CALIBRATION OF CO-ORDINATE MEASURING MACHINE BY SELF TRACKING LASER INTERFEROMETER (LASER TRACER)

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Abstract: *In this paper calibration procedure is presented for calibration of CMM for Geometrical Errors (21 Kinematic parametric errors) by Single self Tracking laser Interferometer (Laser TRACER). Laser tracking system concept is based on interferometric displacement measurement between reference points that are fixed to the base and offset points fixed to the machine head. The laser tracking system can measure three-dimensional coordinates based on the principle of multilateration with high accuracy. In this study, we measured 3D coordinates using the laser tracking system and estimated 21 geometric errors (parametric errors) of the CMM. Additionally to confirm the validity of the proposed procedure, the some of the parameters have been measured by laser measurement system. Result by the Laser TRACER and Laser Measurement system showed good agreement.*

1. INTRODUCTION

Many calibration methods to calibrate CMM have been introduced so far. Some of them make use of a laser interferometer when precise calibration is required [1], and the others geometrical gauges for simple calibration [2]-[3]. Geometrical gauges such as a step gauge and a ball plate have been widely used and accepted as practical standards. Those gauges are effective in some cases, however, are not always appropriate to estimate 21 kinematic parameters of a CMM as the gauges cannot be placed on the effective measurement positions or orientations due to physical limitations. On the other hand, Self Tracking Laser Interferometer (Laser TRACER) is capable of measuring displacement of a target retro-reflector which is fixed on the CMM's ram. Taking advantage of these merits, measurement strategy to estimate 21 parameters has been designed.

The Laser TRACER measures coordinates based on the multilateration principle. It uses only length information without any other information such as angle; therefore direct traceability to the length standard is secured. In addition, the laser tracking system can allocate measurement points flexibly and has no limitation on the measurement volume, whereas measurement points cannot be allocated freely when geometrical gauges are used. This enables us to design an optimum measurement strategy that reduces the uncertainty of parametric errors to be estimated.

In this paper, we propose a calibration method for a CMM using a Laser TRACER, and we report the calibration results.

2. CONSTRUCTION OF LASER TRACER

The distance measurement uncertainty of the self tracking interferometer is the dominant uncertainty contributor of the system. Especially the stability of the point of rotation is of great importance. As commercial tracking interferometers do not offer distance measurement uncertainties in the submicron range a new high precision tracking interferometer has been designed. In this design, the interferometer moves in a gimbal mount around a fixed sphere serving only as a reference mirror for the interferometer. Due to this principle, radial and lateral deviations of the mechanical axes of rotation do not significantly affect the measurement accuracy. The reference sphere does not have any mechanical function; therefore no external forces can alter its position.

The accuracy of the laser TRACER length measurement depends significantly on the quality of the reference sphere surface and its unchanged position in space. To minimize its influences, the reference sphere has a form error below 50 nm. It is mounted on an invar stem to avoid any displacements due to thermal expansion. Atmospheric conditions such as temperature, barometric pressure and relative humidity are monitored to numerically correct the laser signal.

The interferometer uses an external He-Ne laser. The light is transmitted to the interferometer by a glass fibre. This reduces the weight of the laser interferometer and eliminates thermal influences. The reference beam passes directly to the opto-electronic detection unit, while the measuring beam is reflected to the reference sphere and the external reflector before it is superimposed on the reference beam.

A part of the reference beam is redirected onto a four-quadrant diode. The four quadrant diode detects misalignment between interferometer and external reflector. Its signal is used to track the external reflector.

machine. At each grid position, the machine stops and the associated measured displacement L is recorded by the tracking interferometer. The nominal displacements can be directly calculated from the position of the reference point and the positions of all three axes. Errors of the machine show up in differences Δl_i between the measured and the nominal displacements. If a systematic error behaviour of the machine is assumed, these differences can be used to evaluate the parametric errors by a "best-fit" calculation based on the kinematic model. Preconditions for this are a sufficient number of measurements and a well conditioned linearized system of equations.

