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LASER TRACKER TEST FACILITY AT SLAC – PROGRESS REPORT*

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Abstract

Physics experiments at SLAC require high accuracy positioning, e. g. 100 µm over a distance of 150 m or 25 µm in a 10 x 10 x 3 meter volume. Laser Tracker measurement systems have become one of the most important tools for achieving these accuracies when mapping components. In order to improve and get a better understanding of laser tracker measurement tolerances we extended our laboratory with a rotary calibration table (Kugler GmbH) providing an accuracy of better than 0.2 arcsec. This paper gives an overview of the calibration table and its evaluation. Results of tests on two of our Laser Trackers utilizing the new rotary table as well as the SLAC interferometer bench are presented.

INTRODUCTION

The calibration facility at SLAC allows testing of distance and angle measurements separately. Angle measurements are tested on a rotary table. Distance measurements are compared to an interferometer bench for distances of up to 32 m. Both tests together give us a better understanding of the instrument and how it should be operated. The observations also provide a reasonable estimate of covariance information (weight) of the measurements according to their actual performance for network adjustments.

ROTARY TABLE

The rotary table RT264TB is built by Kugler GmbH, Salem, Germany. It holds a circular mounting platform with a diameter of 280 mm. The platform sits on two different kinds of air bearings (see Fig. 1). A planar air bearing is located directly below the face plate providing the lifting capacity for the platform and the load. The second air bearing, a calotte type spherical bearing, counters the planar bearing and provides lateral stability due to its shape. The angular position encoder consists of a Renishaw Signum RESM angle encoder system with a 200 mm diameter stainless steel ring with 20 µm graduations and four symmetrically positioned read heads (Renishaw SR). The system is specified with 1 arcsec graduation accuracy and 0.01 arcsec resolution. The use of four read heads eliminates the angular reading errors caused by the eccentricity of the measurement system relative to the rotary axis of the table.

