge sediment build up in the riverbeds. However, the net overall movement in the vicinity of the rivers is upward.

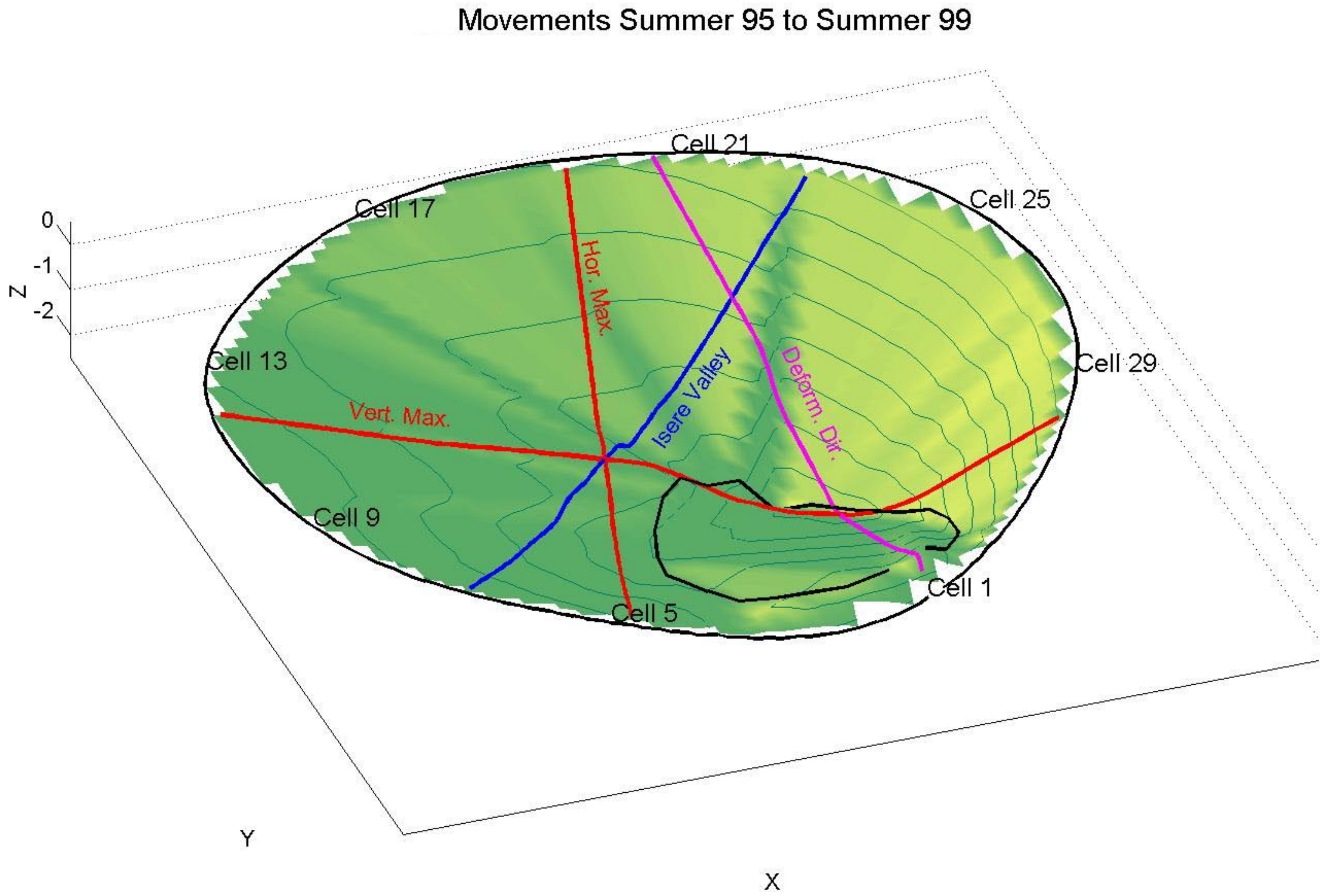
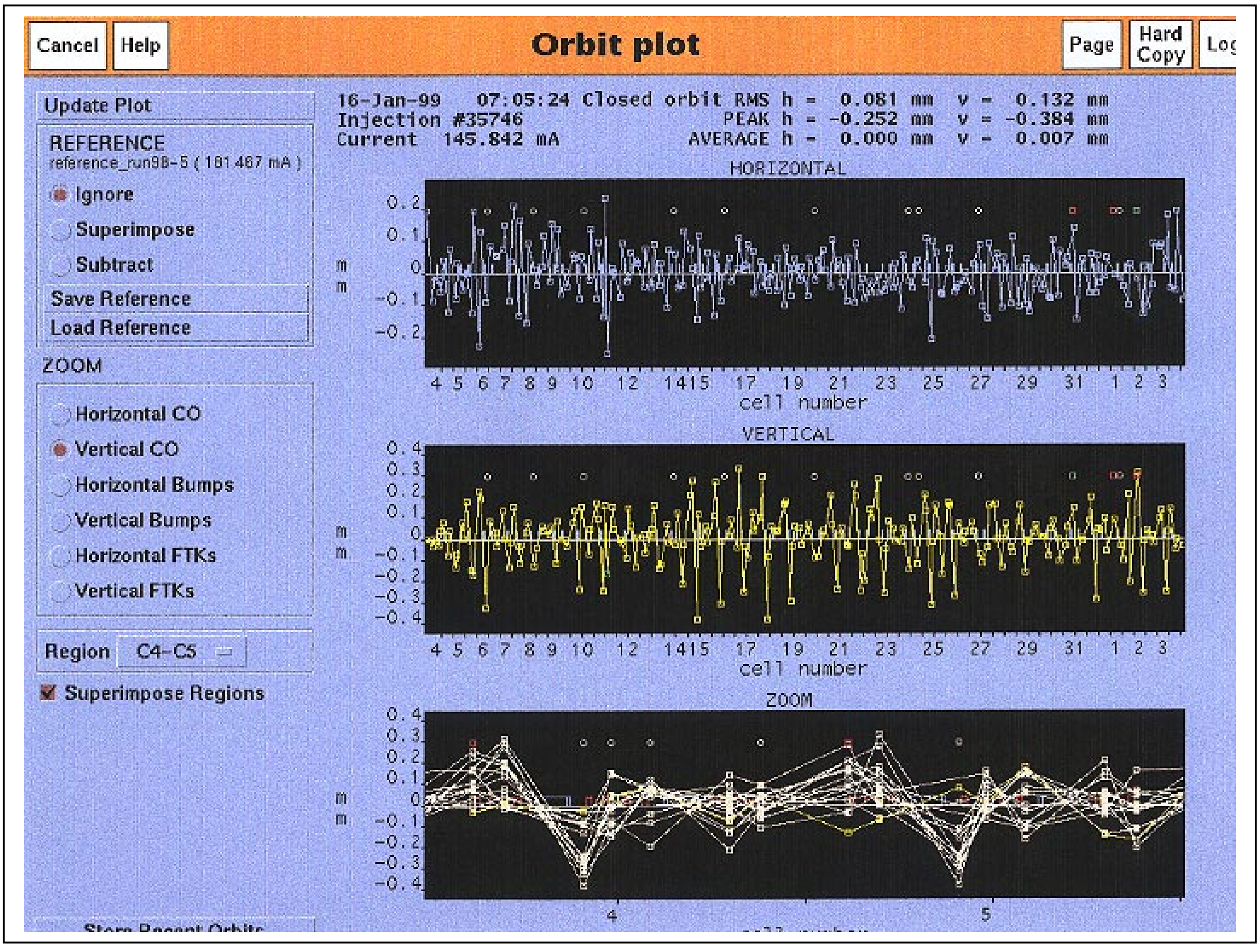