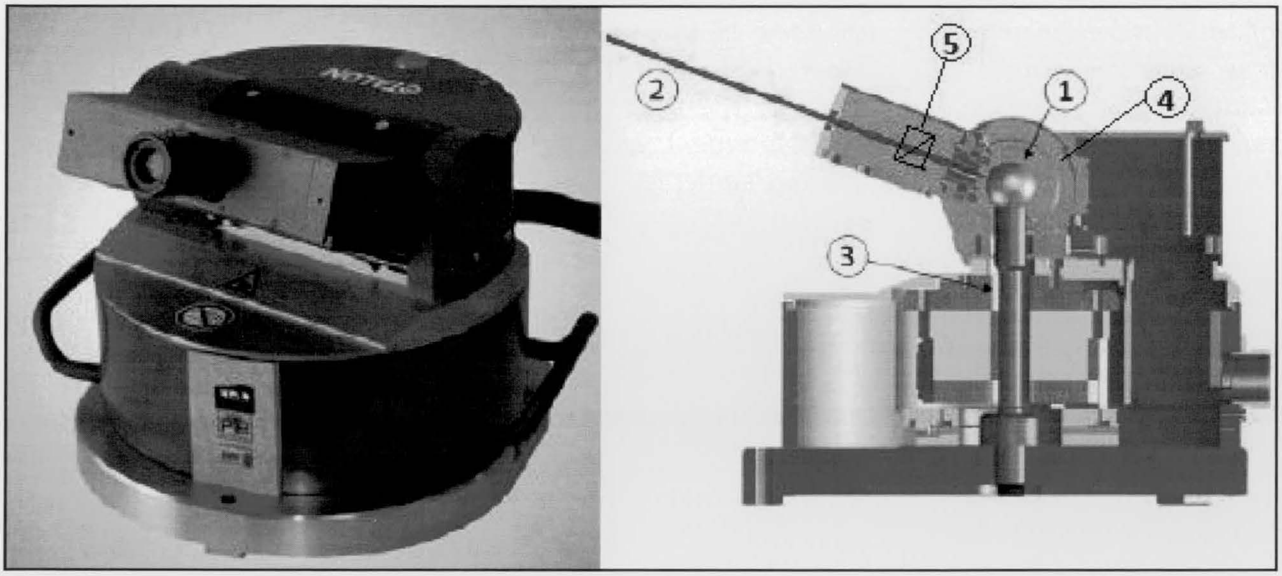


Fig 1. Laser TRACER

1. Reference sphere 2. Measuring beam of the laser interferometer 3. Mechanically decoupled pillar for the reference sphere 4. Gimbal Mount 5. Pivoted Interferometer

3. PRINCIPLE

3.1 Procedure

The concept is based on displacement measurements between reference points that are fixed to the base and offset points fixed to the machine head. These measurements are realized by a tracking interferometer that is mounted on the work piece table and a retro reflector that is attached to the machine head. Fig. 2 shows a setup

For each combination, the machine is moved through a set of positions in a spatial grid that encompasses the entire working volume of the

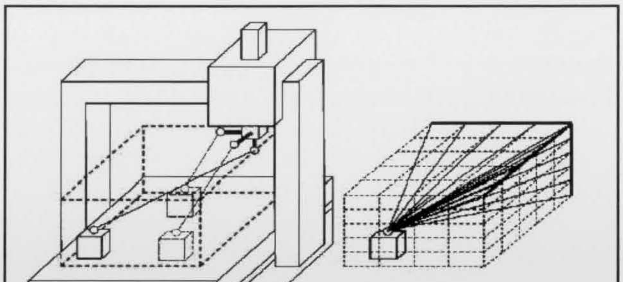


Fig 2. A Laser TRACER in at Least Three Positions on the Workpiece Table (A) Tracer positions, (B) Spatial Grid

3.2 Methodology and Key Points Followed For Measurement Strategy

Laser TRACER works together with metrological software Trac-cal developed by M/s Etalon, AG, to facilitate experiment set-up. This software allows

