# INSTRUMENTATION AND CALIBRATION AT THE ESRF

*D. Martin*
*With special acknowledgements to the following ALGE Group Members*
*G. Gatta, B. Perret, N. Levet, L. Maleval, C. Lefevre and J.D.Maillefaud*
*ESRF, Grenoble France*

## 1. INTRODUCTION

This presentation will dwell principally on the recent efforts and achievements made in the domain of instrument calibration at the ESRF. In particular we will focus on the TDA5000/5 motorized total station with Automatic Target Recognition (ATR). As part of the discussion we will broach the subject of potential achievable precision with this instrument.

## 2. INSTRUMENTATION AND SURVEY NETWORKS

The ESRF uses the Leica TDA5000/5 motorized theodolite with automatic target recognition (ATR) for all high precision survey work. This instrument provides an extremely high measurement rate accompanied by very good precision. Typically, three teams of two people make the full storage ring survey in one 8-hour shift (3200 angle and distance measurements). The standard deviation in the distance and angle measurements are better than 0.15 mm and 4.7 µrad (1 arcsec) respectively. The standard deviation in the absolute point determination is 0.15 mm. In order to achieve these results, great efforts have been made in the proper calibration procedures for this instrument.

Since February 2001, the ESRF has been accredited under the ISO/CEI 25 and more recently the ISO/CEI 17025[1] standard for electronic distance measuring instruments (EDM's). This ensures the greatest rigor in the determination of distance measurements made at the ESRF. More recently, attention has been turned to angle calibration. This paper will discuss these measurements in the cadre of calibration and quality assurance.

In the case of the ESRF, it is important to note that the major axis of the absolute error ellipse, a measure of quality in point determination, is aligned in the radial direction or direction perpendicular to the travel of the beam in all cases (theodolite, distinvar/ecartometer, laser tracker). This implies that the radial direction is the least well determined in the network. Recall that for the ESRF at least, and accelerators in general, the radial direction is the most sensitive to alignment errors. Because of the confines of the tunnel and the network configuration, this

[1]ISO International Standards Organisation, CEI Commision Electrotechnique Internationale or International Electrotechnical Commision

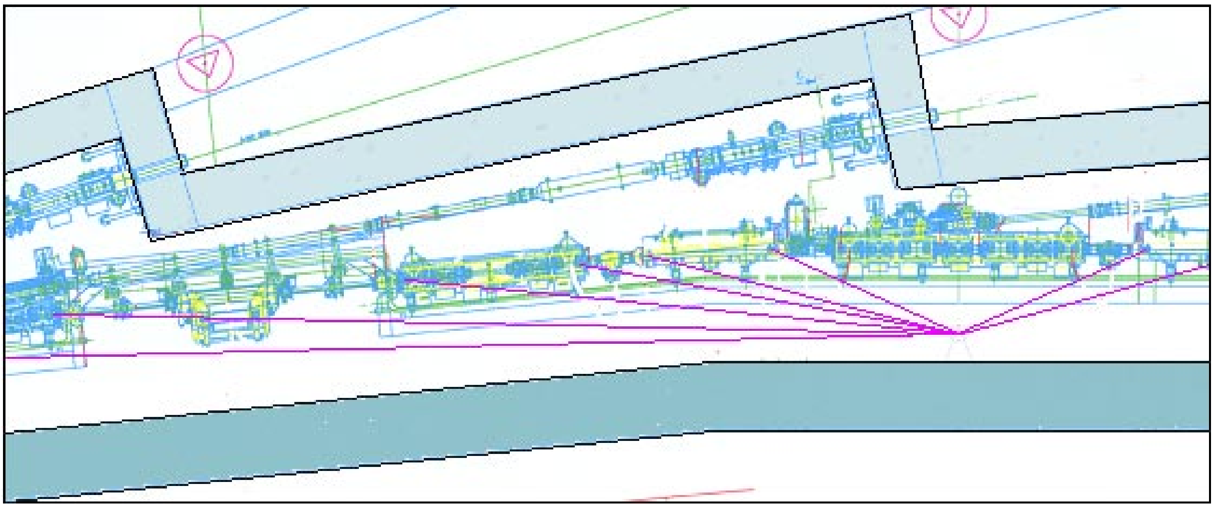

Figure 1 Network and measurement configuration of the ESRF tunnel.