Figure 5 Net overall deformation vertical and horizontal movements on the ESRF site. There is a settling (sinking) along the TL1 TL2 injection zone axis. The elongation of the site is roughly parallel to this axis while the vertical maximum (and the rivers) is perpendicular to it.



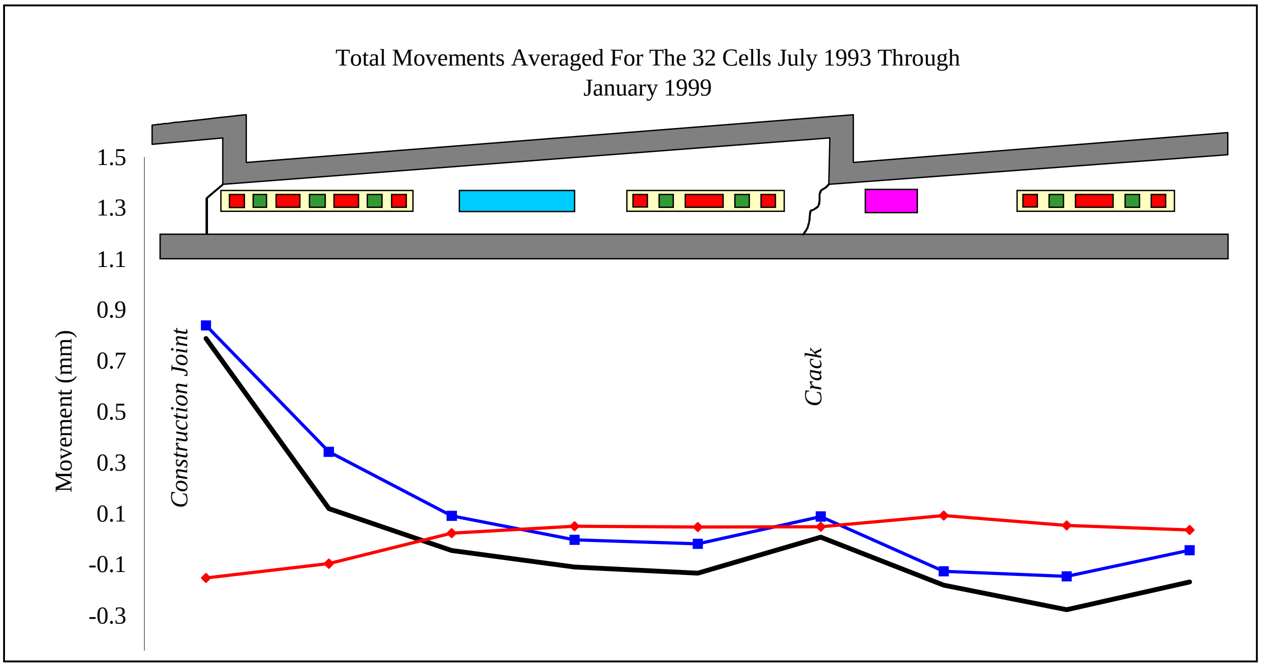


Figure 6 Movements seen by the closed orbit plot at the construction joints between adjacent cells and overall movements at these joints July 1993 through January 1999. This movement is continuous and must be regularly corrected.