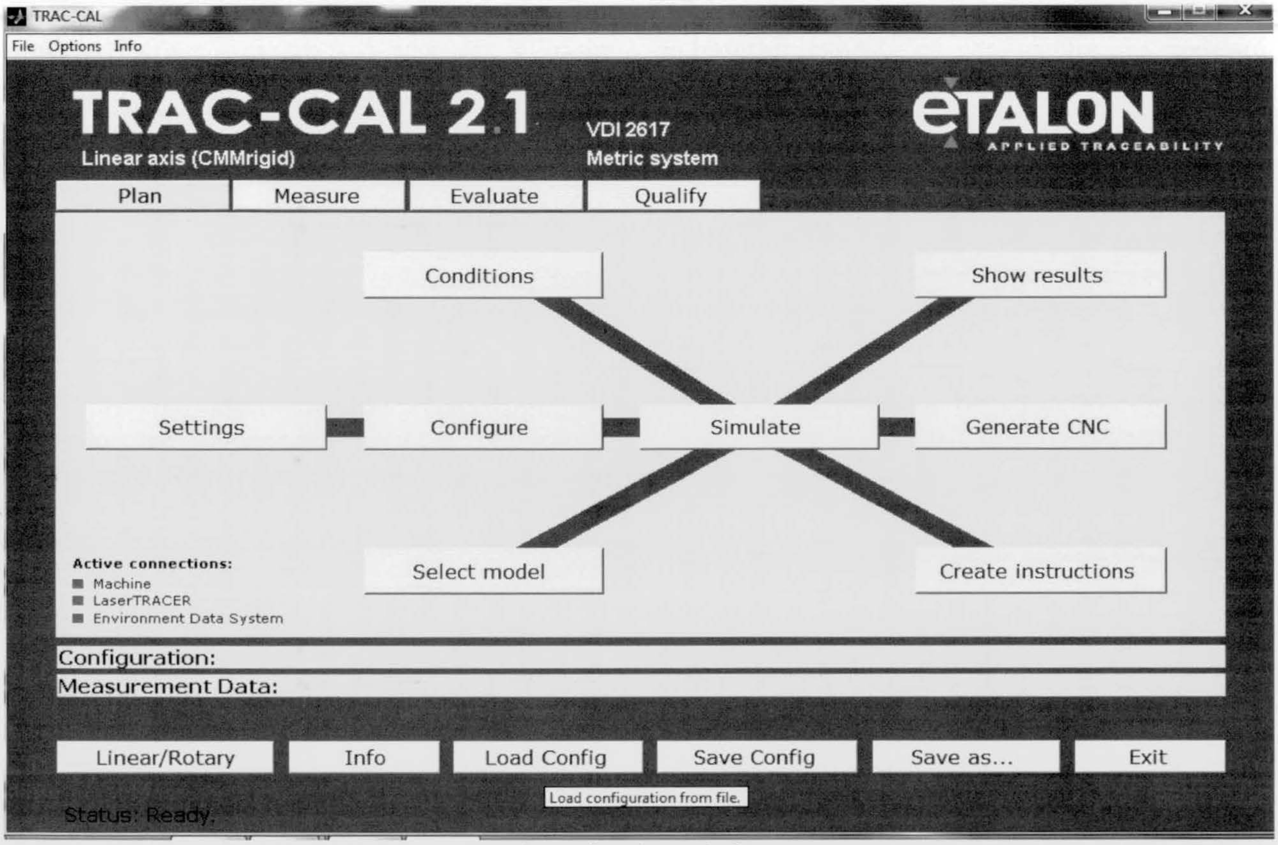


Fig 3. Planning Window

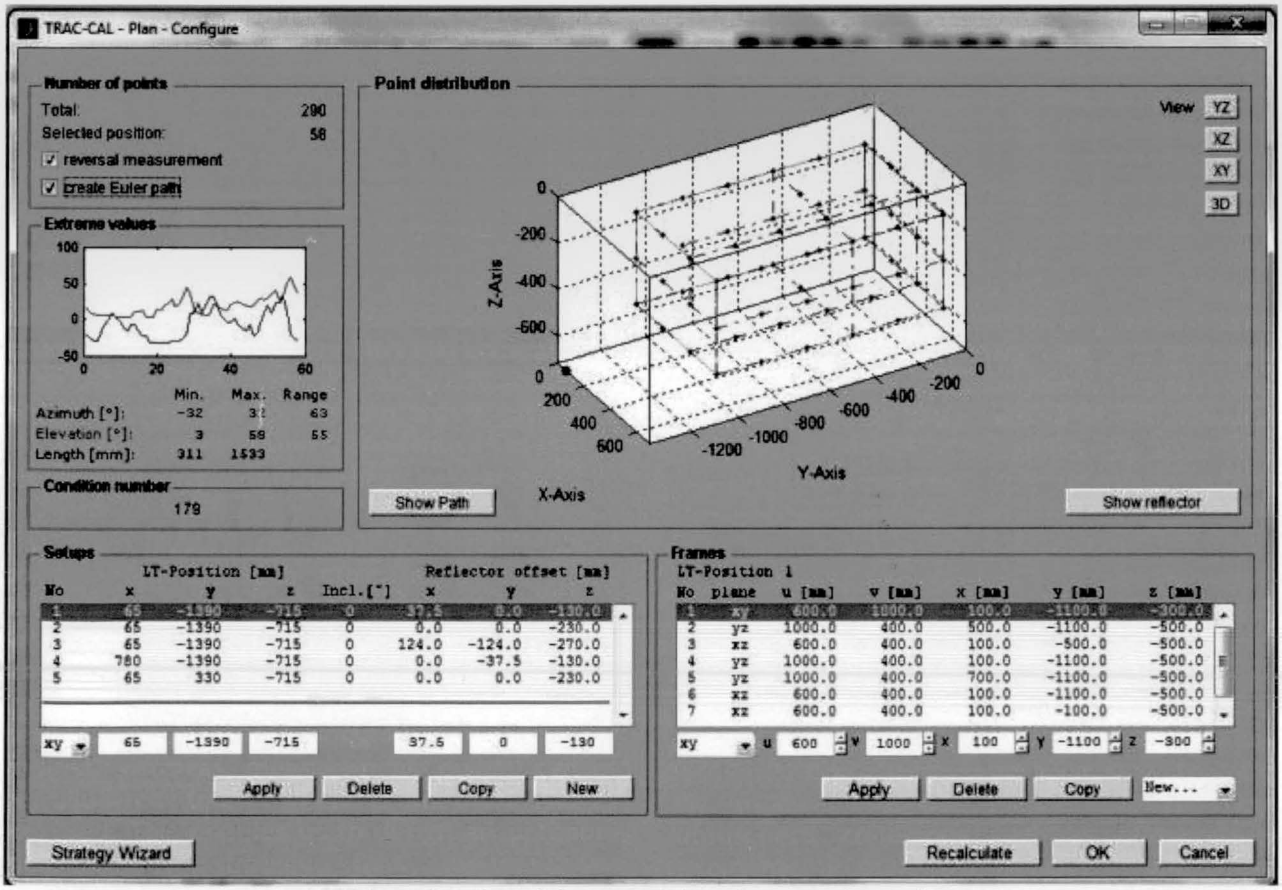


Fig 4. Planning of the LT Positions & Measuring Paths

also to generate a geometric error correction matrix in a format suitable for machines offered by different manufacturers.

Multilateration technique is used in Laser TRACER as it is able to measure only the distance from its Position to center of retro-reflector. This method was primarily used in GPS satellite navigation systems. It has also been used for many years in the so-called Internal GPS measurement systems to measure large objects, and more recently also used to correct the accuracy of the measuring machines and to create a coordinate measuring systems with a very large range.

Next part of the paper shows the exemplary usage of Laser TRACER combined with Trac-cal software for geometric error identification carried out on Carl Zeiss CMM.

3.3 Planning Experiment with Trac-Cal Software

The first thing that has to be done is planning the experiment, including Measurement volume, measuring paths, selection of Co-ordinate system, indentifying and selection of kinematical model. Figure 3 shows the planning window of the TRAC-CAL.

After that, the generation of measuring paths takes place. In this step, the shape of measuring paths, positions of Laser TRACER in machine volume and offsets at which the retro-reflector is mounted have to be designed. (Figure 4).