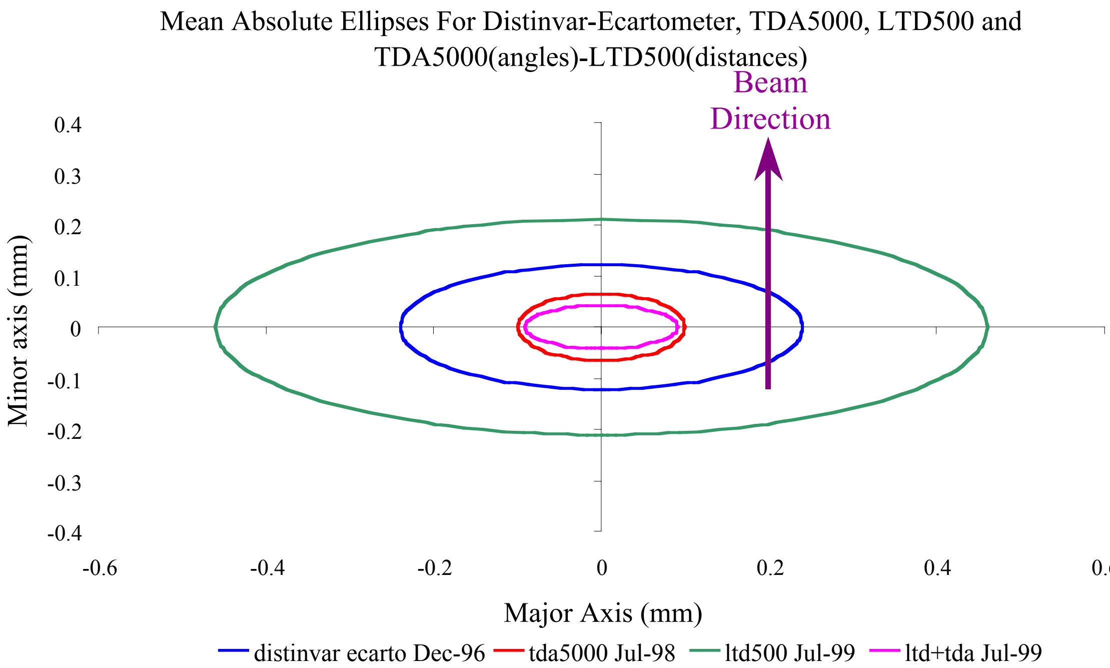


Figure 2 ESRF machine survey network error ellipses for different instrument configurations. The perpendicular direction to the electron beam travel (radial direction) is the most sensitive to angle measurements.

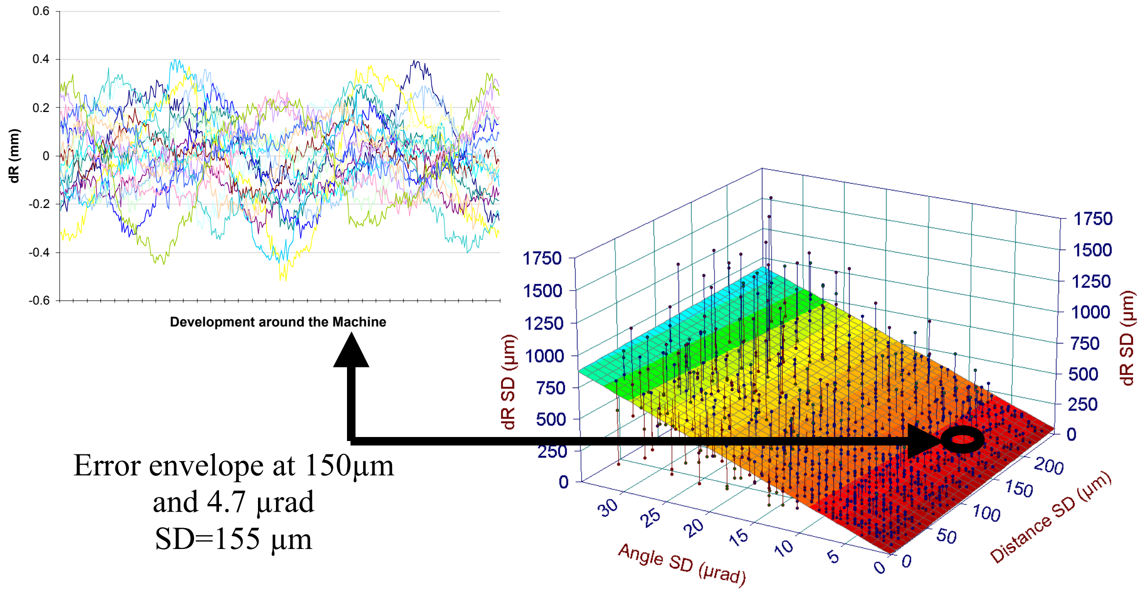


Figure 3 The incertitude surface derived from simulation associated with the ESRF machine network

