New Concept for Simplified Recalibration of Hexapod Positioning Units in Industrial Environment

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Abstract

Hexapod positioning units reach very high repeat accuracy due to their parallel geometry. To gain very high absolute accuracy as well, either very precise fabrication and assembly are required or expensive measurements have to be made to assure the theoretical model exactly matches the actual geometrical parameters. Any replacement of components leads to the necessity of a new measurement which cannot be arranged in an industrial environment [1]. To avoid the need of disassembling the hexapod for measurement when replacing one leg, an approach is developed to determine all necessary geometrical parameters, influenced by this replacement, exclusively by performing TCP (Tool Center Point) measurements. The reachable calibration precision, depending on the replacement leg as well as the used measurement system is worked out in this elaboration.

1 Introduction

Basically 7 error parameters have to be considered for one replacement leg (see Fig. 1), three components each for base and platform joint position errors and one for the error in leg length. The measurement log for each replacement leg provides all information about the error in leg length already before the calibration, so this parameter is eliminated. The remaining 6 parameters are identified based on their effects on the virtual leg length l_{virt}. The virtual leg length depicts the length calculation via inverse kinematics for the nominal model, using the real 6DOF (Degrees Of Freedom) TCP measurement (see Fig. 2). The actual-theoretical comparison leads to:

$$\Delta l = l_{virt} - l_{nom} \tag{1}$$

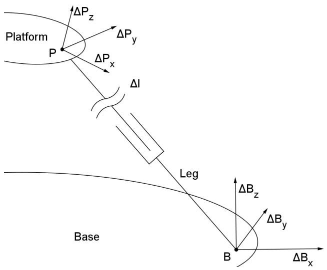

Figure 1: Error model for one leg

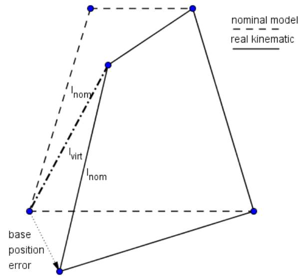

Figure 2: virtual leg length for baseposition error

2 Recalibration approach

The impact of error parameters on l_{virt} is approximately linear for small errors if the following conditions are avoided with a wide range when measurement poses are defined:

- Angle between leg and base- or platform-x-axis equals 90°
- Angle between leg and base- or platform-y-axis equals 90°
- Leg parallel to base or platform (impossible)

Calculating these impacts for virtual infinitesimal errors at different poses of the nominal hexapod model using the inverse kinematics, an influence-matrix V is derived. To solve the system of equations for the 6 considered error parameters 6 poses are necessary. Based on the assumption of linearity the error parameters x are identified from:

$$V \cdot x = \left(\Delta l_1, \Delta l_2, ..., \Delta l_6\right)^T \tag{2}$$

The most important criterion for choosing measurement poses is the resulting condition of the matrix V [2]. It describes, as a factor, the effect of positioning and measurement errors on the parameter identification. The calculation of this condition for many different poses was automated so data is acquired with acceptable effort, and the best calibration poses can be chosen depending on the above mentioned conditions as well as the condition of V. A flowchart of this recalibration approach is shown in Fig. 3.

3 Estimated calibration precision

Based on the geometry of the considered hexapod positioning unit, large series of simulations led to measurement poses that create an influencematix V of 2-norm condition $c_2 = 82$. Simulations with random distributed measurement errors showed that the maximum error e_l of l_{virt} affects the parameter identification (2) in worst case by $e_l \cdot k$:

$$k = 0.085 \cdot c_2 \approx 7 \tag{3}$$

To predict the reachable calibration precision e_l has to be determined, which depends on the measurement system (3.1) and the leg positioning precision (3.2). Reducing e_l to less than 3 µm for example, leads to an uncertainty of parameter identification of less than 21µm.

