

# Angular position sensor & calibration bench results:

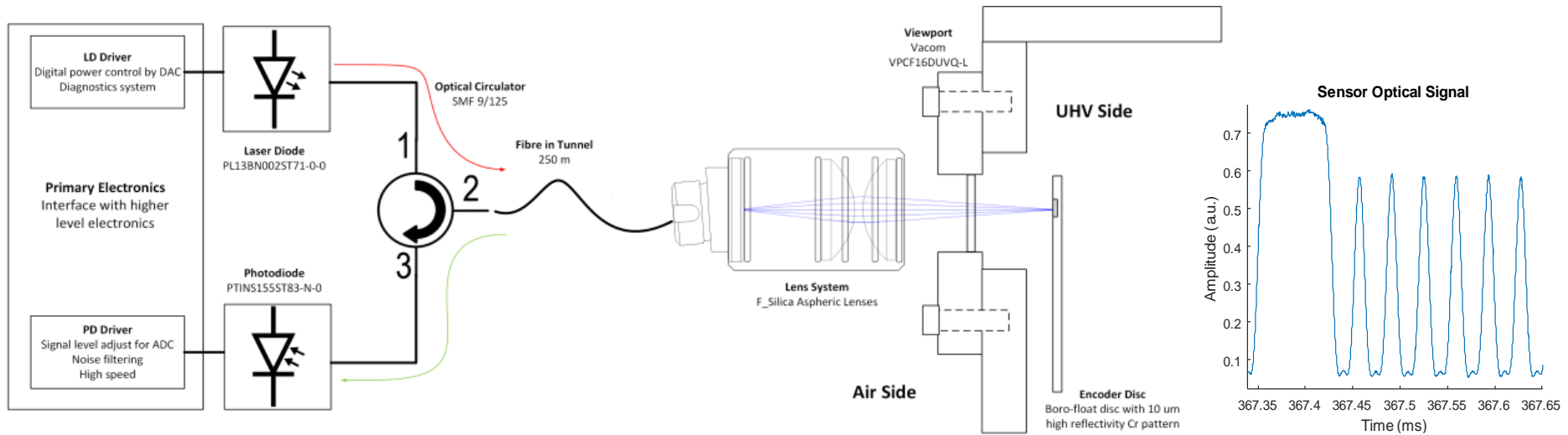
## LAB Scanner calibrations

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BE-BI-PM

LIU BWS Follow-up meeting  
27/04/2017

# 1. Optical Position Sensor

## 1.1 Working principle and schematic for PSB



### Working principle:

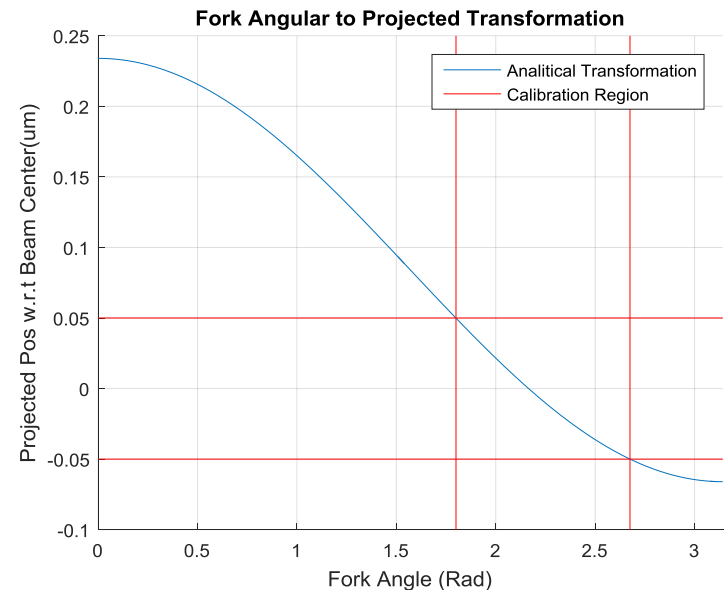
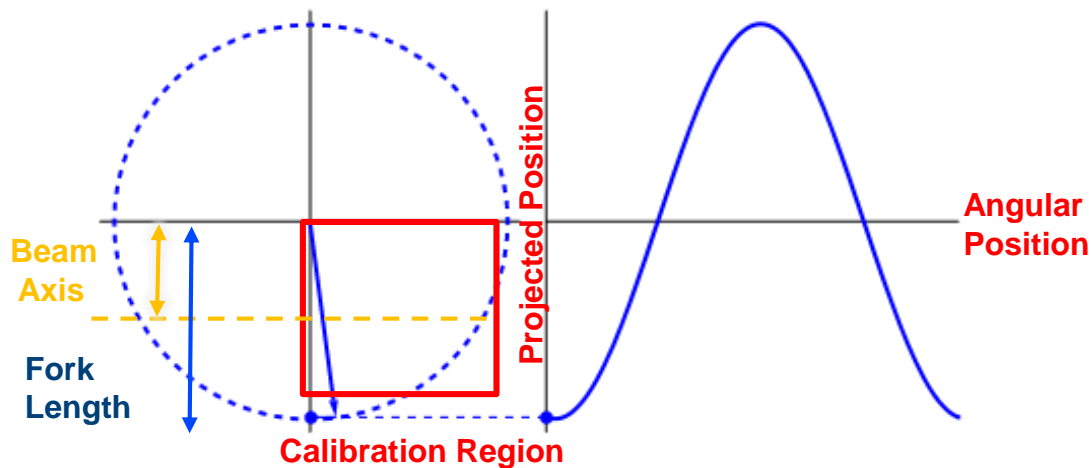
- Fibre-optic based passive incremental encoder.
- Single fibre per detector.
- Continuous light focused into a reflective track.
- Reflections collected, pseudo sinusoidal signal.
- On-Track references allow start-counting locations.