direction is the most sensitive to angle measurements while the direction along the travel of the beam is most sensitive to distances. This is demonstrated in figure 1 where we see the majority of the observations are along the direction of the beam. The error ellipses for surveys made on the ESRF machine with these different instruments are shown in figure 2. Neither the Distinvar/Ecartometer pair nor the Laser Tracker can compare with either the intervention time or the precision of the TDA5005. There is a clear explanation for this. The angular precision of the laser tracker is approximately 13 dmg (20.2 µrad) whereas the angular precision of the TDA5000 theodolite is approximately 3 dmg (4.7 µrad)[2]. Even the remarkable distance accuracy of the laser tracker (18 µm) is insufficient in the ESRF context to offset its comparatively poor angular accuracy.

When a network configuration has been fixed, the relationship between point determination, and in particular radial error, with respect to distance and angular precision can be studied. Simulating the survey network under different precision conditions does this. An incertitude surface as shown in figures 3 and 4 can be constructed. This surface can then be used to estimate radial error for different instrument precisions. This surface shows that for an amelioration in radial error standard deviation of 10 µm either the distance precision must be increased by 48 µm or the angle precision must increased by 0.41 µrad. The measured and modeled dR standard deviations are close to these values lending agreement to the model.

[2] These are values issued from least squares calculations of the ESRF machine network. Leica the manufacturer of the LTD500 laser tracker quotes its precision as 10 ppm or 18 µm or µrad for the mean ESRF distance of 18 m. Leic quotes the TDA5005 precision as 0.5 arc seconds or 2.42 µrad

Because the network is fixed, to improve radial precision, one must improve instrument accuracy. The only way to do this is by instrument calibration.

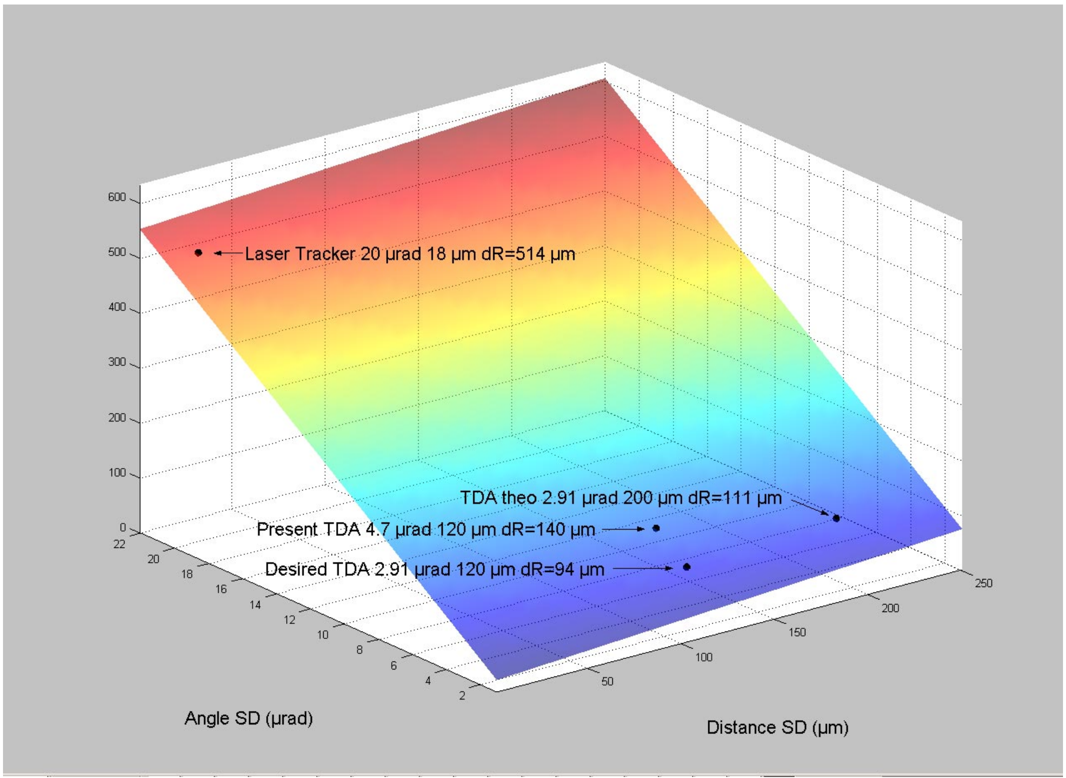


Figure 4 ESRF machine network radial error incertitude surface with different instrument configurations. For comparison, the laser tracker measured standard deviation in dR is 461 µm while the TDA5005 is 105 µm.

