International Hydrographic Review, Monaco, LXIX(2), September 1992

ACCURACY INVESTIGATIONS ON A POLAR POSITION-FIXING SYSTEM

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Abstract

This paper affords an insight into some investigations about geodetic devices carried out by the Federal Institute of Hydrology in Germany. The methods developed and the results of the field tests are presented. The qualities determined and the accuracy of the device correspond in almost all cases with the statements of the manufacturer.

MOTIVATION AND AIMS

The Federal Institute of Hydrology has, amongst other things, the task of investigating and developing new devices and procedures for hydrological surveying. Within the scope of the investigations, it must test to what extent the device or procedure is suitable for use by the Federal Shipping Authority (WSV - Wasser- und Schiffahrtsverwaltung). The POLARTRACK unit was introduced to the market by the Krupp Atlas Elektronik company (KAE) in autumn 1990. The purpose of the investigation was:

a) to develop methods of investigating the unit, and
b) to perform the device investigation as such.

POLARTRACK LASER TRACKING SYSTEM

A polar position-fixing system measures the polar coordinates for range, direction and vertical distance with respect to a target point at certain instants in

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time. Once the horizontal reference angle is known, planar cartesian coordinates and an ellipsoid height difference between the target and the location can be calculated. POLARTRACK consists of the components shown in Figure 1. After the tripod has been set up, the hand-held terminal is used to control the unit. The Positioning Unit mainly serves to perform automatic tracking of the Scan Unit with regard to a target. The location of the Positioning Unit in space (coarse angle) is scanned by means of incremental shaft encoders. The Scan Unit has the task of measuring all observable quantities. The range measurement is performed by two separate transmission and reception optics using the pulse method. The deviation of the reflector from the optical axis is measured in a scan field (fine angle). Through addition of the coarse angle, the final angular measurement value is formed. At close range (d < 1100 m), the size of the scan field is automatically doubled to 20 mrad. The device is equipped with an electronically controlled automatic level compensator.

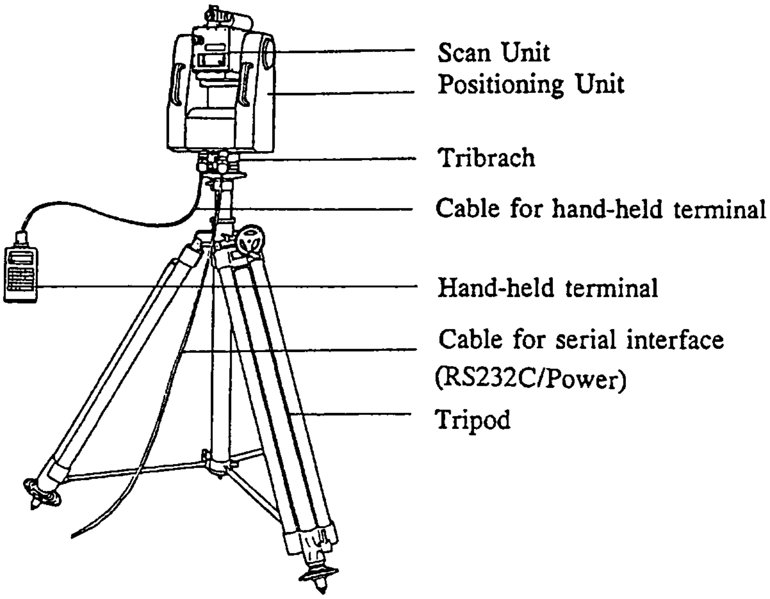

FIG. 1.- Components.

The unit is fitted with a simplex telemetry unit. POLARTRACK can also be controlled via this telemetry system; to do this, the data stream is interrupted at regular intervals. The unit can be calibrated and adjusted by the user himself without any need for sending it back to the factory. The manufacturer's data regarding the device's characteristics are given here in the form of an excerpt:

Range accuracy:	±15 cm + 5 ppm
Angular accuracy:	±10 cm + 5 cm/km
Height accuracy:	±5 cm + 5 cm/km
Data transfer rate:	between 5 and 10 Hz

The most important operating functions are as follows:

DAT: Input of the system data (location coordinates etc.)
REF: Aiming at the reference reflector
SET: Manual aiming at any reference point without issuing commands
LOC: Automatic target tracking
CHK: Measuring any point without a reflector

ERRORS OF POLAR POSITION-FIXING

In the accuracy investigation, a distinction had to be made between the device-related errors, external error influences and the so-called model errors; their individual magnitudes had to be determined or estimated sufficiently precisely. Moreover, it was possible to differentiate between the attainable device accuracy under laboratory conditions and, at the opposite extreme, under field conditions with average external influences. Since the statements to be made by the Federal Institute of Hydrology must apply to a wide range of operating conditions, the second method was selected.

