

Tests of the Leica Total Station for Survey & Alignment of the MINOS Detectors

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An important step in the survey and alignment of the MINOS detectors is the selection of a device to be used for this work. The Leica TCR307 reflectorless total station is under consideration for this role. As a total station, it measures both distance and angle. The manufacturer's specifications of the accuracy are $3\text{mm} \pm 2\text{ppm}$ for distance measurements up to 80 m without a reflector and 7 arc-seconds for angular measurement. Surveyors from the Fermilab Alignment & Metrology group took measurements to determine the performance of the Leica TCR307 under conditions comparable to those expected during construction of the actual detectors. These tests measure the accuracy of the TCR307 within a reference frame established with a set of highly accurate control measurements and the repeatability of measurements with the TCR307.

Test Setup

Two scintillator modules were laid side by side on the floor of New Muon Lab. A grid of chalk lines 2 feet apart was laid out on the modules and these were used as guides for the placement of stick-on survey targets and pencil marks. There were a total of 26 targets and 26 pencil marks (see Figure 1). Each was approximately 0.5 inch from the edge of the module.

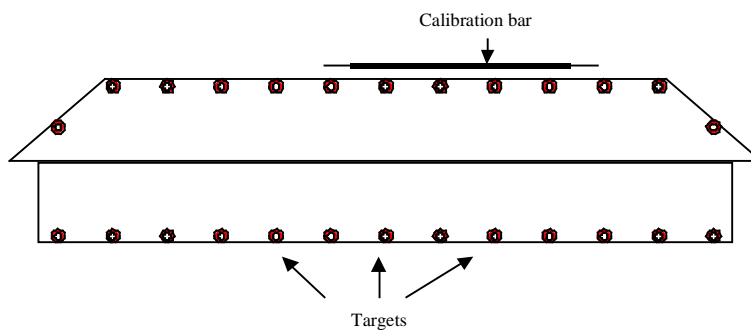


Figure 1 Placement of survey targets on scintillator modules in New Muon Lab. Positions are approximate. Target size is exaggerated for clarity (actual size = 0.75"). A pencil mark (not shown) was made beside each target for comparative measurements.

The figure is shown facing south. The survey shots were taken from station locations to the north and west on the mezzanine. Two Kern E2 BETS stations were set up on the north mezzanine to establish a reference frame for the Leica measurements. The calibration bar shown in the figure is used to establish a scale for the BETS stations. These stations have a greater nominal accuracy than the TCR307 and establish a “true” frame of reference for the purpose of these tests. The TCR307 shots were taken from three positions: a) the north end of the mezzanine, between the two BETS stations; b) the northwest corner of the mezzanine; c) the west end of the mezzanine across from the modules. The mezzanine was measured to be 20.5 feet above the floor, comparable with the 20-foot height planned for the mezzanine in the MINOS Far Detector Hall. The station-to-target distance was in the range of 11 m to 15 m.

Data

Six sets of measurements were made with the Leica total station. The measurements included shots of all 26 targets and shots of all 26 pencil marks from each of positions a, b, and c. The data shown depict the differences in various measurements. Figure 2 shows the approximate positions of the modules and the survey stations.

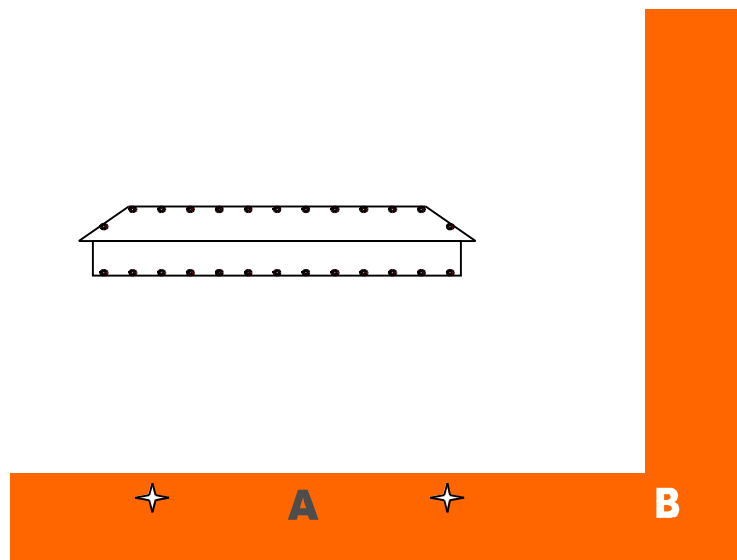


Figure 2. Layout of the test modulus and survey station positions in the New Muon Lab (not to scale).

Comparison of Leica with BETS

Figure 3 shows a comparison of the Leica data with the BETS. For the purpose of this comparison, the error in accuracy of the BETS is considered to be negligible. The result may be considered a measurement of the absolute accuracy of the Leica. The data plotted are obtained from the RMS values for the differences between the Leica and BETS measurements. The bar height depicts $\sqrt{(x_{\text{RMS}})^2 + (y_{\text{RMS}})^2 + (z_{\text{RMS}})^2}$, where x_{RMS} represents the RMS value of the differences between the BETS and Leica measurements of x for each target/mark and similarly for y_{RMS} and z_{RMS} . The x - y plane is that of the detector surface.