All of the aforementioned deformations are approximately smooth. This type of deformation has little effect on the operation of the machine and is transparent to the beamlines. The final movement signature is observed at the floor construction joints of the machine tunnels. It is systematic and very pronounced. It is clearly identifiable on the machine vertical closed orbit and requires continual correction. This movement is seasonal and characterised by a large upward motion in the autumn followed by a comparatively small downward movement in the spring. The net effect is a permanent upward motion at the construction joints and cracks. Its magnitude is a function of the proximity to the joint.

4. Realignment

To counter the aforementioned deformations, periodic realignment is made. In the Storage Ring vertical movements are made using the jacks located under the girders. They are made with beam in the machine and are controlled both by the beam and the HLS system. Horizontal movements are made with precise adjustment screws located on the quadrupole girders. Both of these alignment systems permit a considerable economy in time. A vertical realignment takes roughly two hours. The horizontal realignment operation is fully completed within fours hours. However, after a horizontal realignment, a full survey of the machine is made to control the movements. Clearly the gain in time offered by the TDA5000 motorised theodolite described in section 2 of this paper is an important parameter in the success of this operation.

Both horizontal and vertical movements on the SR dipoles and all Booster elements are made more conventionally using hand tools. Movements in the Booster are controlled using precise dial gauges followed by a full planimetric and vertical control survey. Table 2 gives an overview of the equipment used, periodicity and time required for the main accelerator alignment activities.

Activity	Equipment	Time Requirement	Periodicity
Storage Ring			
Storage Ring level survey	Zeiss DINI 11 electronic level	Three teams of two persons eight hours each (6 man days)	6 times per year
Storage Ring planimetric survey	Leica TDA5000 motorised theodolite with ATR	Four teams of two persons eight hours each (8 man days)	6 times per year
Storage Ring quadrupole girder vertical realignment	Jacks with simultaneous control by HLS and machine.	Two hours	Twice per year (January and August)
Storage Ring quadrupole girder horizontal	Precise screws located between the jacks and the girder.	Four hours	Once per year

realignment			
Storage Ring dipole girder/crotch horizontal / vertical realignment	Hand tools with inclinometer for concurrent control. Control survey after completion of operation	Four teams of two persons eight hours each (8 man days)	Once per year
Booster			
Booster level survey	Zeiss DINI 11 electronic level	Three teams of two persons eight hours each (6 man days)	Twice per year
Booster planimetric survey	Leica TDA5000 motorised theodolite with ATR	Three teams of two persons eight hours each (6 man days)	Twice per year
Booster horizontal/vertical realignment	Hand tools and precise dial gauges for concurrent control. Control survey after completion of operation	Two teams of two persons four shifts of eight hours each (16 man days)	Approximately once every two years
Transfer Line 1 (TL1) is controlled and realigned at the same time as the booster. Similarly TL2 is controlled and realigned when either the Booster and/or the Storage Ring are realigned.			

Table 2 Main alignment parameters for the various ESRF accelerators and transfer lines.

5. Alignment of Vacuum Chambers and So-Called *Exotic* Elements

One of the ESRF ALGE group's main activities during shutdown periods is the alignment of Storage Ring *exotic* devices. These devices include the insertion device vacuum chambers, the RF cavities, the kickers and septum etc… A full list of these elements is given in table 3. This activity is typically divided into four main steps. First the beam axis position must be determined with respect to the ALGE survey monuments. This is done in the laboratory. When a device is installed in the Storage Ring a pre-alignment is made followed by a bake-out. The precise final alignment is made after all other interventions on a device have been completed. Most ALGE group alignment activities are finalised with a protocol to the concerned equipment responsible giving details of its final position. These devices are resurveyed periodically to determine if they have moved over time.

6. Beamline and Frontend Alignment

The Survey and Alignment group provides service to more than forty beamlines. This work consists of both installation and maintenance. Although, there are still new beamlines in the planning stages as well as under construction, the majority has been built. Consequently the main activity on the beamlines is installation, upgrade and replacement of devices (e.g. monochromaters, support tables etc…), maintenance and control.