## 3. INSTRUMENT CALIBRATION

### 3.1 Distance Calibration

The ESRF calibration bench is used to determine the zero and cyclic errors of EDM instrument/reflector pairs. The zero error, or the offset between the distance measured by the instrument and the true distance, is first determined. Then the instrument prism is moved along the bench and distances are measured by the EDM. A photograph of the ESRF calibration bench setup is shown in figure 5. These distances are compared to simultaneously measured interferometer distances. The results are a calibration curve as shown in figure 7 below. A Fourier series can model this calibration curve. Residuals with respect to a modeled curve are generally less than 0.1 mm. This curve can then be used to correct measured distances. When these corrected distances are used in the least squares adjustment of the machine network there is a net amelioration in the distance standard deviation from 0.18 mm to 0.12 mm and consequent

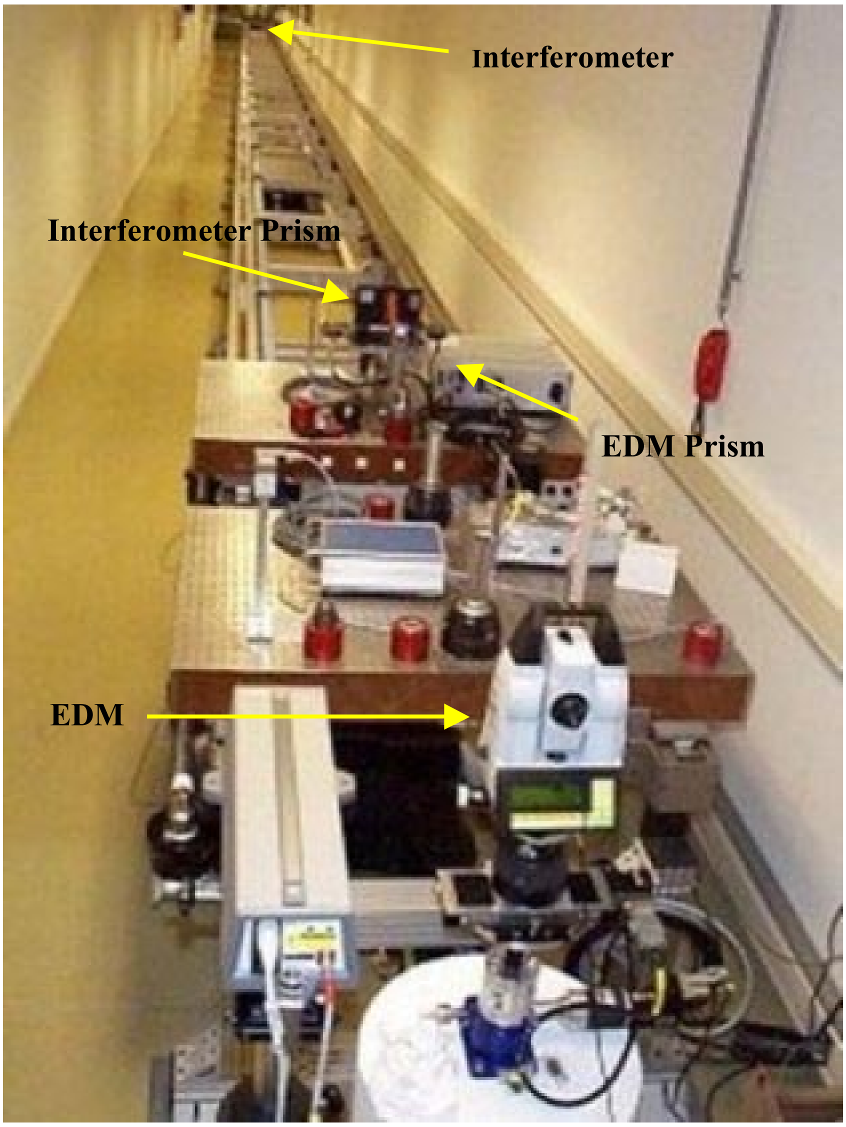


Figure 5 Photograph of the ESRF calibration bench

improvement in the radial error incertitude. Furthermore, the distance residuals become more normal when the distance calibration is used (refer to figure 8).