4. EXPERIMENTAL VERIFICATION

After experiment is planned, the required measurements in all specified Laser-TRACER positions have to be conducted. At least four positions of LT should be planned, but more positions could facilitate determination of all geometric error components for obtaining greater accuracy. It is also important to change the offsets at which the retro-reflector is mounted. The offset specifies the distance of reflector center to reference point at the machine probe head. Figure 5 presents measurements done at CMM.

The experimental verification was performed on a high accuracy CMM in a good laboratory environment with controlled temperature conditions. A Laser TRACER is used as Self Tracking LASER Interferometer system developed by NPL,UK[4]. Retro reflector is attached to the machine head to track the machine movement. Cat's eye Retro reflector (Figure 6) has acceptable range of ± 60°. Laser TRACER has been firmly fixed over the CMM bed at 5 different positions and different offsets of Retro-reflector as per the planning.

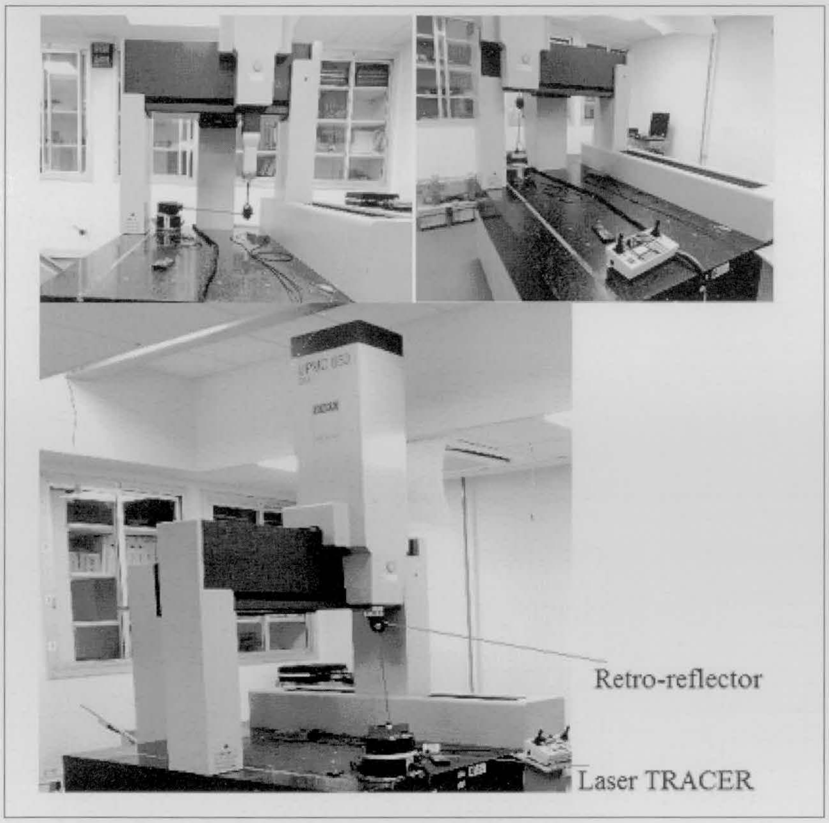


Fig 5. Measurement Setup Over CMM

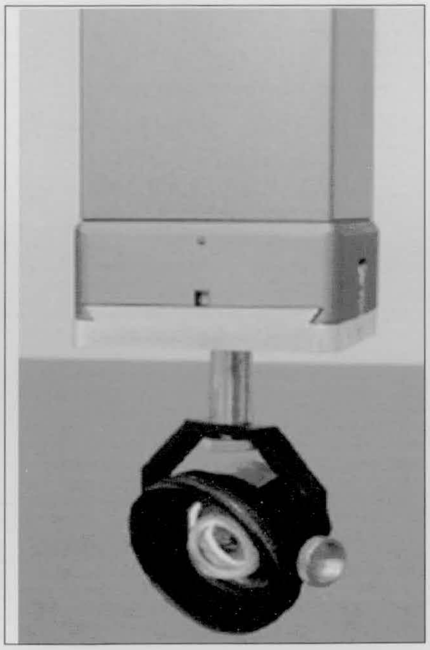


Fig 6. Cat's Eye Retro-Reflector

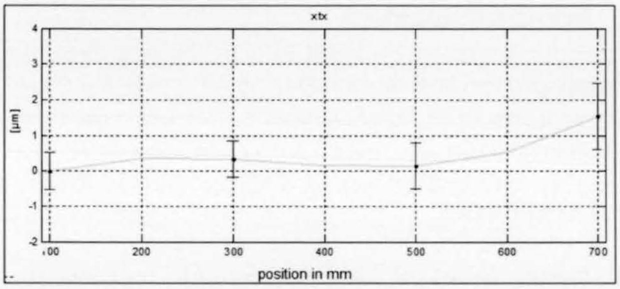
5. RESULTS

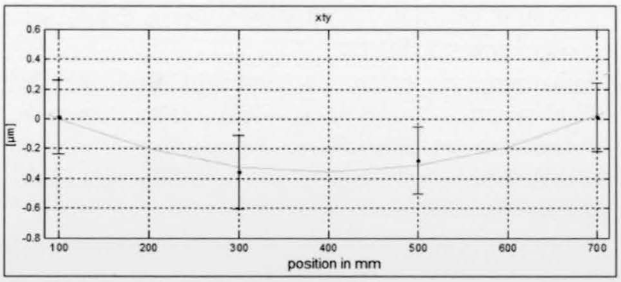
Results could be computed after all planned measurements are finished. Trac-cal software solves the system of equation describing the multilateration method, determines the coordinates of points at which center of reflector stopped during measuring sequence and using methodology similar to that known from Novel method determines components of geometric errors. Results could be presented both in graphical and textual way.

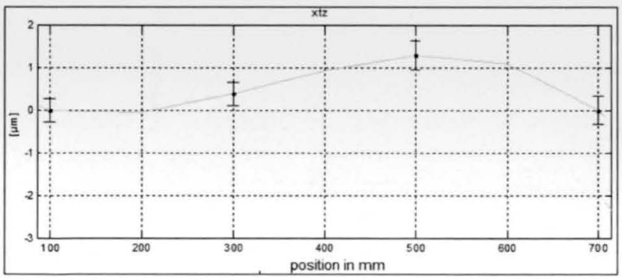
Described software gives also opportunity to create automatic reports from performed measurements and generate compensation matrices for different types of machines, depending on producer and machine controller. This matrix can be then uploaded into the controller and used to compensate the identified vectors.