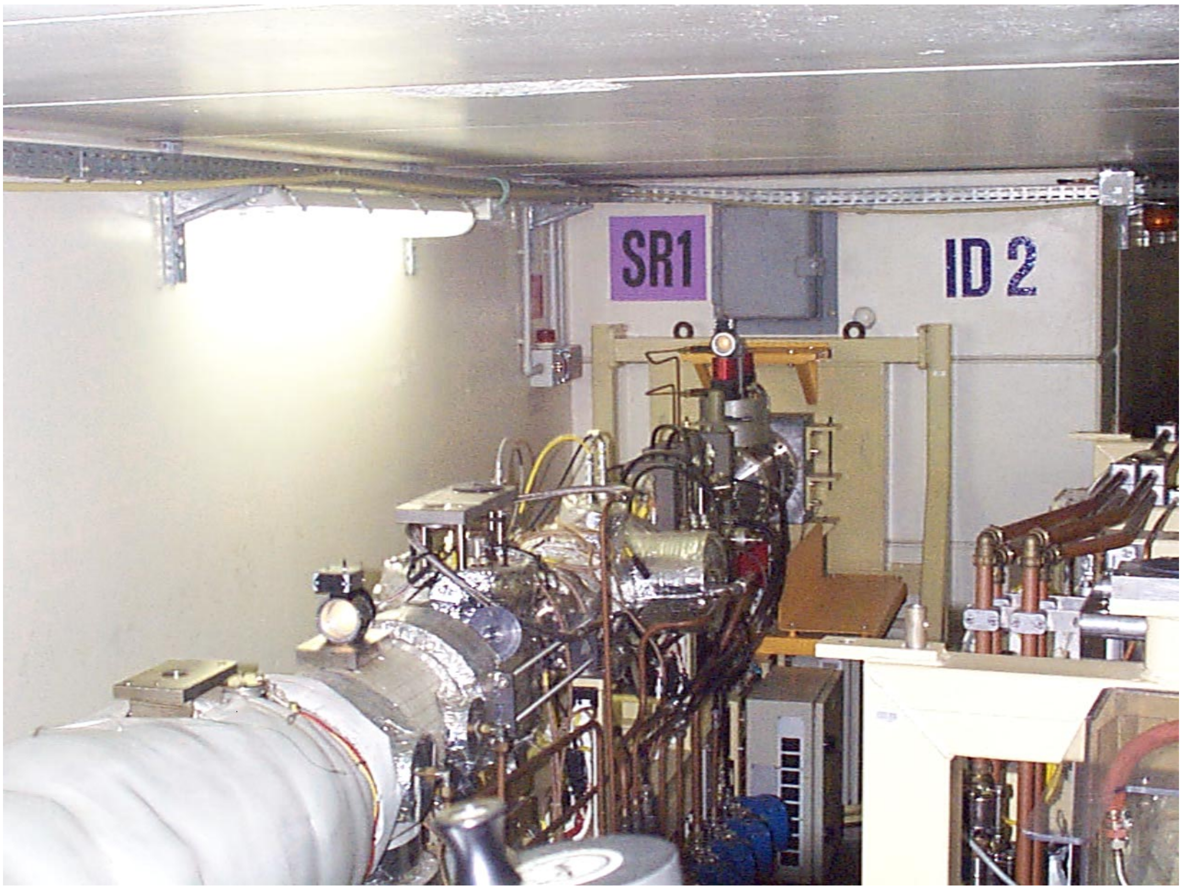


Figure 7 Typical ESRF front end and port end showing the alignment window. The front ends and beam lines are normally set out on a distance and bearing from the source point. This bearing is transferred to beam line brackets installed in the optical hutch of the beam line. From these brackets all other beam line components can be aligned

Most operations require setting out devices on a pre-set bearing at a given distance from the beamline source point. This is done using classical survey techniques. First the theodolite is set up on the machine survey monument located at the beamline source point. The theodolite horizontal circle zero bearing (V0) is then determined using the known position of machine survey monuments. The theodolite is then pointed on the appropriate bearing and the frontend module 1 and 2 can then be aligned. In a similar manner, the beamline brackets in the optical hutch are set out and aligned. The various components of the beamlines are then positioned using the beamline brackets as a reference. The height of frontend and beamline elements is transferred from the machine using a precise level and invar staff.

7. The ESRF Calibration Bench

The ESRF Survey and Alignment group is equipped with a very modern calibration bench. This bench was originally conceived to calibrate invar wires used in the distinvar/ecartometer survey mentioned in section 2 of this paper. Quickly it was realised that the bench could also be used for the calibration of Electromagnetic Distance Measuring equipment.

Electromagnetic Distance Measuring instruments (EDM's or distancemeters) are one of the principal workhorses of modern surveying. They are typically either mounted co-axially or on top of a theodolite. There are four distinct errors (zero error (a), cyclic error (c), scale error and the pointing error) associated with instruments commonly available on the market today. The scale error is more appropriately determined by other means. Pointing errors can normally be avoided in regular operation by using appropriate survey techniques and at the ESRF by carefully aligning the distancemeter beam in coincidence with the interferometer laser beam and the bench. Consequently, two of these errors, the zero error and the cyclic error, can be determined using the ESRF calibration bench. The EDM error is measured at regular intervals (e.g. 10 cm) along the bench.

$$\mathrm{EDM}_{\mathrm{error}} = a + c$$

where

$$c = \sum_{i=1}^{\infty} \left(x_i \sin 2\pi i \frac{D}{\lambda/2} + y_i \cos 2\pi i \frac{D}{\lambda/2} \right)$$

The ESRF calibration bench is not perfectly rectified. This raises two problems. The first requires that to avoid loosing the interferometer count, its prism must be servo-controlled with the laser beam centred on it. The EDM prism, on the other hand, is fixed so its beam is not necessarily centred on the prism. This raises a potential for a pointing error. The second problem with the non-rectified bench is the variation in the distance A_p (i.e. the distance A at position P as shown in figure 9) as the servo table is displaced. To determine if the pointing error and the variation of the distance A_p due to parasitic movements of the servo table are significant, a full survey of the rectitude of the bench was made.

$$\text{Rectitude offset vector} = \sqrt{(-A(\gamma) + \Delta l + \Delta h(\beta))^2 + (A(\alpha + i) - \Delta l(\beta) + \Delta h)^2}$$