### Detector Construction:

- Single mode fibre 9/125 um for 1310nm. (RH)
- Continuous laser @ 1310nm
- F. Silica Aspheric lenses 0.5' diam.
- Optical Glass/Metal disk with 20um pitch pattern
- Slit-to-Slit projected increment → 26um

# 1. Optical Position Sensor

## 1.3 Angular-to-Projected position transformation



Analytical Projected position w.r.t. beam axis:

$$P_{Proj} = L_{B.axis} - L_{fork} \sin\left(\varphi - \frac{\pi}{2}\right)$$

Disk provider guarantees 1um accuracy (systematic) on 10mm of track:

- Slit-to-slit projected distance : 26.6 um (Interpolation possible)
- Projected systematic position error on a scan: ~1.33um

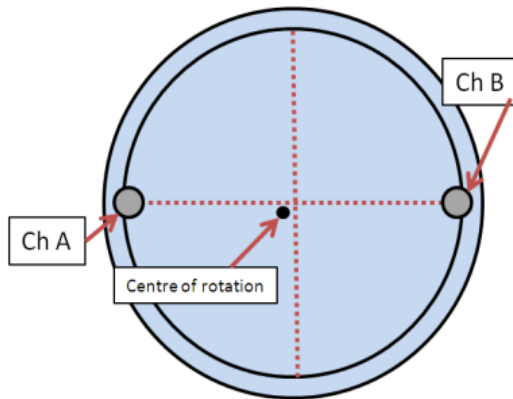
PSB Optical position Sensor Resolution				
Fork Length (FL)	150			mm
Impact Angle ( $\alpha$ )	34			deg
Track Radius (TR)	93.5			mm
Slits Pitch	20	30	40	$\mu$ m
# of slits on disk	29374	19583	14687	slits
Disc angular Resolution	213.9	320.8	427.8	$\mu$ rad
Linear Resolution ( $\Delta P$ )	32.09	48.13	64.17	$\mu$ m
Projected Resolution ( $\Delta Y$ )	26.6	39.9	53.2	$\mu$ m

# 2. Disk eccentricity impact and palliation

## 2.1 Dual Sensor for eccentricity compensation

- **Mounting off-centre rotation:**

- Cyclic (sinusoidal) position error proportional to eccentricity in function of angle.
- Position error seen in opposite phase in each sensor (displaced 180 degrees).
- Angular position of both sensors used for eccentricity characterization and compensation.
- Complete revolutions required for full characterization.



$$\Delta\theta_A = \Delta\theta + \frac{2e \sin(\theta)}{D} + \dots$$

$$\Delta\theta_B = \Delta\theta + \frac{2e \sin(\theta + \pi)}{D} + \dots$$

$$\frac{\Delta\theta_A - \Delta\theta_B}{2} = \frac{2e \sin(\theta)}{D}$$

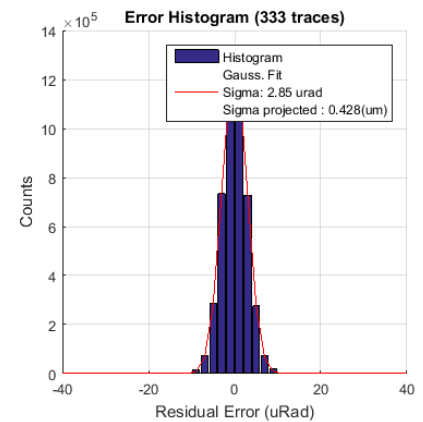
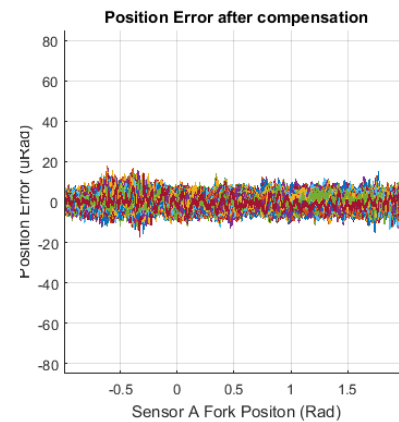
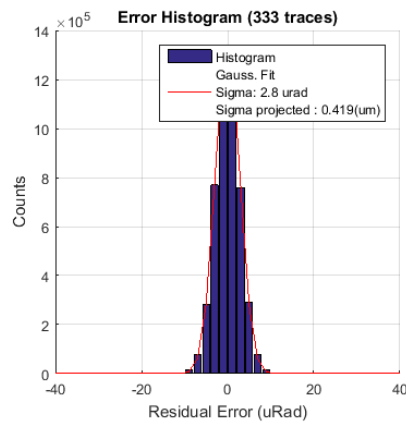
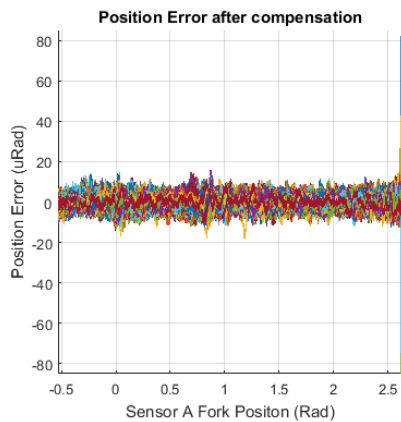
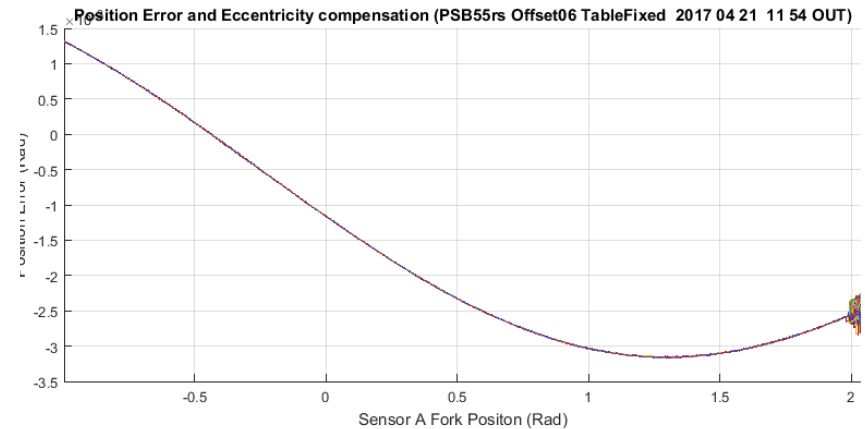
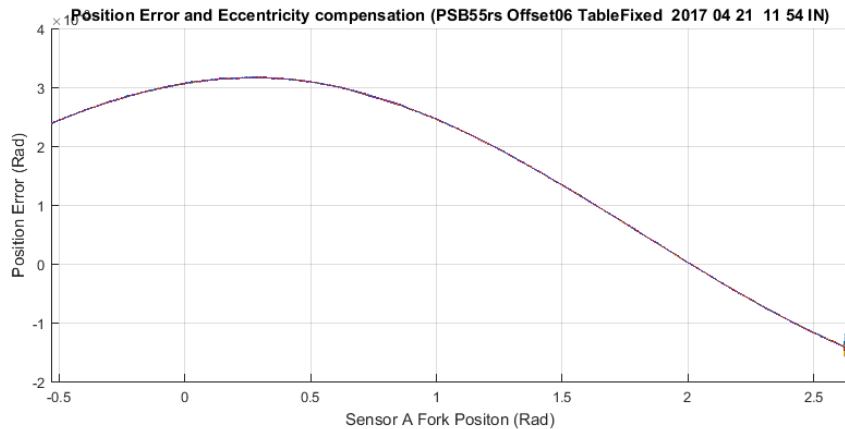
**Systematic Error Position Error**