It is the intention of the ALGE group to extend the present accreditation for EDM instruments for distances up to 100 m. At present, tests are being conducted with the mirrors in a fixed position at one end of the bench. The theodolite is placed at the other end of the bench laterally offset by 30 cm from the laser interferometer. The EDM reflector is positioned on the carriage as usual. The carriage is moved along the bench at 10 cm intervals and simultaneous interferometer and EDM distances are taken. This method requires that three instrument setups be used to ensure overlap in the measurements. Although much work remains, results are promising with a difference standard deviation between the established calibration and the new 100 m calibration in the overlap zones of better that 0.1 mm (see figure 9). This is very close to the residuals associated with the model shown in figure 6.

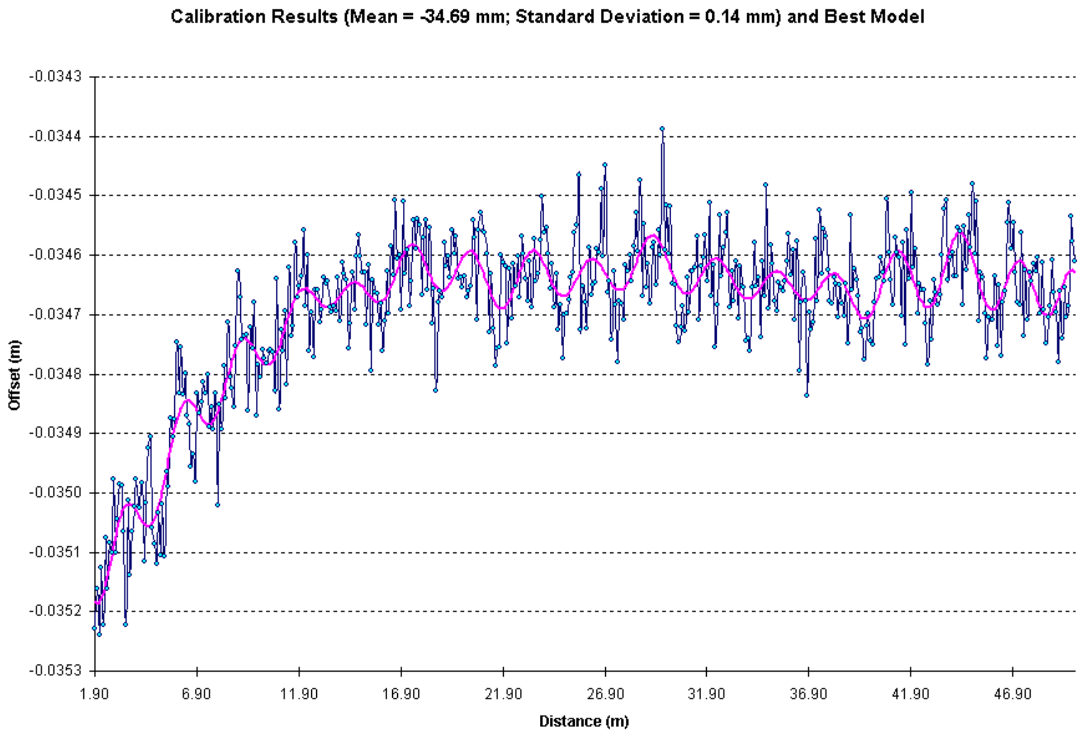


Figure 6 Typical calibration curve for an EDM. Deviations from the smooth modeled curve are 0.06 mm.