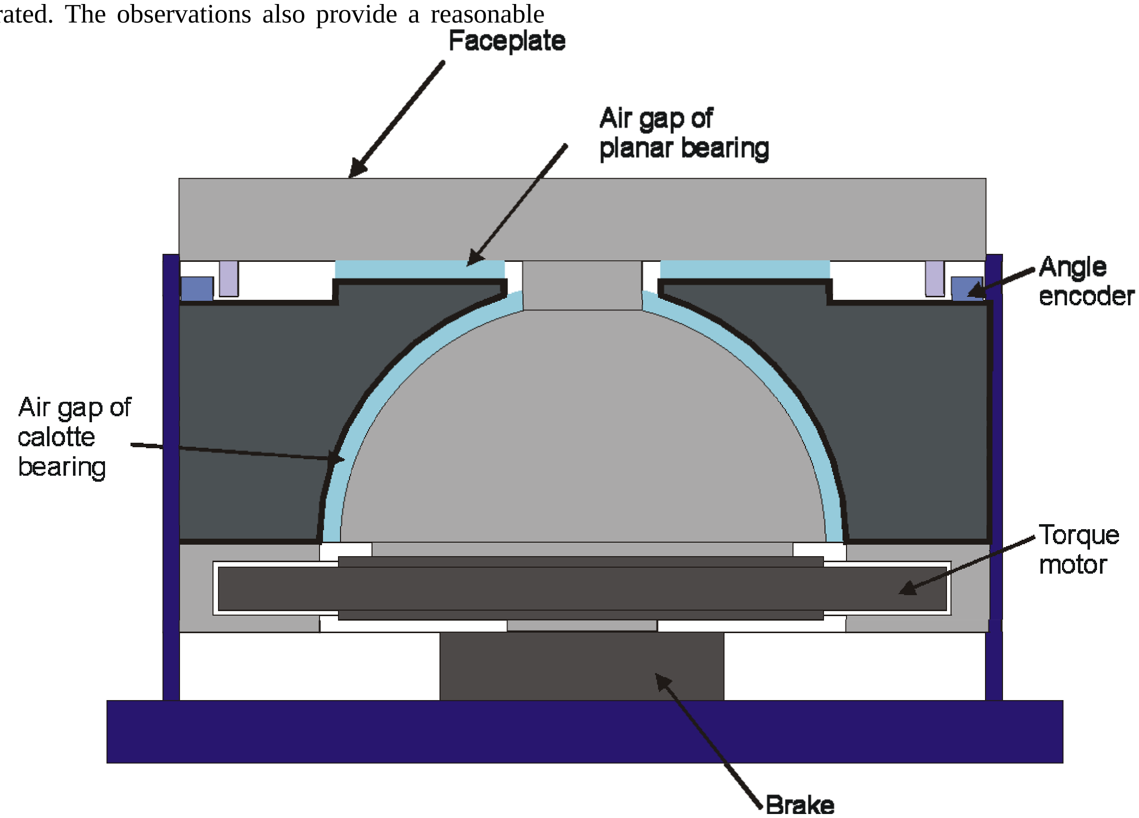

Figure 1 Schematic of the rotary table (Manual [1]).

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Calibration of the rotary table

The verification and calibration of the angular readings of the rotary table is based on the principle of the rosette technique [2, 3 and 4]. The rosette technique is used to calibrate precision polygon prisms (precision polygon prisms have mirrors distributed around a circle at regular angles). Step 1 of the calibration process (see Fig. 3), is to measure the difference of the angle between two adjacent faces from that of two autocollimators. Step 2 is to rotate the polygon prism by the angle between two faces without changing the autocollimators and measuring the difference of the angle between the next two adjacent faces from that of the two autocollimators. This step is repeated for the n sides of the polygon until every angle difference is measured. The sum of the angles measured must result in 360 degrees. With this information the angle between the two autocollimators can be determined and the deviations of the readings can be attributed to deviations of the individual angles from the nominal.

This technique is designed to calibrate polygon prisms which limits its use for the calibration of the rotary table to the n sides of the polygon prism. The approach used for calibrating the rotary table is slightly different. Two autocollimators are again used with a constant angle between them (see Fig. 4). But instead of using a polygon we use a fixture with only two mirrors, where the angle between the mirrors is also constant. The technique applied can be described in steps. The first step is to set the fixture with the mirrors in a way that mirror ‘a’ is in line with autocollimator ‘a’ (see Fig. 4, Step 1). Step 2 is to rotate the table together with the fixture until mirror ‘b’ is in line with autocollimator ‘b’, thereby rotating the table by an angle x (x needs to be evenly dividable into 360). Step 3 consists of holding the rotary table in position while placing the fixture back into the position with mirror ‘a’ in line with autocollimator ‘a’ (see Fig. 4, Step 3). Step 4 is a repetition of step 2, the table is again rotated by an angle x. The steps are repeated until a full circle is completed. A prerequisite for this method is that the internal positioning system of the rotary table can determine the zero position with high accuracy identifying when the full circle is completed. By counting the steps needed to complete the circle, angle x can be calculated and the angles measured by the rotary table at every step can be compared to multiples of x. Angle x can be set to any angle evenly dividable into 360 by changing the position of one autocollimator. The advantage of using a small angle x for a higher resolution is countered by the fact that the technique described tends to drift due to the summation of the angles measured.

The Kugler rotary table has a total of four angle encoder read heads spaced 90 degrees from each other. By analyzing the results of the calibration runs it turns out that the deviations repeat themselves every 90 degrees. Therefore the deviations can be attributed to the graduation ring and the errors of the read heads can be neglected. The results of multiple calibration runs are depicted in Fig. 2. The absolute value of an angle between two positions of the rotary table can be determined with ±0.2 arcsec accuracy after applying the calibration data to the internal positioning system.

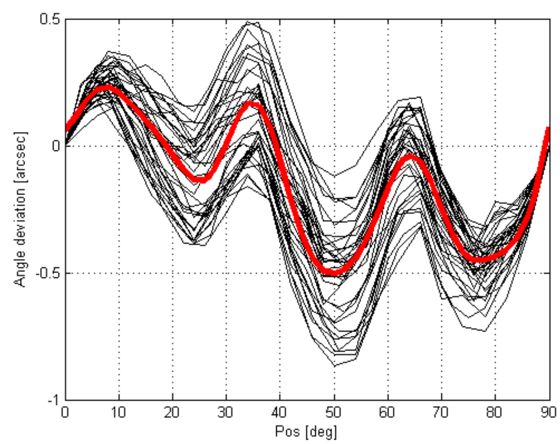

Figure 2: Results of the rotary table calibration. (Single calibration run – black lines; estimated calibration result – red line).