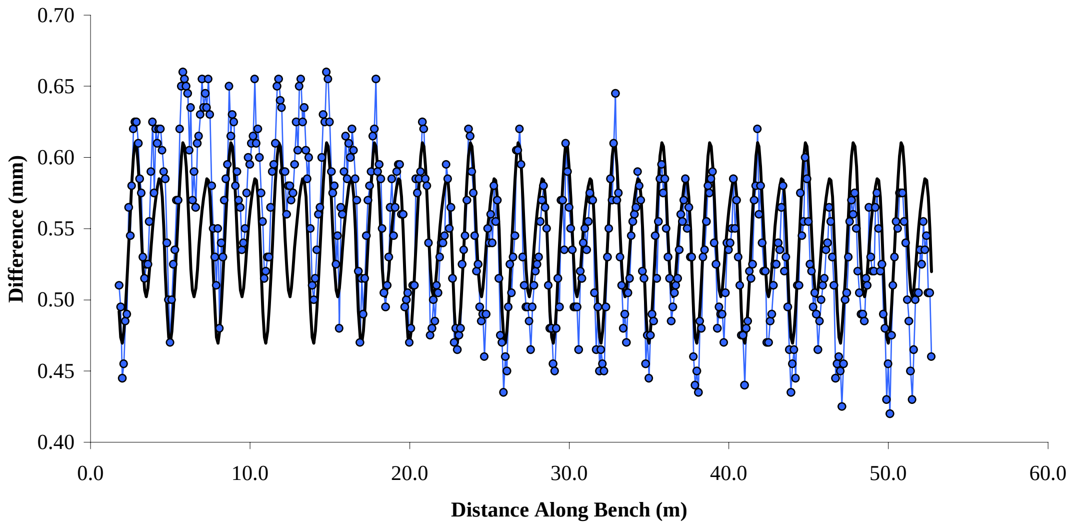
Measurements show that the maximum offset is 2.1 mm. Adding this offset to the maximum expected centring error of the EDM of 1.5 mm, we attain a maximum centring error of the EDM prism of 3.6 mm. Tests show that this magnitude of pointing error has no influence on the measured distance D_{EDM}. Similarly, changes in the distance A_p due to parasitic movements of the carriage are negligible. Ignoring the terms in A, the EDM error equation:

$$\mathrm{EDM}_{error} = (D_i + A_0 + D_0) - (A_x + D_{EDM})$$

can then be rewritten as:

$$\mathrm{EDM}_{error} = D_i + D_0 - D_{EDM}$$

Difference Between Interferometer and DI2002 Readings (EDM Error) and Fourier Series Model of this Error 1.7 to 52 m



Difference Between Model and Measured Error 1.7 to 52 m

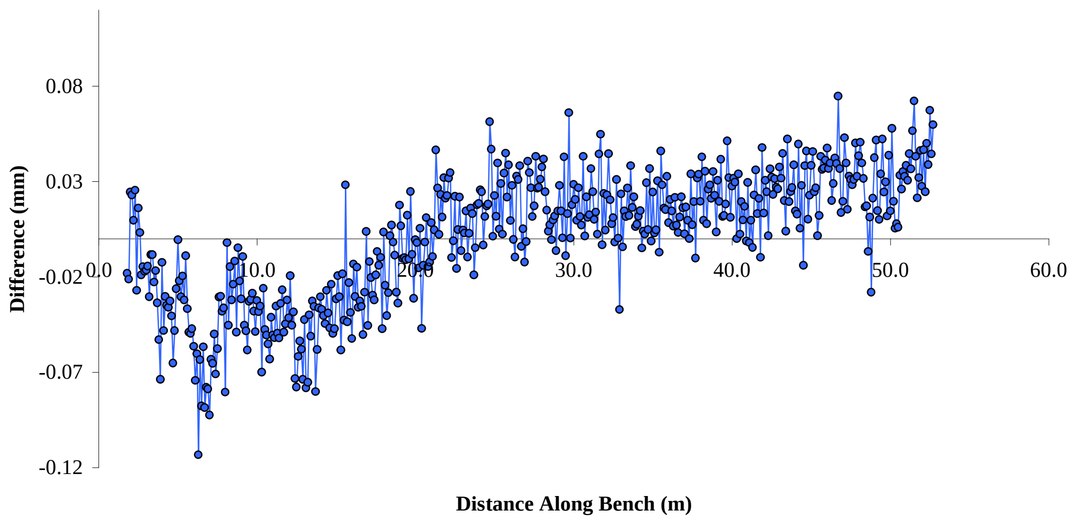


Figure 8 Typical EDM error modeled with a Fourier series and the difference between the observed values and the model.

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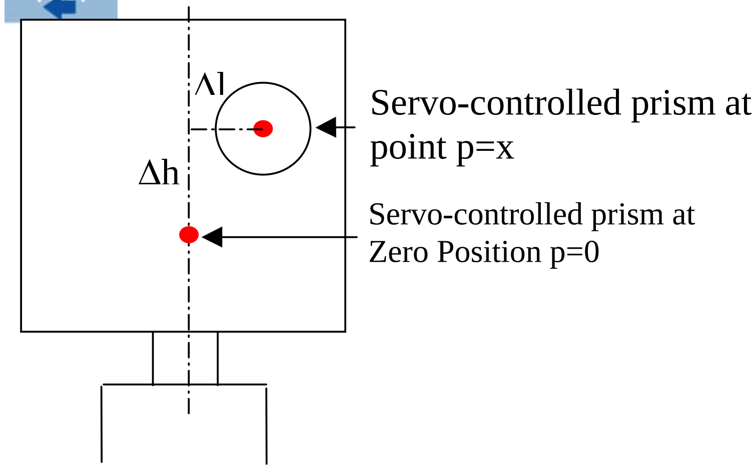