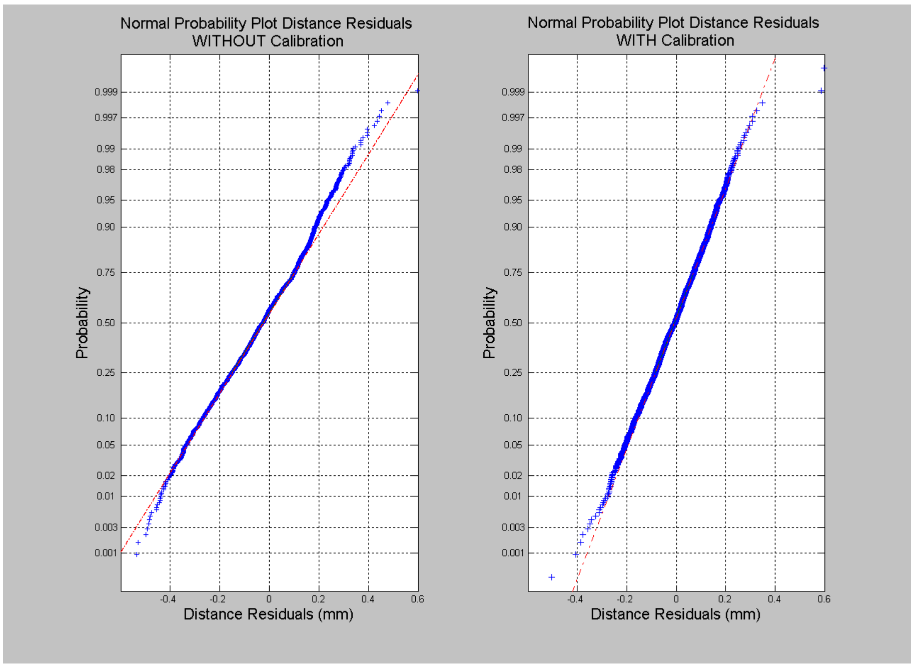


Figure 7 Distance standard deviations issued from the least squares calculation are more normal after the calibration model is employed

.

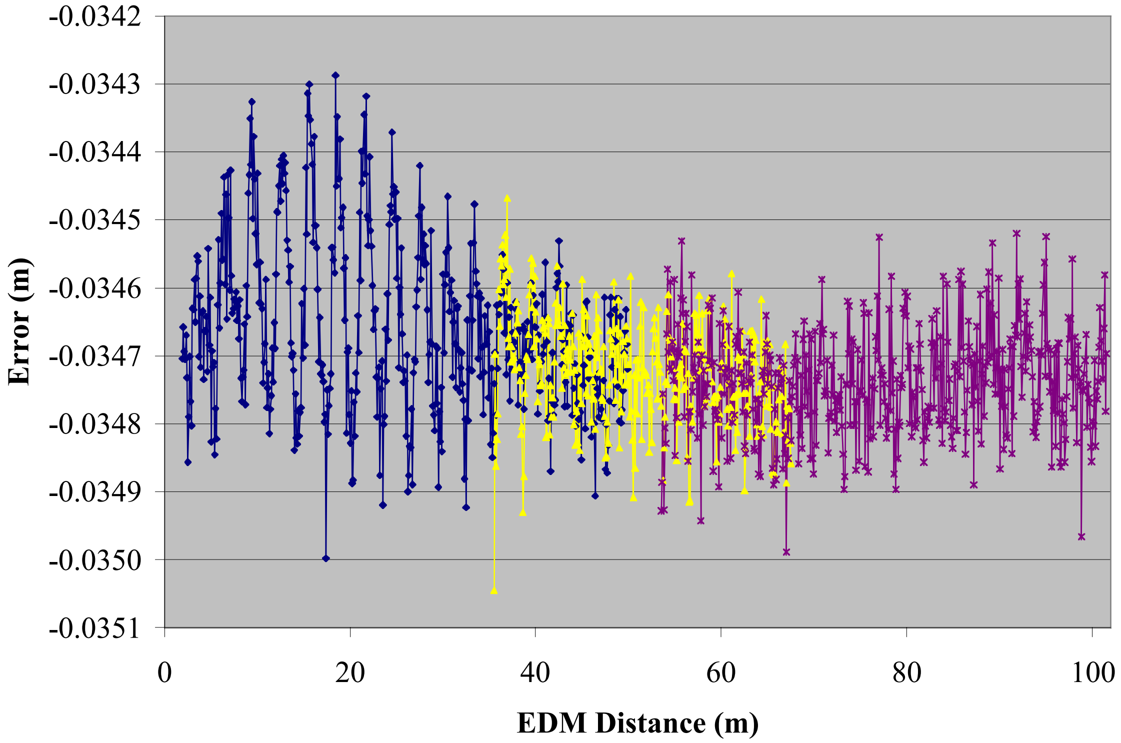


Figure 8 Results for the 100 m calibration. Standard deviations between values in the 'overlapped' regions are 0.08 mm.

### 3.2 Angle Calibration

As has been shown, considerable improvement has been made in the distance standard deviation at the ESRF by employing rigorous calibration techniques. Being at the limit of the TDA5000/5 distance measuring capacity, one can only expect improvement by increasing the accuracy of the angle measurements. From the discussion on potential achievable precision, one can expect a dramatic improvement in the radial error incertitude for a comparatively small improvement in angle measurement accuracy. Clearly, in the case of the ESRF at least, there is a very strong incentive to improve the angle measuring accuracy. One method of improving angle precision is to calibrate the angle encoders as is done at Leica.