**Possible to quantify off-centre displacement only with trough position sensors**  
**Reproducibility of Eccentricity curve can be taken as a diagnostic tool for precision determination**

# 2. Disk Eccentricity Impact and Palliation

## 2.2 Correction reproducibility: Results with Scans @ 55 Rad/s

**Max Pos. Error 3.8mRad (570um Proj.) → Disk off-centre by 177um**

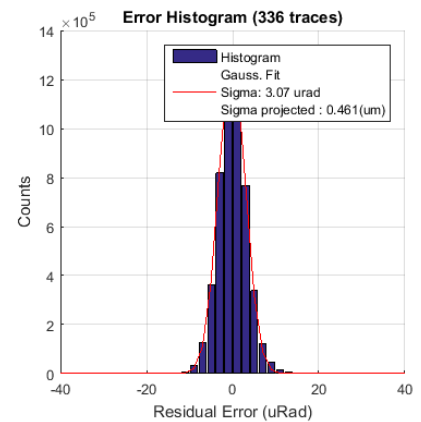
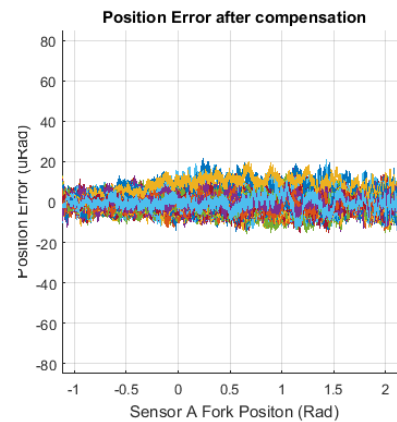
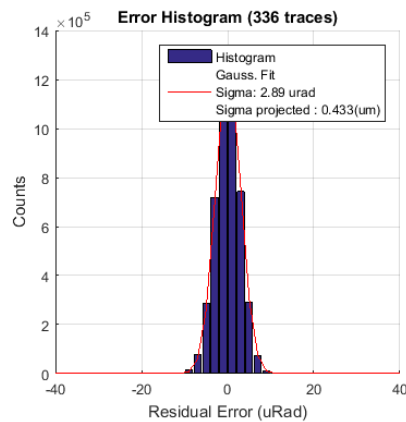
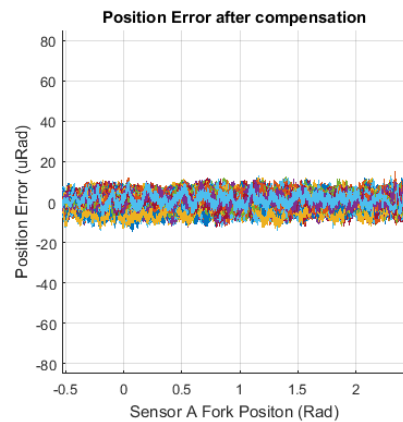
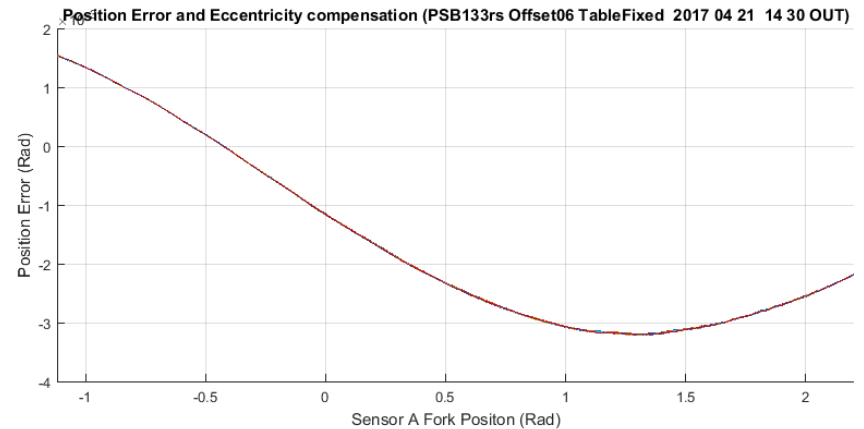
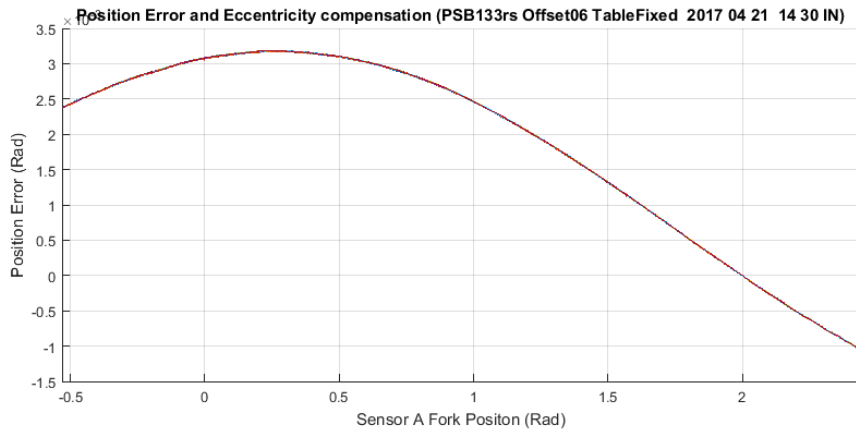