The columns labeled RED are the data for the surveying targets, the columns labeled PEN are the data for the pencil marks and the columns labeled ALL are for the combined data sets. The A, B, or C designation of the columns indicates the position from which the data were taken. It is immediately obvious that the data taken with surveying targets achieve significantly better accuracy than those taken with pencil marks do. A possible cause is that the reflectivity of the aluminum module renders the pencil marks difficult to shoot accurately. The data also show a clear dependence on the position from which they were taken. Although variation of distance might account for a small portion of the dependence, it is primarily due to the differing angles at which the ambient light is reflected from the aluminum surface and the differing perspective of the target array as seen from the survey station. It was found that the shots taken on the pencil marks were susceptible to significant deviations due to shadowing from objects within the hall, whereas the shots taken with targets were not.

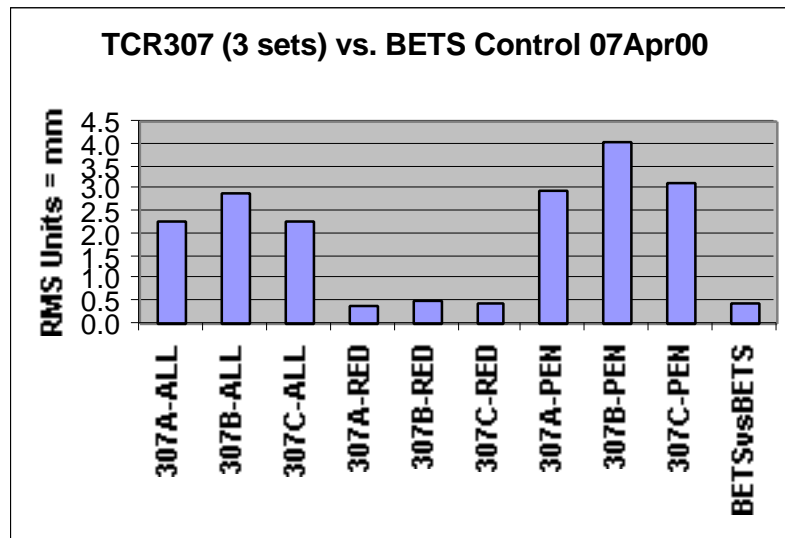


Figure 3. RMS values of the TCR307 measurement deviations from the BETS values (see text). The average is taken over all 26 targets (RED), 26 pencil marks (PEN) and the combined data for all 52 (ALL). A comparison between two BETS measurements gives an indication of the precision of the BETS measurement.

Repeatability Tests of Leica

Figure 4 shows an intercomparison of the Leica data taken from positions A, B, and C. The column designations AB, AC, BC indicate the positions for which the data are compared. Once again, the data represent the RMS values of the measured differences of data taken with targets, with pencil marks, and for the combined data set. The improved consistency of the measurements taken with surveying targets is clear from the figure.

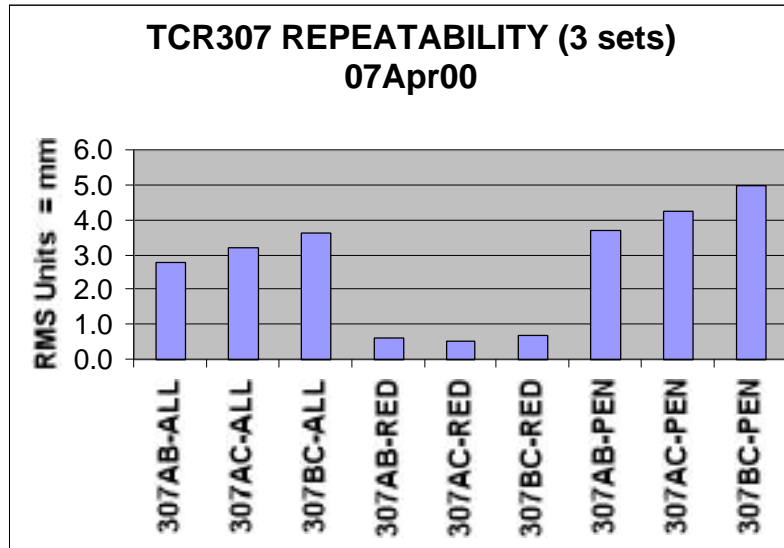


Figure 4. RMS values of the deviations when measurements with the TCR307 are taken from different locations (see Figure 2). The averages are taken over 26 targets (RED), 26 pencil marks (PEN) or all 52 points (ALL).

Expected Accuracy

The accuracy achieved in these tests may be compared with that expected from the reported 7 arc-second ($34 \mu\text{rad}$) resolution of the TCR307. Dividing this angle by distances of 11 – 15 m gives an expected linear resolution of 0.34 – 0.51 mm, consistent with the target data of Figure 3.

Conclusions

These tests indicate that the Leica TCR307 total station performs within the manufacturer's stated accuracy. It is clear that the system's performance is dramatically improved when surveying targets are used. Assuming that the station-to-target distance during detector construction is no more than 15 m, the survey measurements may consistently achieve accuracy on the order of 0.5 mm.

For the purposes of track reconstruction in the detector, the important uncertainties are those of the scintillator strips within the basis reference frame in the far detector hall. This is determined by the uncertainty of the strip location within the module, the uncertainty of the module location on the detector plane, and the uncertainty of the location of the plane within the basis. There are two contributions to the second uncertainty: The first is the uncertainty in placing the survey target on the module and the second is the uncertainty in surveying the target. If a jig or template is used to position the targets, 2 mm is a reasonable ballpark guess at the target placement error.

The uncertainty in strip placement within the module is estimated at 2 mm. Assuming a 0.5 mm survey error and adding the errors in quadrature, the total error in the strip position is then estimated at 3 mm. The author is indebted to Stu Lakanen and Terry Sager of the Fermilab Alignment & Metrology group for their help in preparing this note.