At the ESRF an angle dependence on distance has been observed[3]. A second method of improving angle accuracy is to model this dependence. One ESRF TDA5005 instrument behaves differently from the two others when angles taken at short distances are compared. We have developed an empirical angle correction as a function of distance for this instrument. When uncorrected this error has important consequences on the results of the machine radial error. This

[3] The manufacturer of this instrument recommends it be used in ATR mode at distances greater that 6 m.This error concerns principally distances inferior to this limit.

angular dependence is shown in figure 9. Moreover, even when corrected, the angle residuals issued from the least squares adjustment are not normally well distributed. For these reasons, recently a method using the ESRF calibration bench has been developed to determine the angular error of a theodolite as a function of distance. This method appears to work well and will be fully exploited in the next year in an effort to improve the angle measurements precision. Reults of a calibration are shown in figure 10.

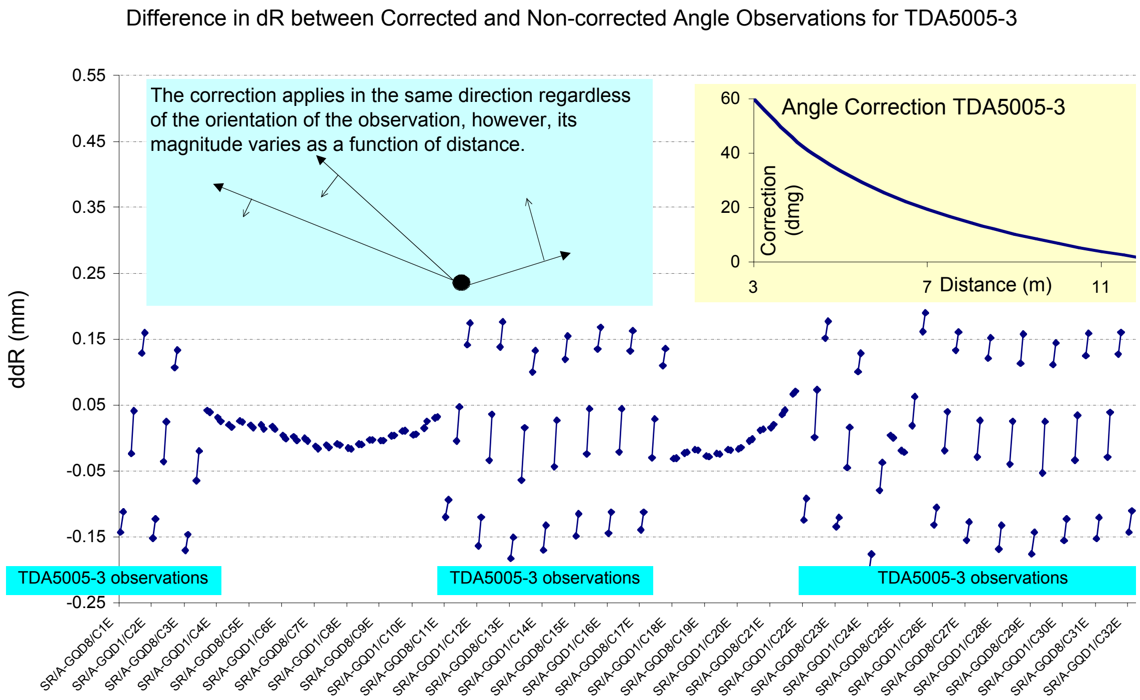


Figure 9 Radial error as a function of instrument used. When uncorrected this error has important consequences on the results of the machine radial error.