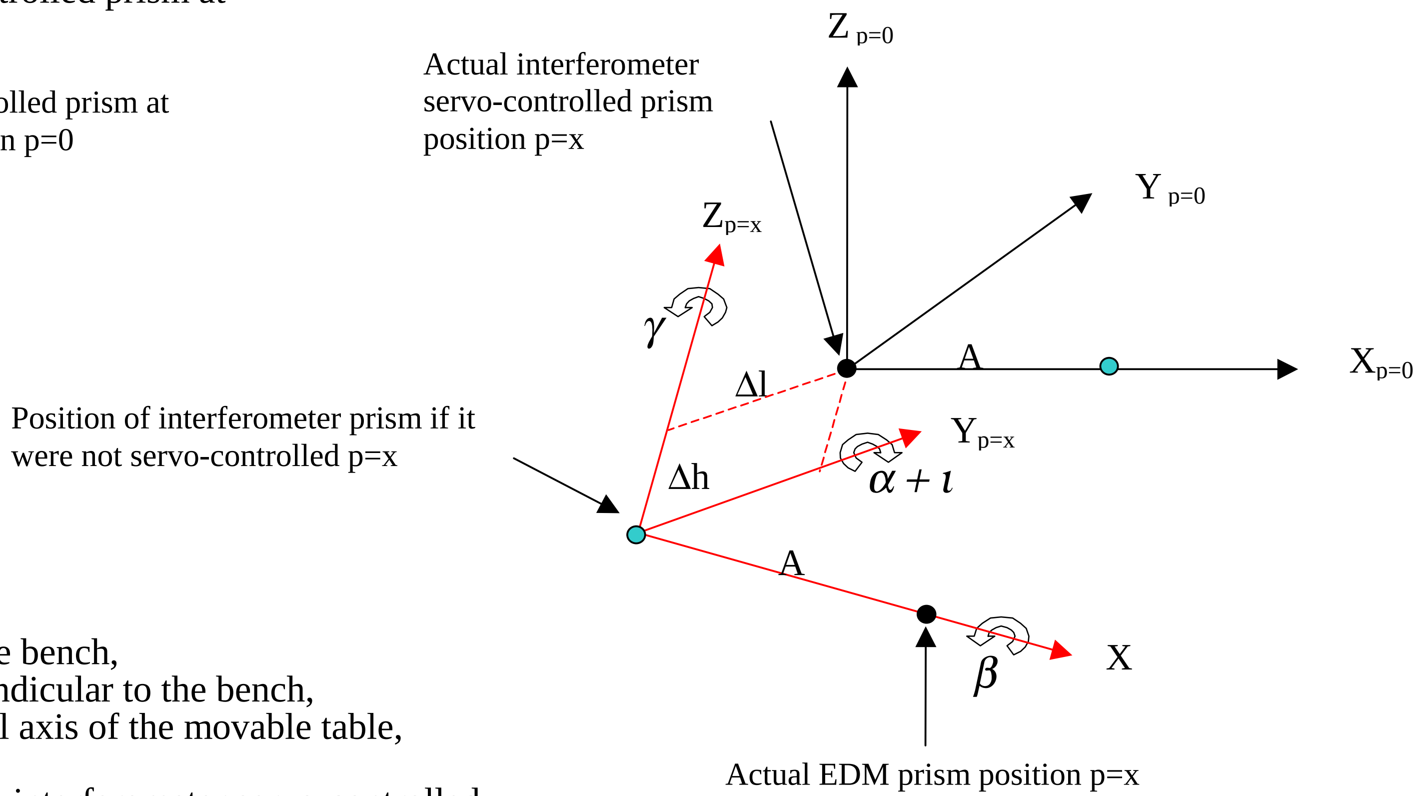

- α, *Pitch* tilt in the direction of the bench,
- β, *Roll* tilt in the direction perpendicular to the bench,
- γ, *Yaw* rotation about the vertical axis of the movable table,
- i, mean slope of the bench,
- Δl, horizontal displacement of the interferometer servo-controlled prism at point p=x with respect to point p=0,
- Δh, vertical displacement of the interferometer servo-controlled prism at point p=x with respect to point p=0.

Figure 9 As the carriage moves along the calibration bench the interferometer prism being servo-controlled moves. However, the EDM prism is fixed. This could potentially introduce pointing errors. In fact the parasitic movements of the bench are so small that they can safely be ignored.

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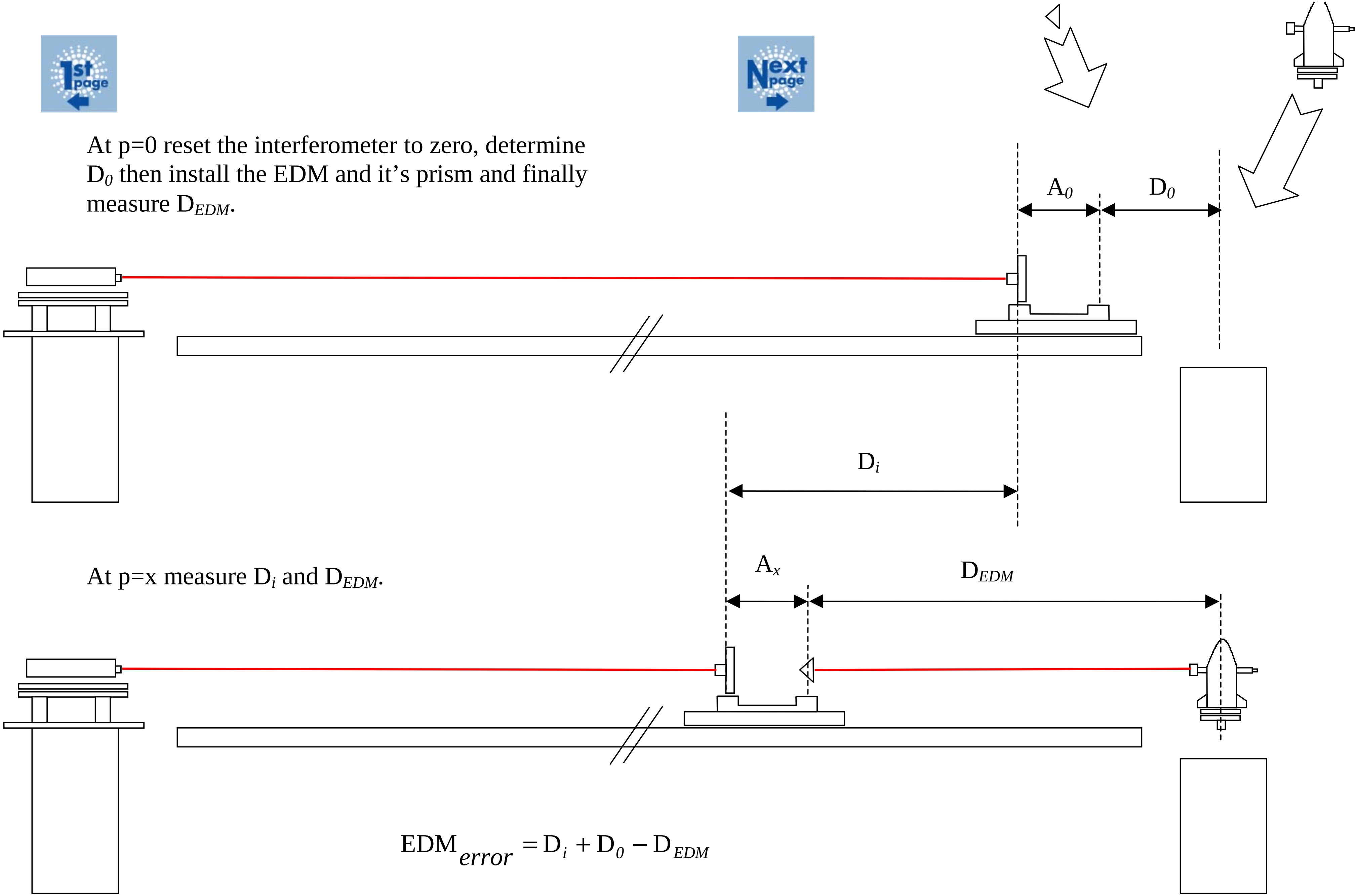