**Encoder Reproducibility (Precision) ~ 2.9urad → 0.43 um**

# 2. Disk Eccentricity Impact and Palliation

## 2.3 Correction reproducibility: Results with Scans @ 130 Rad/s

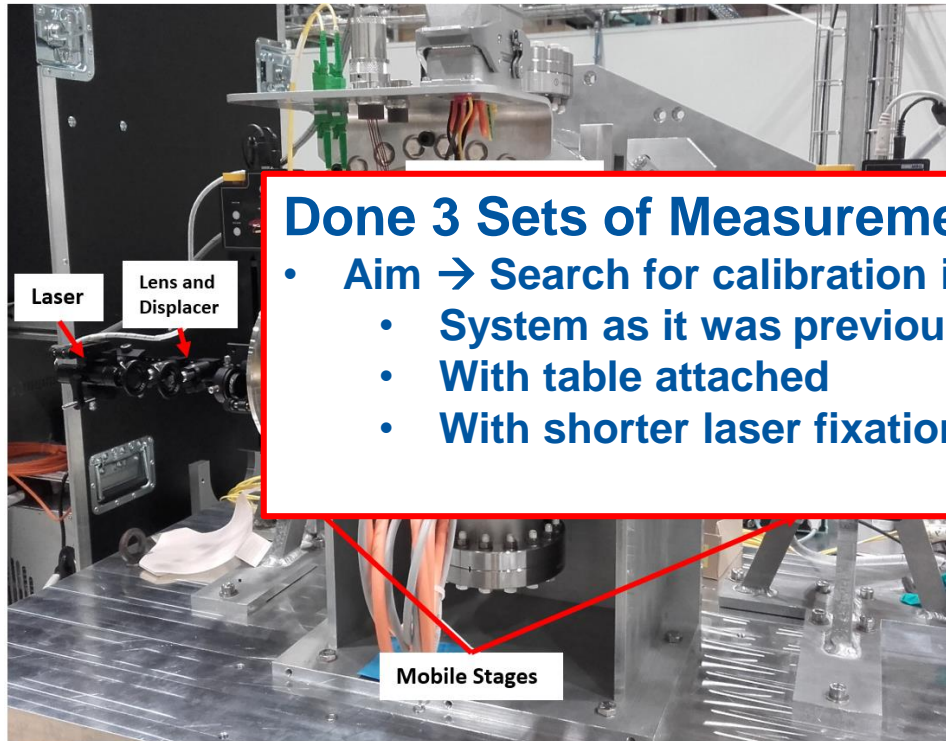
**Max Pos. Error 3.8mRad (570um Proj.) → Disk off-centre by 177um**



**Encoder Reproducibility (Precision) ~ 3uRad → 0.46 um**

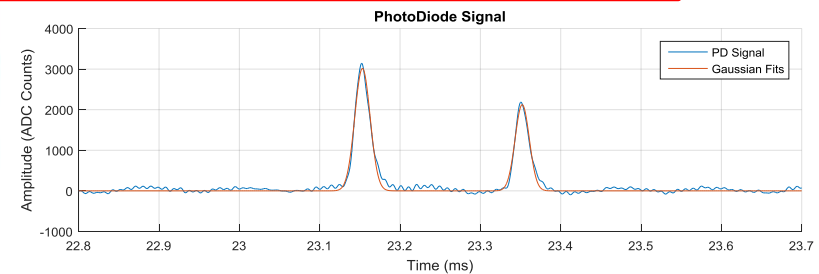
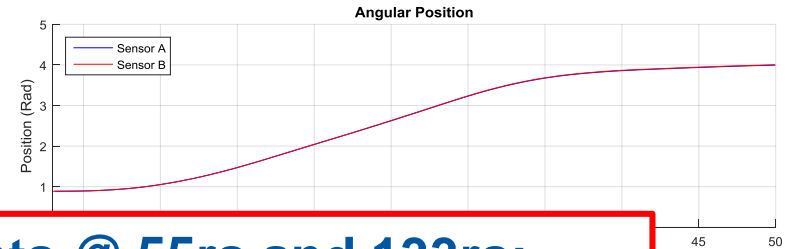
# 3. The Calibration Bench