The device-related errors can be subdivided into random measurement deviations and systematic measurement deviations. Addition constants and data age must be emphasized here as the quantities that must be determined. Here typical external errors are faulty centering, issuing of target commands and variations in the refracting layers of air. Model errors are mainly refraction deviations from the model value and non-detectable geodesic undulations.

MEASUREMENT PROGRAMME

In setting up the measurement programme, various questions had to be answered, the overall task extent had to be analysed and these had to be transformed into a solution concept.

Defining the Problem

First of all, the project was defined in the manner described in Section 1 and, amongst other things, the manufacturer's data had to be checked with methods still to be developed. The error influences already recognized were specified, in addition to the determination of suitable reference values that were intended to serve as conventional true values with sufficient reliability and that were specified as target parameters. The selectivity required for a statement appropriate to practice was determined for the target parameters. The unit had to be investigated for its accuracy with and without telemetry in static and dynamic applications using various methods.

Measurement Concept

The range of the unit had to be determined under practical conditions. In these trials, the signal strength and the number of reflector rings were varied. The decisive qualitative criterium is the relative frequency of measurement gaps.

The response threshold, i.e. according to DIN 1319 Part 2 "that value of a required minimum change in the measurement parameter that causes an unambiguous change in the display", had to be determined for a selected measurement range. For this purpose, a reflector was moved by precisely specified amounts along and across the measurement beam and also shifted in height. The response threshold is identical to the maximum attainable measurement accuracy.

In a geodetic reference grid consisting of five reference pillars, for which the spatial distance, height difference and angles were known, the angular accuracy of POLARTRACK had to be determined and compared for various modes (REF, SET).

The precision and trueness of the distance measurements were tested on a calibration path of the State of Rhineland-Palatinate that consisted of 11 reference pillars set up in a straight line. The largest testable range was 1500 m, which is still within the close range of POLARTRACK. In order to test the reproducibility of the angular measurements, the average value of the measurements to the farthest arrow were taken to serve as a comparative value for all other measurements. For the same reason, the range measurements to all arrows were observed for the forward and return path.

For the evaluation of the static measurements, a software package was developed to permit evaluation of the measurements and graphic display on a plotter. The software calculates all relevant statistical quantities and produces a line diagram and frequency diagrams with which the measurement accuracy can be evaluated in relation to the uncertainty of measurement defined in DIN 1319.

It was also necessary to check whether the measurement values were filtered within the unit. To see whether this was indeed the case, a target was tracked on a specified geometric path. For this purpose, a target reflector was fastened to a circular disk. The disk was made to rotate, and the polar position-fixing system was made to track the reflector, whereby its measurement values were transferred to a PC, which stored the data together with the measurement instant. The spatial position of the reflector was registered through electronic scanning at discrete instants in time. Through interpolation of the actual reflector position for each measurement instant, it is possible to create a conventional true value (desired value). Moreover, it is possible to determine the age of the data by desired/actual comparison.

As a further kinematic test method, the target tracking was performed with a vehicle that was intended to provide a movement as similar as possible in speed and shape to that of a measurement vessel. The actual movement of the target had to be reproducible and therefore a land-based vehicle was designed (Fig. 2). A local reference grid was set up for the tests, as a basis from which the locations of the polar position-fixing system and the vehicle tracks could be calibrated in position and height.