$$EDM_{error} = D_i + D_0 - D_{EDM}$$

Figure 10 Because the distance A does not vary significantly along the bench due to parasitic movements of the carriage, the EDM error equation can be simplified.

A full evaluation of the measurement incertitude of the ESRF calibration bench has been made. This measurement incertitude is expressed by:

$$I = \pm 2 * \sqrt{4100 + \left(\frac{q}{2\sqrt{3}}\right)^2 + 0.08 * D} \quad \mu m$$

where q is the distancemeter resolution. For example, with q as 0.1 mm (as with the TDA5000), the incertitude is less than 150 µm.

In the past the ESRF calibration bench was used to provide a service to exterior companies. It is the intention of the ESRF to seek COFRAC accreditation and to resume this calibration activity in the year 2000.

8. Conclusions

On the occasion of the Sixth International Workshop on Accelerator Alignment, the ESRF Alignment and Geodesy group has presented several of its activities. This paper is a collage of posters, an oral presentation and visits.

We have demonstrated the reasons for our migration from the distinvar/ecartometer pair to the TDA5000 motorised theodolite with ATR. This instrument provides the most satisfactory results of any available on the market today. Of course this statement must be tempered by the specific application circumstances of the ESRF.

Several long-term ESRF site deformation signatures have been identified and discussed. It is very difficult to provide a clear explanation for these movements. Their net result can be described by the analogy to an upturned saddle with its maximum adjacent to the rivers and a horizontal elongation of the site roughly perpendicular to them.

A brief description of the main machine and beamline alignment activities has been given Finally, the ESRF calibration bench has been presented and our intention to reopen the calibration service to exterior companies in the coming year.

9. Acknowledgements

We would like to acknowledge the considerable efforts made by C. Mary and L. Loiacono both in the preparation of the posters presented during this conference as well as their participation in the workshop itself. It is important also to acknowledge all of the Survey and Alignment group members – B. Perret, J. Davison, A. Jalokinos, A. Lestrade, D. van Uye, L. Maleval - without whom this work would not be possible. Finally, we would like to acknowledge the work of E. Claret on the calibration bench.

10. References

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Alignment Accuracy & Survey Periodicity of the Storage Ring Devices

S3 Septum : Commonly surveyed & aligned device

CV4 : Device needing an occasional intervention

: Values with documents which refers to the alignment precision

: Limit of adjustment values due to the accuracy of either the physical definition of the device or the adjustment system

: Estimation of the necessary adjustment accuracy based on common knowledge of the device use

The Maintenance Survey accuracies take into account both the survey and the device definition accuracies

SM : Number of Survey Monuments on the device

Occas. : Occasionally or when required

	Concerned Beam:				Accuracies (mm)				Periodicity (month)	
					Install		Mainten. Survey		Mainten. Survey	
	Machine Beam (e-)	FE Beam (X ray)	Location	SM	Z	R	Z	R	Z	R
Cell	**G10**									
	CV4		*All Cells except C4*	*0*	*-*	*-*	*0.10*	*0.50*	*Occas.*	
	Kicker 3		C4	1	-	-	0.05	-	6	-
	G15									
	CV5-SM		*C4*	*2*	*0.50*	*0.50*	*0.05*	*0.15*	*Occas.*	
	Kicker 4		C4	1	-	-	0.05	-	6	-
	CV6-Crotch	CV6-Crotch	All Cells except C4	1	0.20	0.40	0.05	0.15	Occas.	12
	High Energy Crotch	High Energy Crotch	C7	2	0.20	0.40	0.05	0.15	Occas.	12
		Visible Light Mirror	*ID5*	*1*	*0.50*	*0.50*	*0.05*	*0.15*	*Occas.*	
		PinHole	ID8	1	0.10	0.15	0.05	0.15	12	12
		Beam-Port		*1*	*1.00*	*1.00*	*0.05*	*0.15*	*Occas.*	
	CV7		*All Cells except C4*	*0*	*-*	*-*	*0.10*	*0.50*	*Occas.*	
	Fixed Crotch	Fixed Crotch	C4	1	0.20	0.40	0.05	0.15	Occas.	12
	G20									
	CV11		*All Cells except C3,C5*	*0*	*-*	*-*	*0.10*	*0.50*	*Occas.*	
	Kicker 1		C3	1	-	-	0.05	-	6	-
	1 jaw-Scraper		*C5*	*2*	*0.05*	*1.00*	*0.05*	*0.15*	*12*	*Occas.*
	1 jaw-Scraper		C22	2	0.05	1.00	0.05	0.15	12	Occas.
	G25									