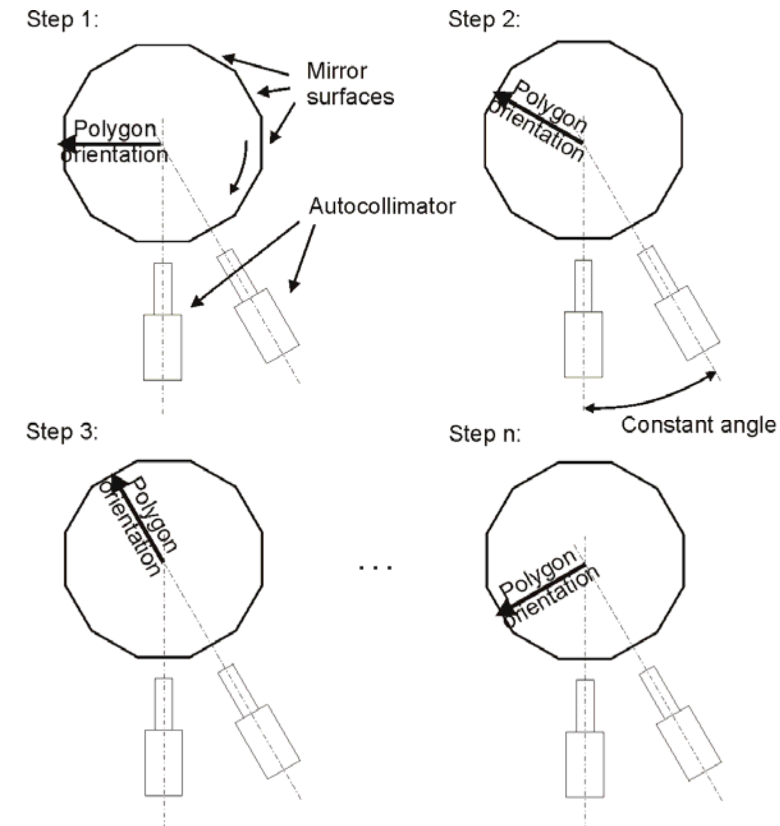

Figure 3: Polygon prism calibration.

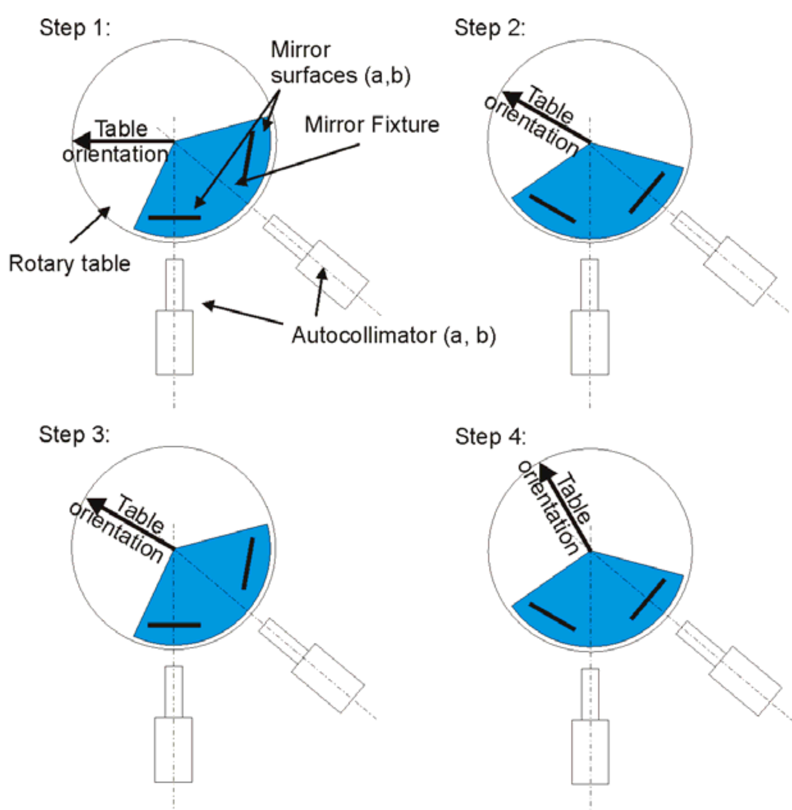

Figure 4: Calibration steps.