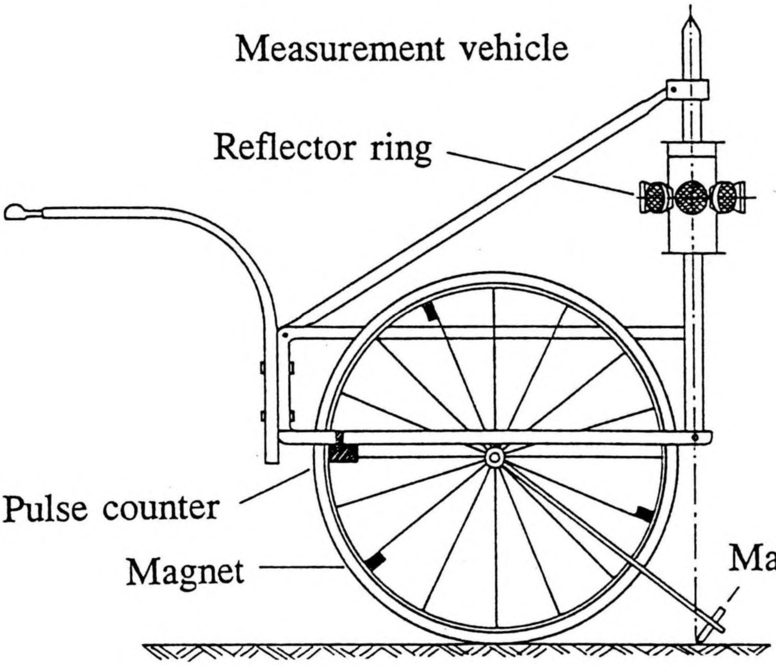

FIG. 2.- Measurement vehicle.

POLARTRACK's measurement values were again recorded with the aid of a PC. During the measurement trip, the vehicle's track was marked on the earth's surface and the passing times of the magnets were stored by means of the pulse counters on a second PC. After this, the vehicle's tracks were calibrated with due care with regard to tachymetry and levelling. For the computer evaluation, a program was produced that lays a spline function through the measured track points, determines the conventional true values and the errors of the measurements for each measurement instant and also splits them up into random and systematic components. The trips were performed radially with regard to POLARTRACK's location for the purpose of analysing the range accuracy and also tangentially for separate analysis of the angular accuracy. This separation was also necessary for independent determination of the data age of the measurement parameters.

Organisation of the Measurement Sequence

The required measurement devices were either already available at the Federal Institute of Hydrology or were lent by the local offices of the Federal Shipping Authority. Provision of POLARTRACK was coordinated with Krupp Atlas Elektronik. The use of the reference pillars was permitted by the Landesvermessungsamt (State Surveying Authority) of Rhineland-Palatinate, which made it possible to realise the planned measurement configuration. The measurement vehicle was produced by the Federal Institute of Hydrology workshop according to own specifications.

MEASUREMENT RESULTS

In the execution of the measurement program, approx. 11,000 measurement campaigns were registered during the static measurements. The kinematic measurement series comprised a further approx. 6,000 measurement campaigns. In each measurement campaign, the range, direction and vertical distance were measured.

The range determination was performed separately for measurements with laser class I (up to 5,000 m) and for laser class IIIa. As shown in Figure 3, the frequency of measurement gaps increases with distance. The use of additional prism rings compensates for this disadvantage to a large degree, so that with two prism rings and laser class I the range of approx. 5,000 m and for laser class IIIa and three prism rings, a range of over 10,000 m is covered. In order to attain these results, however, a clear atmosphere with strong wind and therefore good optical visibility is required.

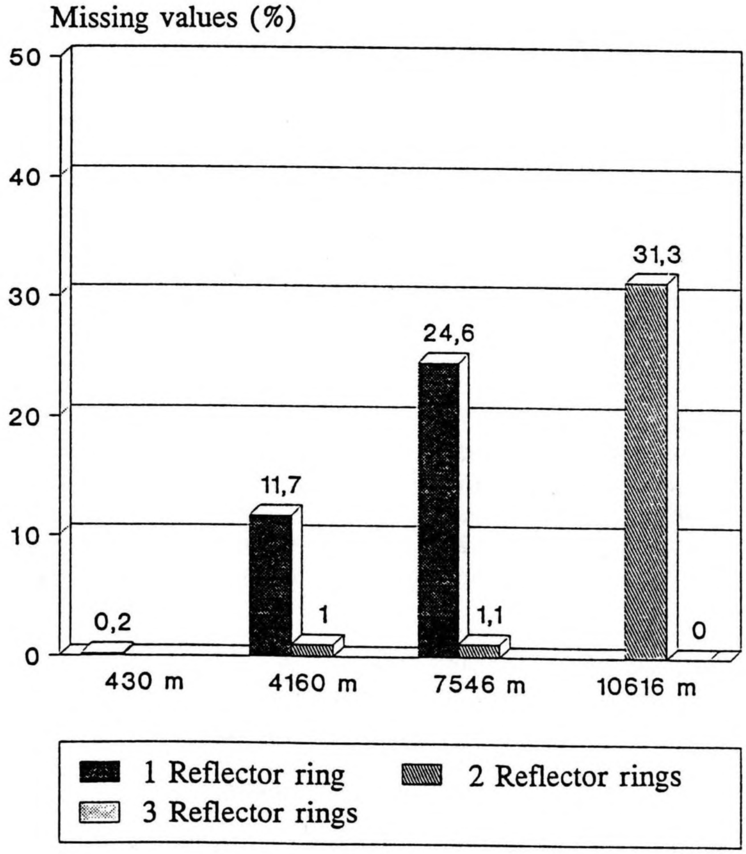

FIG. 3.- Range test.