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	CV12-SM		*C3*	*2*	*0.50*	*0.50*	*0.05*	*0.15*	*Occas.*	
	Kicker 2		C3	1	-	-	0.05	-	6	-
	CV13-Crotch	CV13-Crotch	All Cells except C3	2	0.20	0.40	0.05	0.15	Occas.	12
		Fuse-VBI	BM4,BM19	1	0.05	1.00	0.05	0.15	12	Occas.
		Fuse Chamber	*BM4,BM19*	*0*	*2.00*	*2.00*	*0.10*	*1.00*	*Occas.*	
		PinHole	BM9	1	0.10	0.15	0.05	0.15	12	12
		P-Desorp. Absorb.	*BM31*	*2*	*1.00*	*0.50*	*0.05*	*0.15*	*12*	*12*
		P-Desorp. W Blade	*BM31*	*2*2*	*0.50*	*0.50*	*0.05*	*0.15*	*12*	*12*
		P-Desorp. CV2000	*BM31*	*0*	*0.50*	*0.50*	*0.10*	*0.50*	*12*	*12*
		P-Desorp. mirror	*BM31*	*2*	*1.00*	*1.00*	*0.05*	*0.15*	*12*	*12*
		P-Desorp. Beam-Stop	*BM31*	*1*	*1.00*	*1.00*	*0.05*	*0.15*	*12*	*12*
		Beam-Port		*1*	*1.00*	*1.00*	*0.05*	*0.15*	*Occas.*	
	CV14			*0*	*-*	*-*	*0.10*	*0.50*	*Occas.*	
	GRAAL Detector		C7	0	0.10	0.10	0.10	0.10	Occas.	
	Fixed Crotch	Fixed Crotch	C3	1	0.20	0.40	0.05	0.15	Occas.	12
	G30									
Straight	CV Upstr. BPM			1	0.50	0.50	0.05	0.15	12	Occas.
Section	CV2194-19			0	0.70	2.00	0.10	0.50	12	Occas.
	CV2093-10		C8	0	0.50	1.00	0.10	0.50	12	Occas.
	CV3000-15		C10	0	0.70	2.00	0.10	0.50	12	Occas.
	CV5073-13		C13	0	0.70	2.00	0.10	0.50	12	Occas.
	CV5073-15			0	0.70	2.00	0.10	0.50	12	Occas.
	CV5073-19			0	0.70	2.00	0.10	0.50	12	Occas.
	CV5175-10+BPM			2	0.50	1.00	0.10	0.50	12	Occas.
	CV5000APS-14		C29	0	0.50	1.00	0.10	0.50	12	Occas.
	CV Downstr. BPM			1	0.50	0.50	0.05	0.15	12	Occas.
	BPM Upstr. S3		C4	1	0.50	0.50	0.05	0.15	12	Occas.
	Chamber Upstr. S3		*C4*	*0*	*1.00*	*0.50*	*0.15*	*0.50*	*Occas.*	
	S3 Septum		C4	2	0.20	0.10	0.05	0.10	12	12
	Beam Killer		*C4*	*1*	*1.00*	*1.00*	*0.05*	*0.10*	*Occas.*	
	2 RF Cavities		C5,C7,C25	2*2	1.00	1.00	0.05	0.10	12	12
	CT BPM		*C6*	*1*	*0.50*	*0.50*	*0.05*	*0.15*	*12*	*Occas.*

	Shaker Ceram. Chamber		***C6***	***0***	***1.00***	***1.00***	***0.10***	***0.50***	***Occas.***	
	4 jaw Scraper		**C6**	**2**	**0.05**	**0.10**	**0.05**	**0.10**	**12**	**12**
	Mini-Gap Scraper		***C8***	***0***	***0.50***	***1.00***	***0.10***	***1.00***	***12***	***Occas.***
	Mini-Gap		**C10**	**0**	**0.50**	**1.00**	**0.10**	**1.00**	**12**	**Occas.**
	Wiggler Supra		**C15**	**4**	**0.50**	**1.00**	**0.10**	**0.50**	**12**	**Occas.**
	Upstream In Vacuum		***C11***	***1***	***1.00***	***1.00***	***0.05***	***0.15***	***Occas.***	
	In Vacuum		**C11**	**2**	**0.10**	**0.50**	**0.05**	**0.10**	**12**	**Occas.**
	RF Test Bench		***C8***		***0.50***	***1.00***	***0.10***	***0.50***	***Occas.***	
	Helical Undulator		**C**	**0**	**-**	**0.50**	**-**	**0.15**	**-**	**Occas.**
	CV17			***0***	***-***	***-***	***0.10***	***0.50***	***Occas.***	

Table 3 ESRF Storage Ring so called *exotic* devices, their alignment precision and periodicity of maintenance surveys.