## 3.1 Mechanical components and sample scan data from optical sensors



### Done 3 Sets of Measurements @ 55rs and 133rs:

- Aim → Search for calibration improvements
  - System as it was previously
  - With table attached
  - With shorter laser fixation



Data Acquisition & Stages Control: PicoScopes and Labview Application  
Data Offline Processing : Matlab

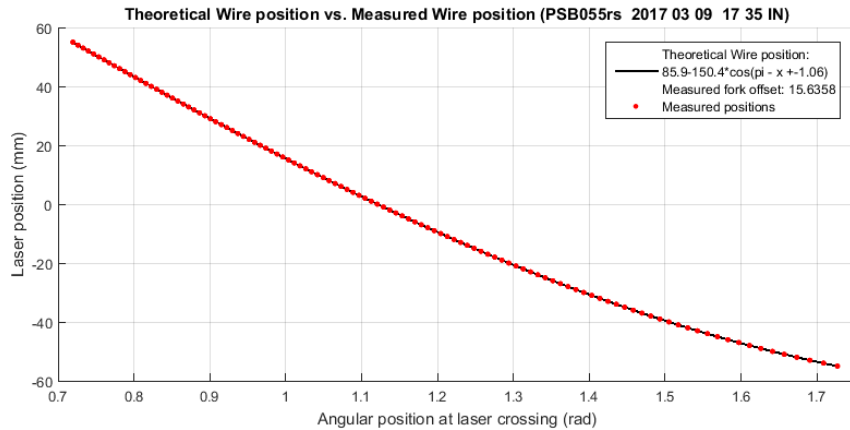
### CHANGES W.R.T. PSB TESTS

- Laser Changed: Higher Power, Lower noise
- Disk holder modified: Better runout
- Disk fixation modified: Copper rings

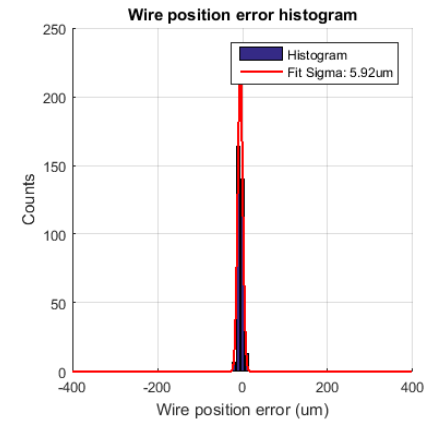
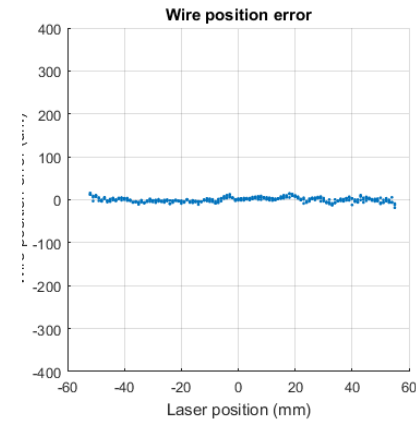
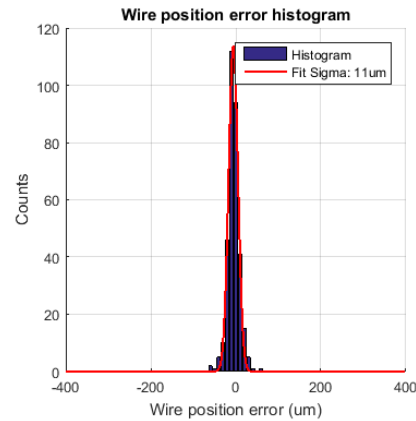
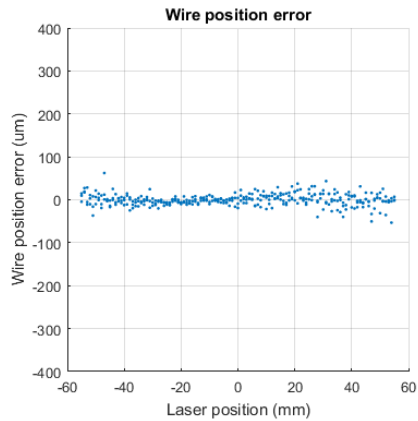
# 3. The Calibration Bench