The response threshold was determined for all three measurement quantities with respect to a target approx. 1,080 m away, whereby the reflector was moved in defined steps. Due to the observed width of the noise band (about 20 cm), the angular measurement values were obtained for the vertical distance from the comparison of the measurement values with the conventional true values, resulting in a response threshold of ±0.009°. For the angular measurements, a response threshold of approx. ±0.007° was observed. If the measurement values are filtered, the response threshold rises to approx. ±0.0035°. The differences are so minimal that one can speak of identical response thresholds for the angular measurements for this bandwidth of measurement noise. The various distance measurements have a response threshold of approx. ±0.05 m.

The evaluation of the range measurements performed on the calibration path provided identical results for the forward and return path. For distances of less than 100 m, an additive constant of 0.02 m and for the larger range an additive constant of 0.12 m were determined. The standard deviations amounted to an average of approx. ±0.03 m. The maximum errors of measurements were less than ±15 cm after taking into account the additive constants. The manufacturer's data were therefore verified. The scattering of the pillar-related average values for the direction measurements are a measure of the precision or repeatability. The repetitive standard deviation was determined to be ±0.003°.

For the angular reference grid, the measurements were performed in three sets using four pillars. In the first set the function REF and in the second set the function SET were used to set the horizontal reference angle. In comparing the measurement results, no deterioration was detected for the manual aiming, but in both sets an orientation error of approx. -0.015° was calculated in each case. In the third set, the compensator was switched off, which also lead to a clear deterioration of the measurement results. Measurement gaps occurred frequently for the angular measurements and for the vertical distance measurements; these were presumably caused by the gusty wind.

The analysis of the measurement values, which were recorded for the disk rotating at a distance of 74 m, provided the certainty that POLARTRACK outputs the raw measurement values to the interface in an unfiltered form (Fig. 4). The average data age was calculated to be 0.36 seconds. In this test, it was not yet possible to provide separate values for the individual observation quantities. The computer evaluation of the measurements yielded mean true errors to the true values of ±0.028 m for the vertical distances. After separating out the systematic components, the accuracy that was attained increased to ±0.017 m. For the angular measurements, a systematic orientation error of -0.183° was observed as for the reference grid. The mean distance accuracy corresponded to the accuracy obtained for the static measurements.

In the last and most time-consuming part of the trials from the equipment and personnel point of view, POLARTRACK was investigated for profile tracks. Here a data age of +0.339 seconds was obtained for the distance measurements. For the angular measurements, a data age of +0.229 seconds was calculated. If the telemetry is included in the data transfer, these values are increased by a further 0.039 seconds.