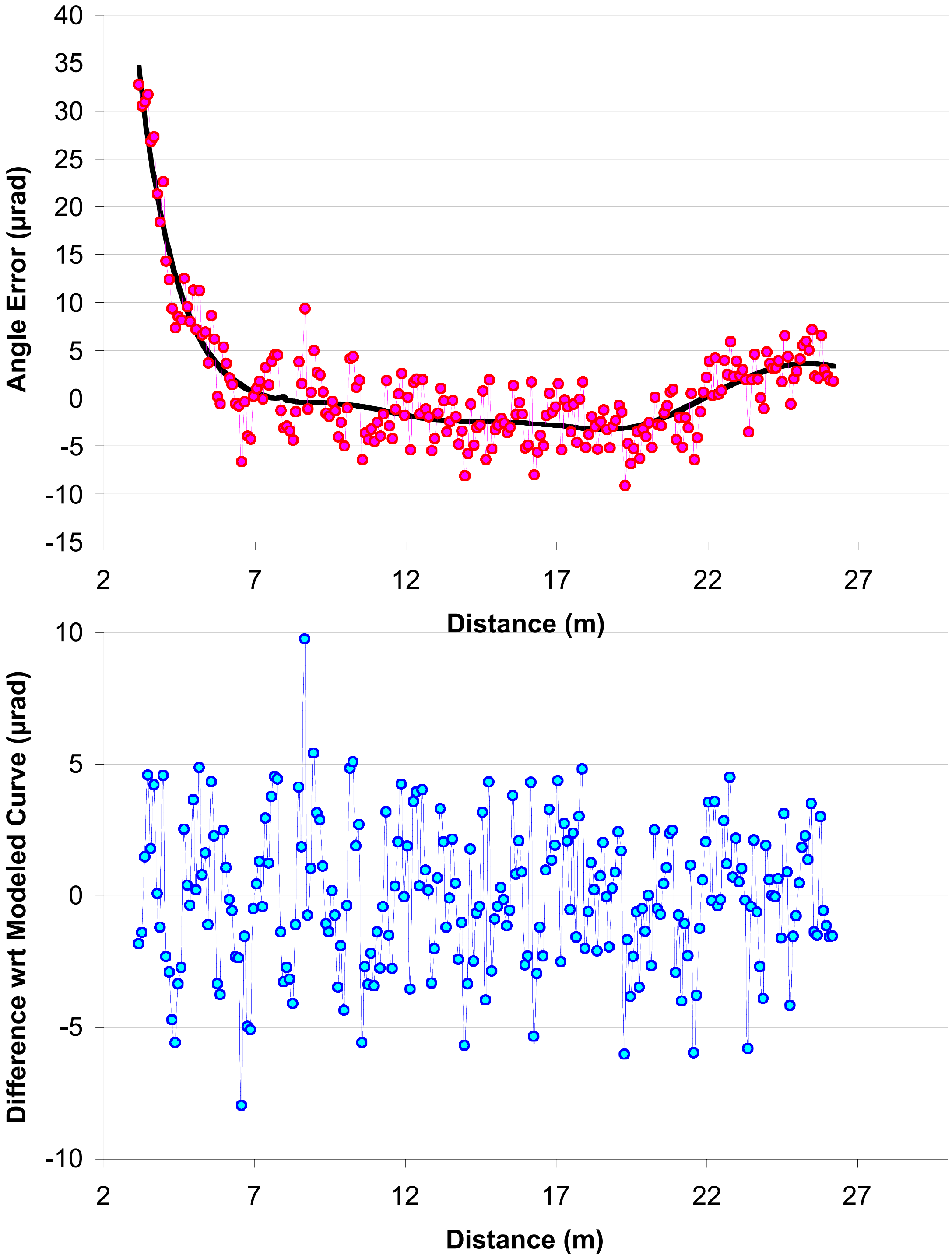


Figure 10 Results of a calibration of angles and residuals with respect to a modeled curve as a function of distance for one ESRF TDA5005 total station.

## 4. CONCLUSIONS

The degree of precision to which we can hope to measure a survey network is dependent upon its configuration and the instrumentation used to measure it. At the ESRF considerable efforts have been made to improve instrument precision and in particular distance measurements by means of calibration. COFRAC accreditation under the ISO/CEI 17025 Norm has ensured that the greatest rigor be applied in the calibration techniques used at the ESRF. Measurements have shown that in order to improve upon alignment accuracy, we must now make an effort to improve angle measurement precision. We are presently developing an angle calibration method that will reduce those errors associated with an observed distance dependence.

## 5. REFERENCES

[1] Gatta G., Levet N., Martin D., Alignment at the ESRF, Proceedings of the Sixth International Workshop on Accelerator Alignment 1999, Grenoble France.
[2] Claret E., Etude de la Base d'Etalonage de l'ESRF, ESGT Le Mans France, July 1999.
[3] Zeiske K, Current Status of the ISO Standardization of Accuracy Determination Procedures for Surveying Instruments, FIG Working Week 2001, Seoul Korea 6-11 May 2001, FIG
[4] Maillefaud J.D., Etude De l'etalonnage des Systems de Mesure d'Angle Pour les Theodolites au Sein de L'European Synchrotron Radiation Facility, ENSAIS, Strasbourg France, July 2002