## 3.2 Calibration results at different speeds: Calibration Table (IN Scans)

### Calibration **PSB** @ 55Rad/s (8m/s)



### Calibration **LAB** @ 55Rad/s (8m/s)



Projected Precision: **11 um**

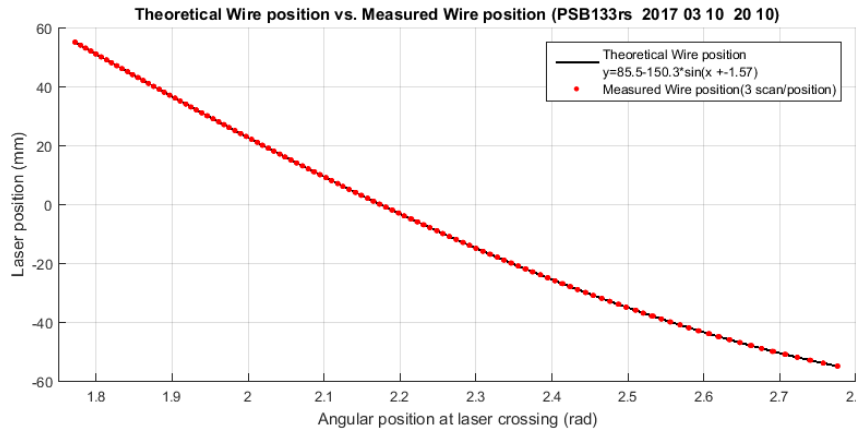
Projected Precision: **5.92 um**



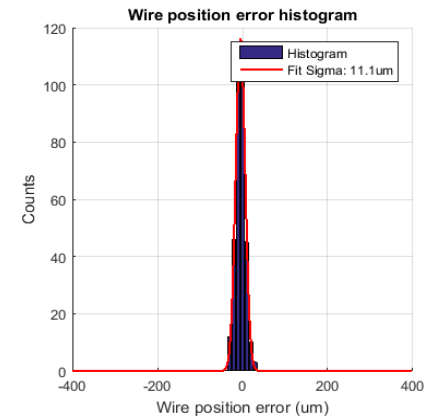
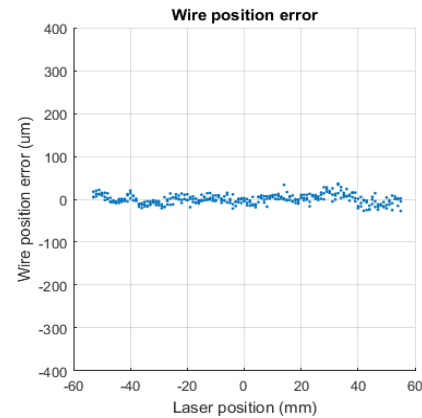
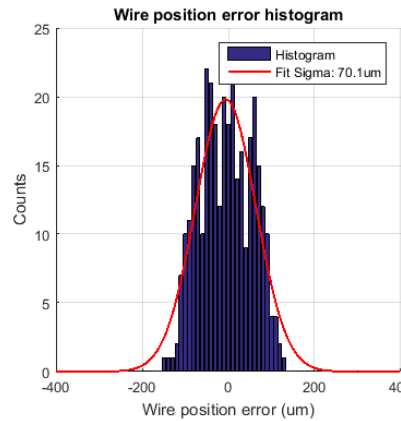
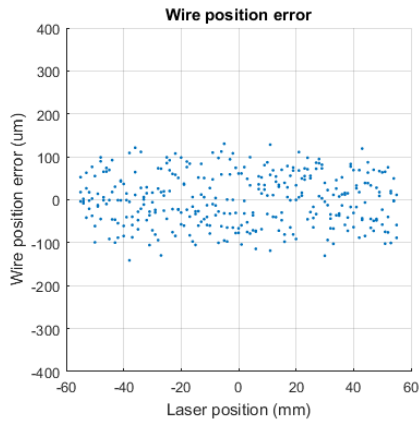
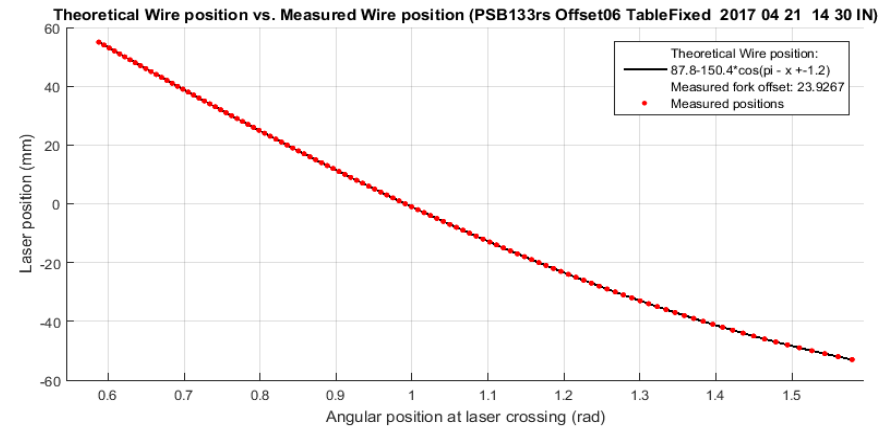
# 3. The Calibration Bench