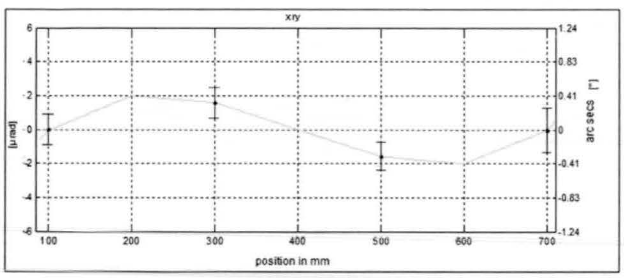
The results have been compared with an

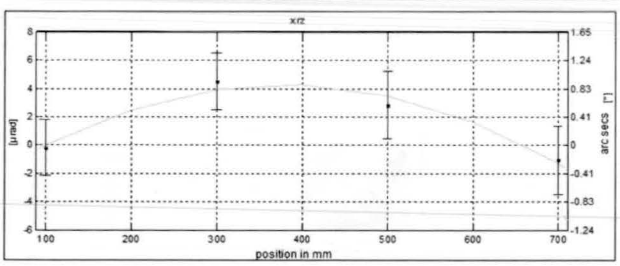
Results by Laser TRACER



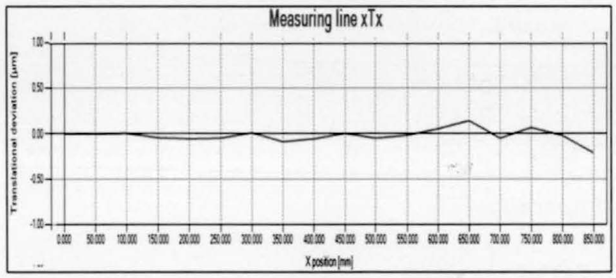


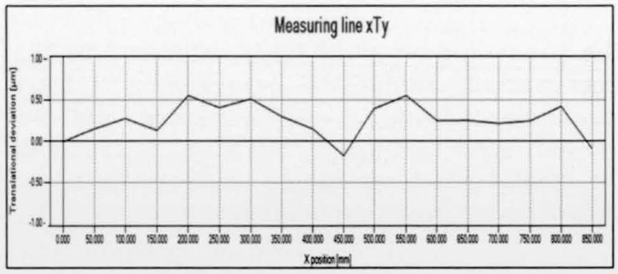


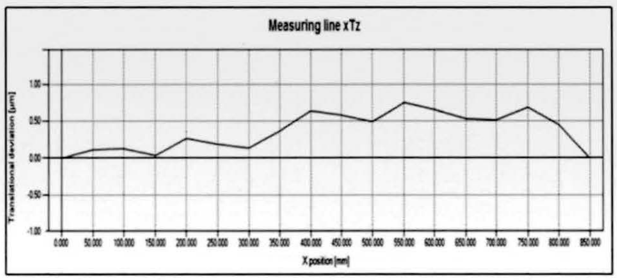


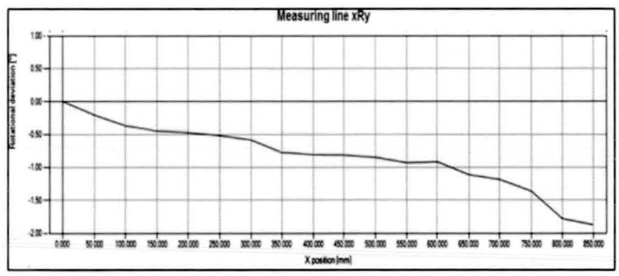


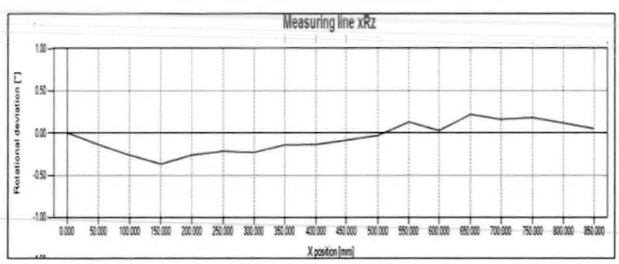
Results by Laser Measurement System











independent error measurement by Laser TRACER and Laser Measurement system. Both methods showed good agreement. Fig shows results of comparison of x axis. The results for Y- axis & Z - axis are showed good agreement as well. How ever calibration results pertaining to X – axis are only reported in this paper.

position in mm Squareness	LASER TRACER (arc secs)	Laser Measurement system (arc secs)
XWY	0.80	-0.1
xwz	-0.71	0.9
ywz	0.60	1.5

Measured results obtained by using Laser measurement system and Laser TRACER are comparable.

6. CONCLUSION

The parametric errors of CMM estimated by the laser tracking system and estimated by a Laser measurement system are comparable and are showed good agreement However, accuracy of the measurement can still be improved by better controlling of Environmental conditions.

Some of the drawbacks of laser TRACER compared to laser Measurement system are, Complete TRACER system is Heavy and Bulkier. Laser TRACER requires more planning to map entire volume of the machine.

Result of geometrical error mapped by Self tracking laser interferometer system like Laser TRACER shown in several papers, including this one proves that laser TRACER could be used successfully in calibration of CMM and machine tools. System is also helpful in reducing time for compensation of CMMs and machine tools for geometrical errors. User friendly software and comparably small dimensions of laser TRACER Head makes it even more comfortable device for geometrical errors investigations.

Laser TRACER is surely a extraordinary Measurement system useful for Volumetric error mapping of 3d working space. It needs to be explored further more for its ability because it has lot of potential.

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