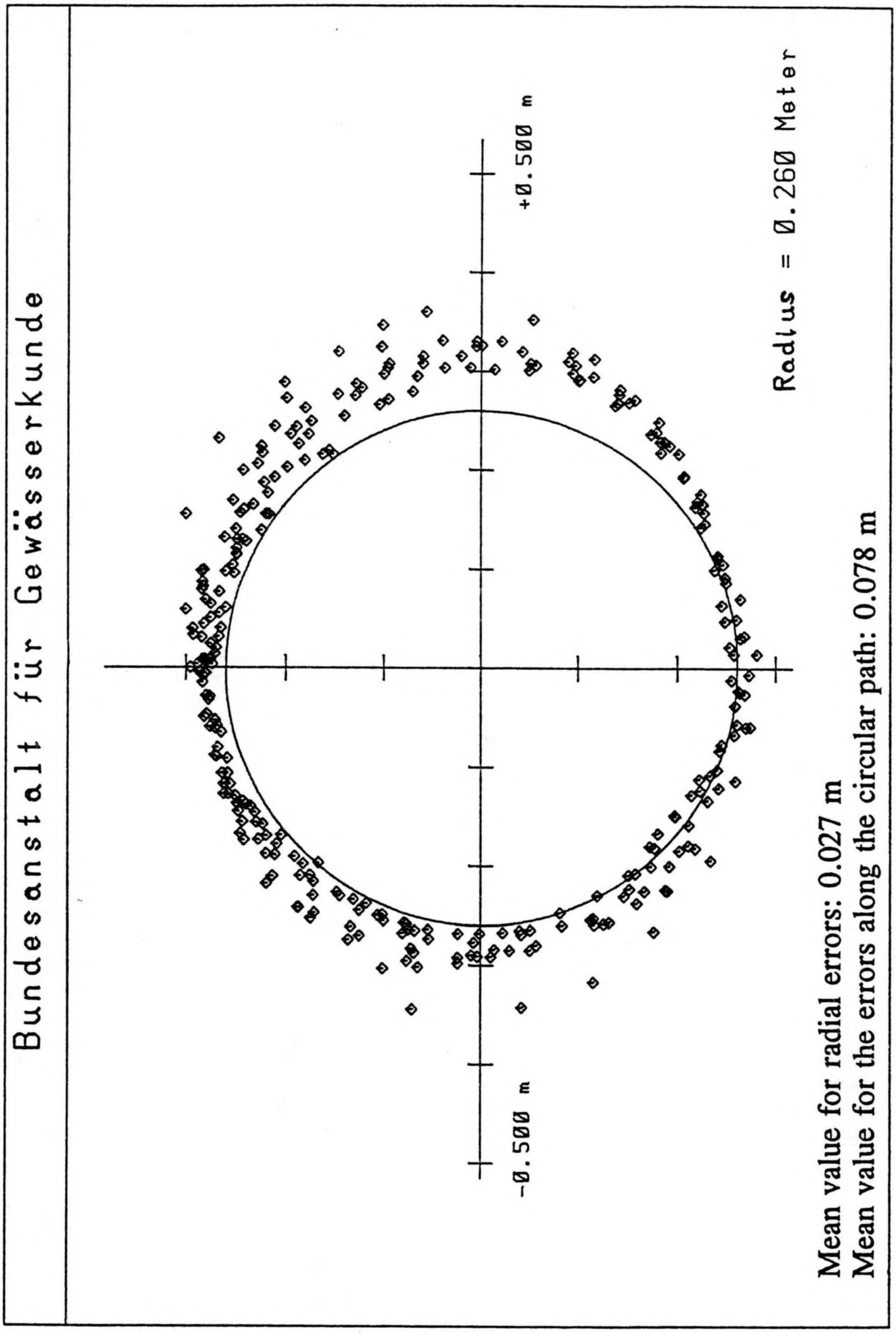

FIG. 4.- Circular tracking test.

The accuracy of the distance and angular measurements is influenced by the type of target. The prism ring that was used had a radius of 15 cm. The angular measurements generally scatter by about ±15 cm for tangential motion because different prisms are aimed at when the Positioning Unit tracks the target. In the radial direction, the device seems to fix successfully on a single prism at close range (< 1000 m). In the computer evaluation, the average corrected deviations are therefore reduced to ±0.0029°, which approximates the response threshold that was determined. The uncertainty of the angular measurements must be specified in all cases as ±15 cm to provide a margin of safety. In this connection, "corrected" means that systematic components were split off; these are ascribed almost exclusively to orientation errors after the additive distance constants were taken into account in the calculation.

The corrected mean distance errors can be specified as ±0.031 m for radial movement. In the tangential direction, the distance measurements are worsened by the frequent change of target prism at the target ring to a value of ±0.059, since the additive constant is no longer a constant value. In total, the measurement uncertainty for distances of less then 5,000 m was considerably better than ±0.10 m, even for tangential motion.

The evaluation of the height measurements provided, after correction of the raw measurement values with the height index error, mean corrected kinematic errors of ±0.0033°, which corresponds to ±0.058 m/km in metric units. In practical applications of the height measurement it is therefore recommended that distances of greater than 1000 m and also the use of several prism rings installed one above the other should be avoided, since the measurement accuracy deteriorates as a result.

The use of the simplex telemetry caused a transfer gap lasting approx. 1 second every 5 seconds. After this period, the measurement value that was transferred was not a current value, but the value measured immediately before the data gap. This caused a data age of approx. 1.4 seconds for this measurement value which, for a speed of e.g. 4 m/s, yields a position-fixing error of 5.6 m.

CONCLUSION

The test methods that were developed were confirmed in the practical execution and evaluation, because they led to the desired results. The measurement accuracy specified by the manufacturer was verified through more precise specification of the individual errors. The individual results of the investigation led to the formulation of operating instructions that should be taken into account during use by the Federal Shipping Authority. Future investigations by the Federal Institute of Hydrology will also be applied to other position- fixing systems on the basis of these investigation methods.

Although position-fixing by means of satellites will gain in importance, polar position-fixing systems will still have to be used in future. It is expected that in some hydrological areas the establishment of a satellite-supported position-fixing system will be uneconomical or impracticable due to signal shadows, so that polar position-fixing will remain a permanent alternative in certain regions.

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