## 3.2 Calibration results at different speeds: Calibration Table (IN Scans)

### Calibration **PSB** @ 133Rad/s (20m/s)



### Calibration **LAB** @ 133Rad/s (20m/s)



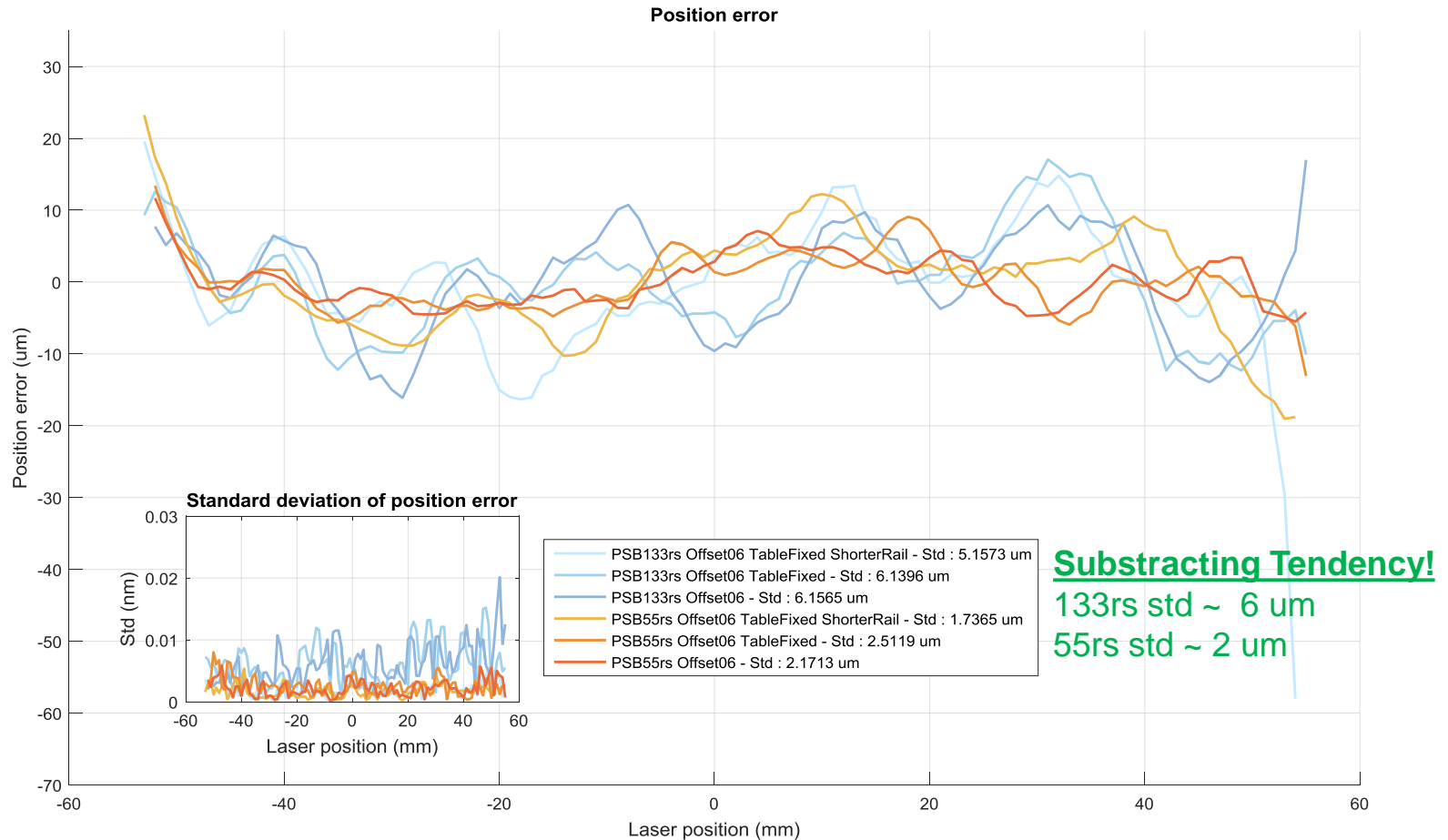
Projected Precision: **70.1 um**

Projected Precision: **11 um**

# 3. The Calibration Bench

## 3.2 Calibration results at different speeds: Calibration Table (IN Scans)

Fit Residuals of all LAB Scanner calibrations: Mean value and Standard Deviations