3.1 Measurement system

The effect of the translational measurement error Δ_{mTrans} on the virtual leg length l_{virt} depends on the angle α between Δ_{mTrans} and l_{virt}.

$$e_{l\,Trans} = \cos(\alpha) \cdot \Delta_{mTrans} \tag{4}$$

The effect of the rotational measurement error Δ_{mRot} on the virtual leg length l_{virt} depends on the distance r between platformjoint and TCP.

$$e_{l\,Rot} = r \cdot \sin(\Delta_{mRot}) \tag{5}$$

TCP measurements with the considered hexapod are done using a high precision coordinate measurement machine in an airconditioned laboratory that provides measurement results within 1 µm precision. A precision cuboid (110x110x30 mm³) is mounted on the platform to perform 6DOF-measurements. This way e_l caused by the measurement system is guaranteed to remain less than 3 µm (r=110mm):

$$e_l = e_{l\,Trans} + e_{l\,Rot}\,,\; e_{Trans} \le 1\mu m\ (4),\; e_{Rot} \le 2\mu m\ (5) \tag{6}$$

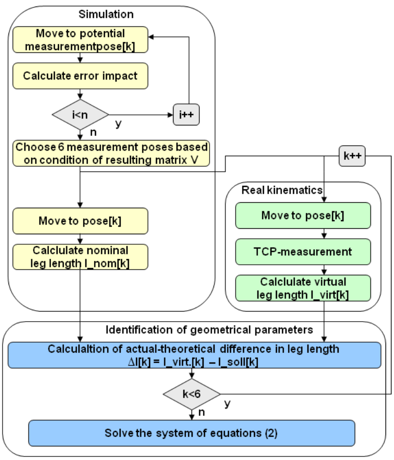

Figure 3: Calibration-flowchart

Figure 4: CMM

3.2 Individual measurement logs

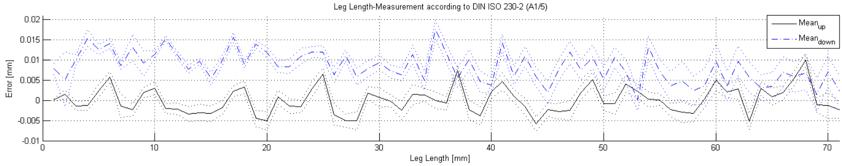

Figure 5: Measurement-log for one series production leg according to ISO [3, N1]

Individual measurement logs as displayed in Fig. 5 provide information about non-linearity and backlash that can partially be compensated in software. Further influences like rotation, temperature and reference offset have to be measured and must be regarded for e_l .

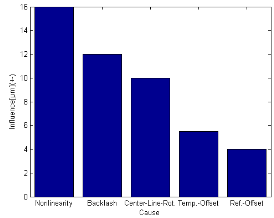

Figure 6: Error depiction

4 Results

The simulation of this recalibration approach, based on iterative direct kinematics, starting from 18 mm base joint position error proves its functionality (see Fig. 7):

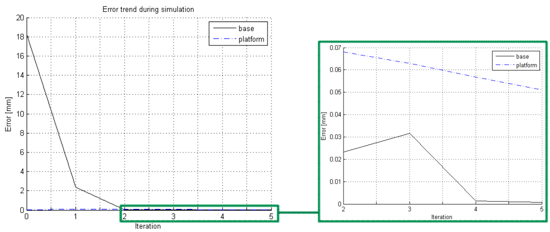

Figure 7: Simulation result

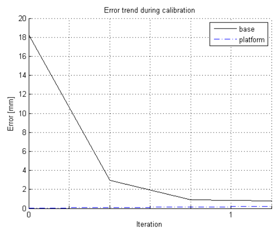

Figure 8: calibration result

The calibration off the real hexapod proves good convergence for the first iterations (see Fig 8). It is limited by the leg's positioning precision as predicted.

References:

[1] K. Großmann, Kinematic calibration of a hexapod of simple design, Production Engineering Vol. 2: 317-325, 2008

[2] T. Franitza, Kalibrierung von PKM mit sechs Freiheitsgraden, Zeitschrift für wirtschaftlichen Fabrikbetrieb ZwF 101(10): 585-590, 2006

[3] C. P. Keferstein, Fertigungsmesstechnik, Vieweg + Teubner Verlag, 7. Auflage

[N1] ISO 230-2, 2006-03, Werkzeugmaschinen – Prüfregeln für Werkzeugmaschinen – Bestimmung der Positioniergenauigkeit und der Wiederholpräzision der Positionierung von numerisch gesteuerten Achsen.