LASER TRACKER HORIZONTAL ANGLE MEASUREMENT SYSTEM INVESTIGATION

Laser Tracker

The tested laser tracker has independent azimuth and zenith angle measurement systems, each consisting of a disk with transmissive gratings and two read heads. Trackers automatically align themselves geometrically with the target by sending out a laser beam which is reflected by the target. The retrace point of the laser beam is projected onto a Position Sensing Detector (PSD). The deviations are either used to steer the tracker head to the target or to correct the readings of the angular encoders.

The rotary table was used to study the quality of SLAC's laser trackers and to investigate the possibility of calibrating them.

Test Setup

The preparation of the calibration process consists of leveling the rotary table. The laser tracker is then mounted on the faceplate of the rotary table (see Fig. 5) and leveled. A small difference (<0.08 degree) in the leveling of the two instruments has only negligible effects on the calibration results (<0.1 arcsec). A translation offset between the axis of the rotary table and the axis of the faro laser tracker has no effect since we use a mirror as a target for the laser tracker [5]. Both misalignment parameters are checked with the internal laser tracker measurement systems. By measuring the zenith angle with the laser tracker to the mirror at different orientations of the rotary table we can determine the parallelism of the two rotation axes. By checking the distances we get the axial displacement of the rotation axes.

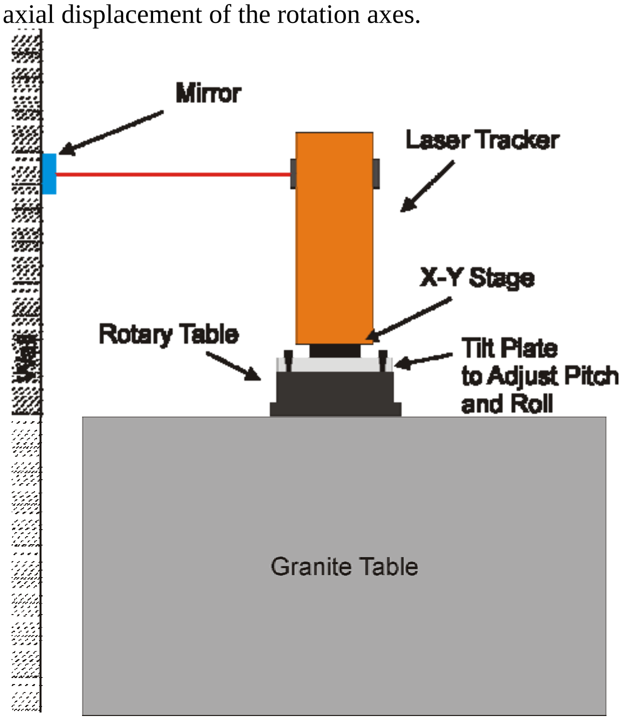

Figure 5: Laser tracker on rotary table.

The calibration of the laser tracker is performed by using the rotary table torque motor to turn the platform, along with the laser tracker. Then measurements to a fixed target are performed with the laser tracker and the readings are compared to the rotary table position.

Results

In the setup described above a mirror is used as the target to eliminate the effects of an offset between the rotation axes. Almost all field measurements are made with a retroreflector (SMR) instead of a mirror. To confirm the assumption that measurements to a mirror are affected by the same deviations as measurements to a retroreflector, we compared the two setups (see Fig. 6). The measurements to the SMR are corrected for the axial offset between rotary table and tracker. Only small deviations can be found which could have been caused by the slightly different test set up. Further investigation has to be performed to eliminate the discrepancy or to explain the difference.

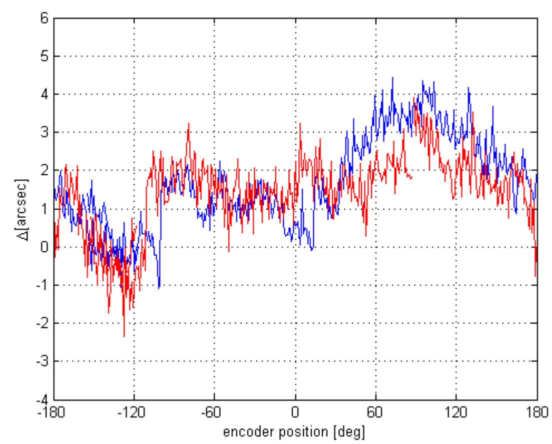

Figure 6: Comparison between mirror target (blue line) and retroreflector target (red line).

The results shown are all taken by targeting a mirror. In Fig. 7 and Fig. 8 the results of calibration runs with two laser trackers are depicted. The range of deviations from the rotary table angle measurements lie within 8 arcsec and 5 arcsec respectively with a newer model giving slightly better results.

The calibration results shown in Fig. 7 and Fig. 8 suggest it would be useful to apply the deviation values to measurements and improve the performance of the instrument. In order to do so it has to be made certain that the deviations are constant for at least the duration of a measurement campaign. To test the consistency of the deviations, the tracker was removed from the rotary table and transported from the laboratory to the office and back. The calibration measurements were repeated the next day. The deviations in the graphs appear repetitive. Further investigations on the stability of the calibration parameters are still necessary.

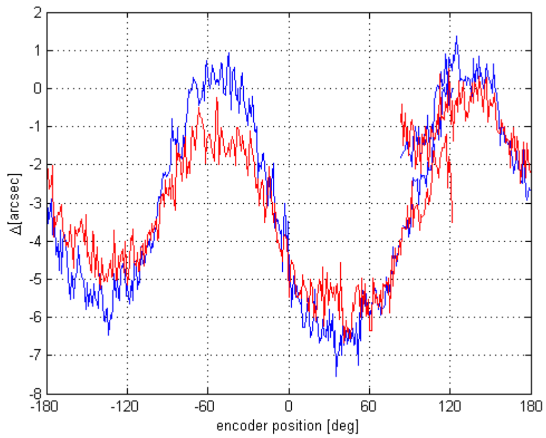

Figure 7: Tracker calibration results before and after transportation (older model).

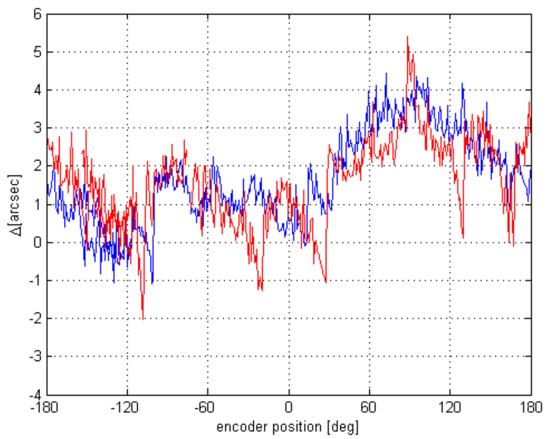

Figure 8: Tracker calibration results before and after transportation (newer model).

Investigations of a small angle area with a high sampling rate did not show any patterns (see Fig. 9).

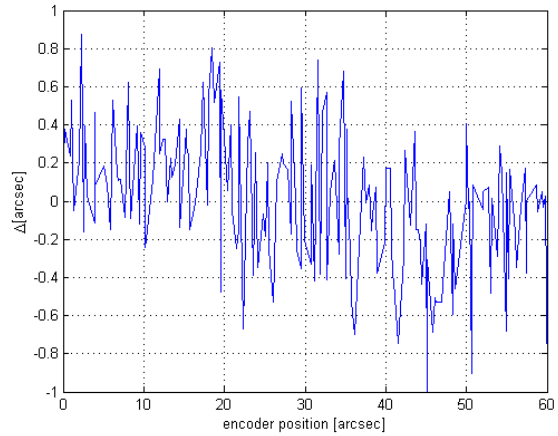

Figure 9: Calibration results with high sampling rate (1 arcsec).

INTERFEROMETER BENCH

The Absolute Distance Measurement (ADM) mode of the laser tracker is the choice of operation at SLAC since it provides a more time efficient measurement operation than the interferometer mode. A calibration of the scale factor of the ADM is possible in the field with the onboard interferometer. The field calibration of the scale factor has the advantage that the instrument is acclimatized. It is not practical to test for higher order deviations in the field. The tests performed in the laboratory include tests of the general performance of an instrument and tests to detect malfunctions.

The principle of the test is to compare the laser tracker distance measurements to interferometer measurements (see Fig. 10).

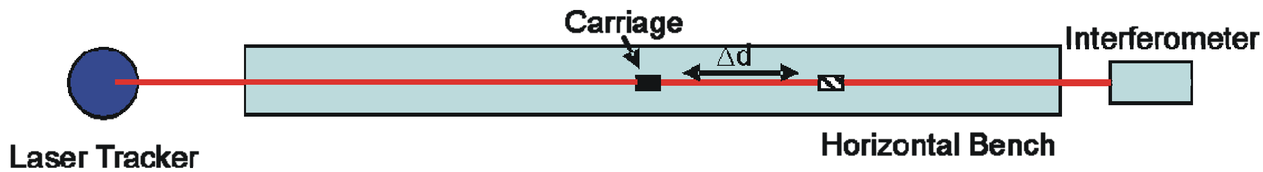

Figure 10: Schematic of the distance measurement test setup.

The results shown in Fig. 11 and Fig. 12 show the improvement of the new Version 2 of the Faro Laser Tracker to better than 10 µm under laboratory conditions.

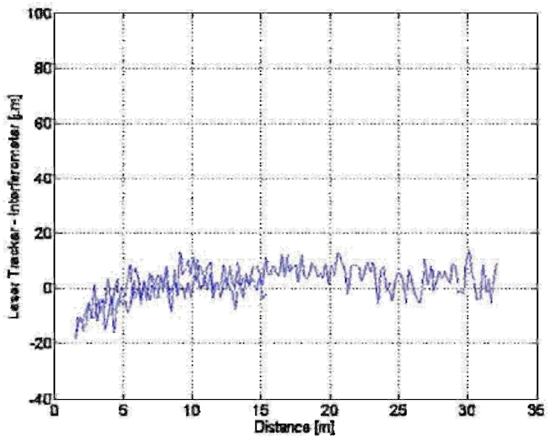

Figure 11: Distance calibration results (newer model).

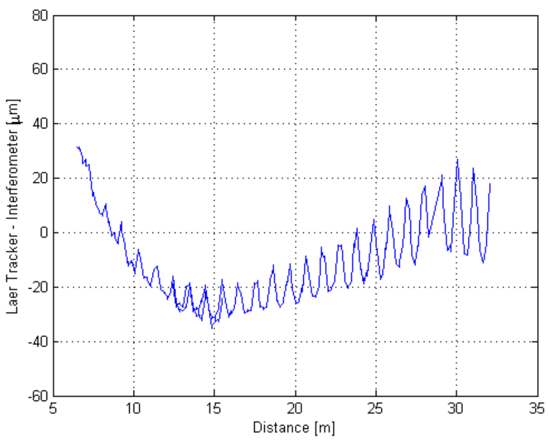

Figure 12: Distance calibration results (older model).

CONCLUSION

The calibration of the rotary table results in an absolute angle accuracy of better then 0.2 arcsec. With the rotary table it is possible to test any horizontal angle measurement instrument as long as it can be mounted to the faceplate of the rotary table, with the rotation axes coinciding. The testing of our laser trackers so far indicate that the deviations of their angle measurement system are stable and can be corrected. With corrections, angle accuracies of 1 arcsec are possible with the two instruments tested. Test of the ADM showed its usability as a replacement for the interferometer mode without losing accuracy under real world conditions.

REFERENCES

[1] Kugler GmbH “Operating Instructions – air bearing rotary table RT264TB”, Kugler GmbH, Salem, Germany (2006).

[2] O. Schreiber, “Untersuchung von Kreistheilungen mit zwei und vier Mikroskopen”, Zeitschrift für Instrumentenkunde 6 (1886).

[3] R. Noch and O. Steiner, “Die Bestimmung von Kreisteilungsfehlern nach einem Rosettenverfahren”, Zeitschrift für Instrumentenkunde 74, Heft 10 (1966).

[4] A. H. Cook “The calibration of circular scales and precision polygons” Br. J. Appl. Phys. 5 (1954) 367-371.

[5] E. Grillmayer, “Untersuchung systematischer Fehlereinflüsse bei Messungen mit dem Kreisel DMT Gyromat 2000”, Shaker Verlag, (2003), p 189.