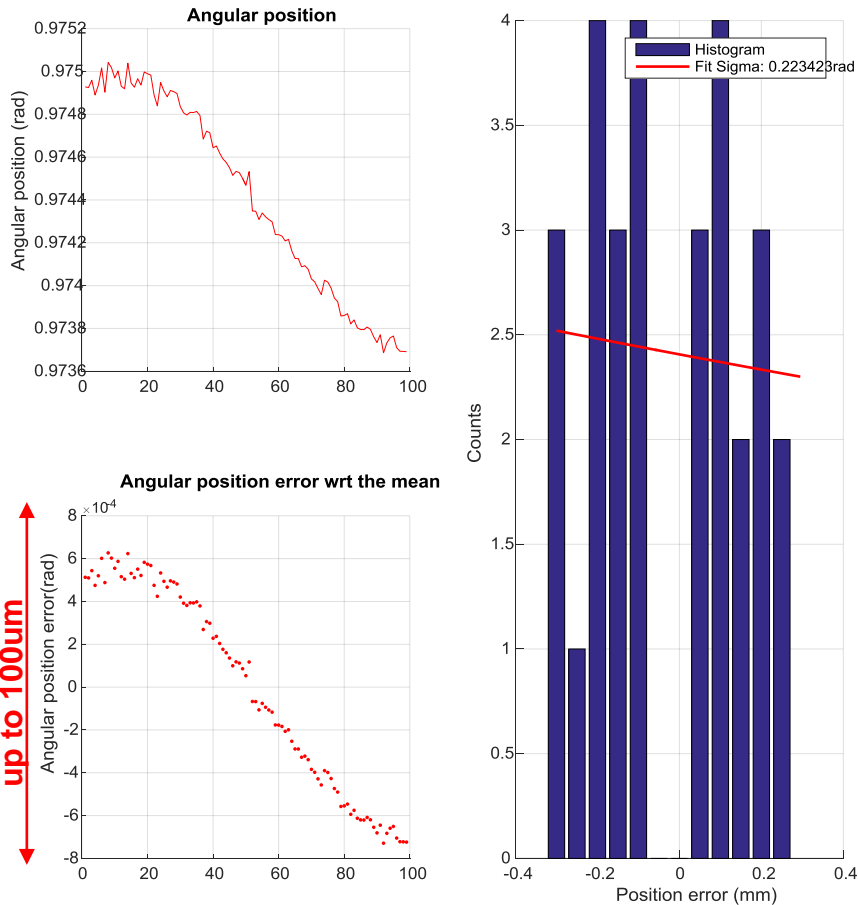


# 3. The Calibration Bench

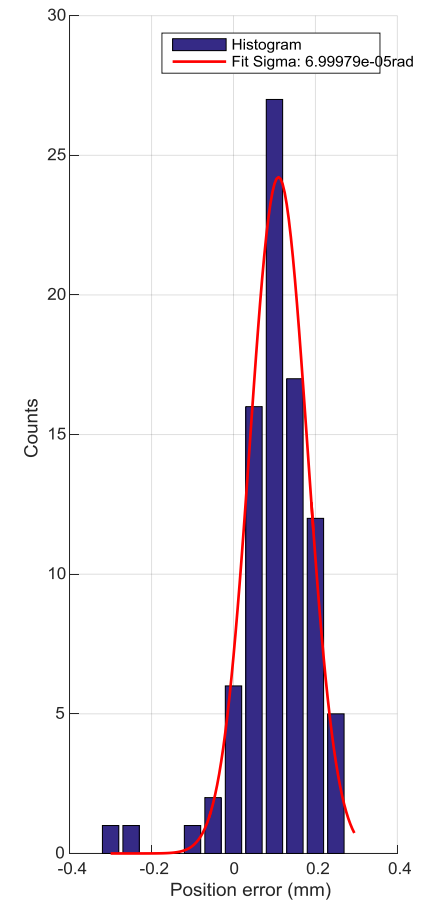
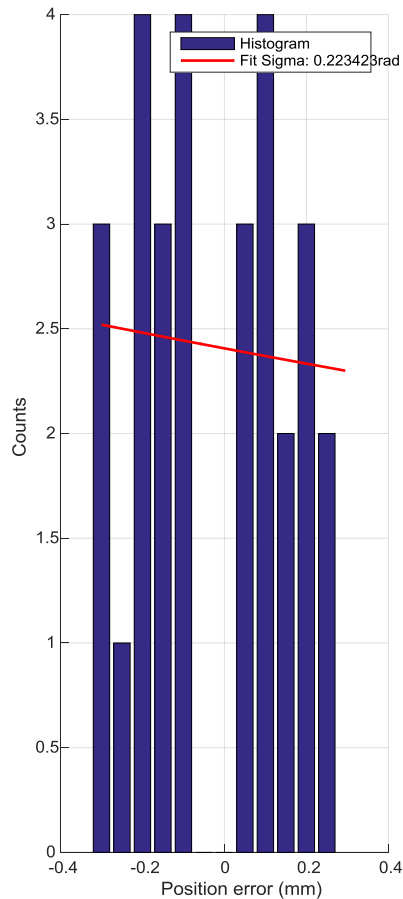
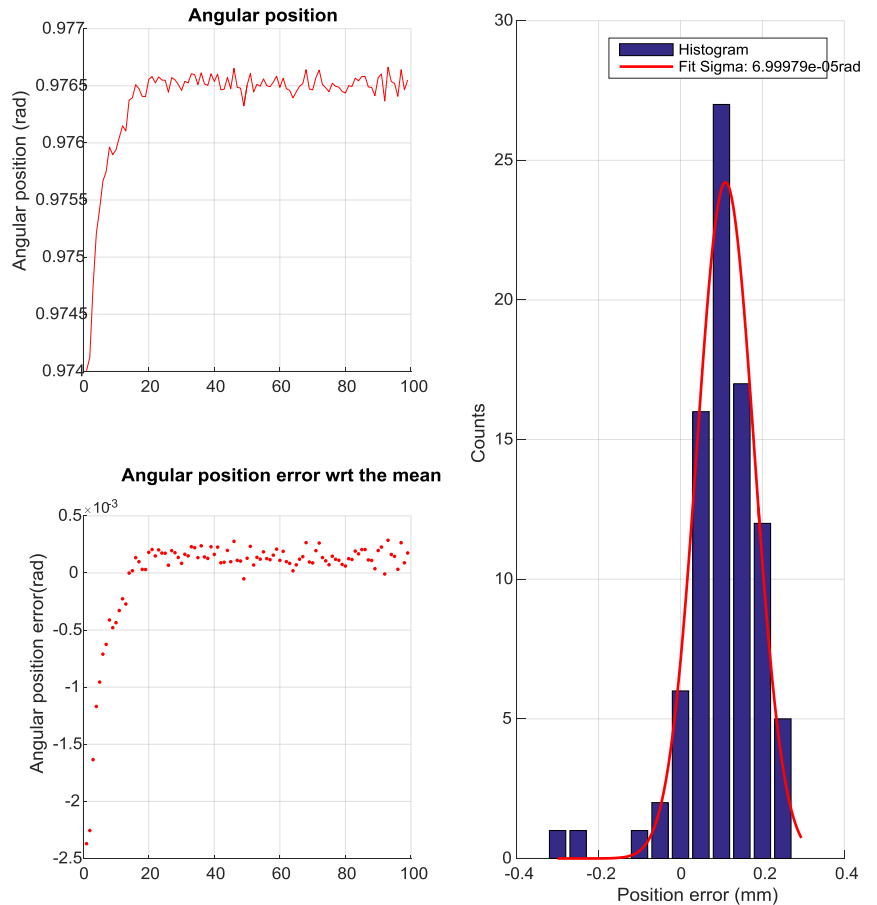
## 3.3 Findings when performing single position scans

When calibrations are done after another one at different speed....

Wire Projected position error histogram (PSB55rs Offset06 TableFixed ShorterRail 100Scans Cer



Wire Projected position error histogram (PSB133rs Offset06 TableFixed ShorterRail 100Scans Cen

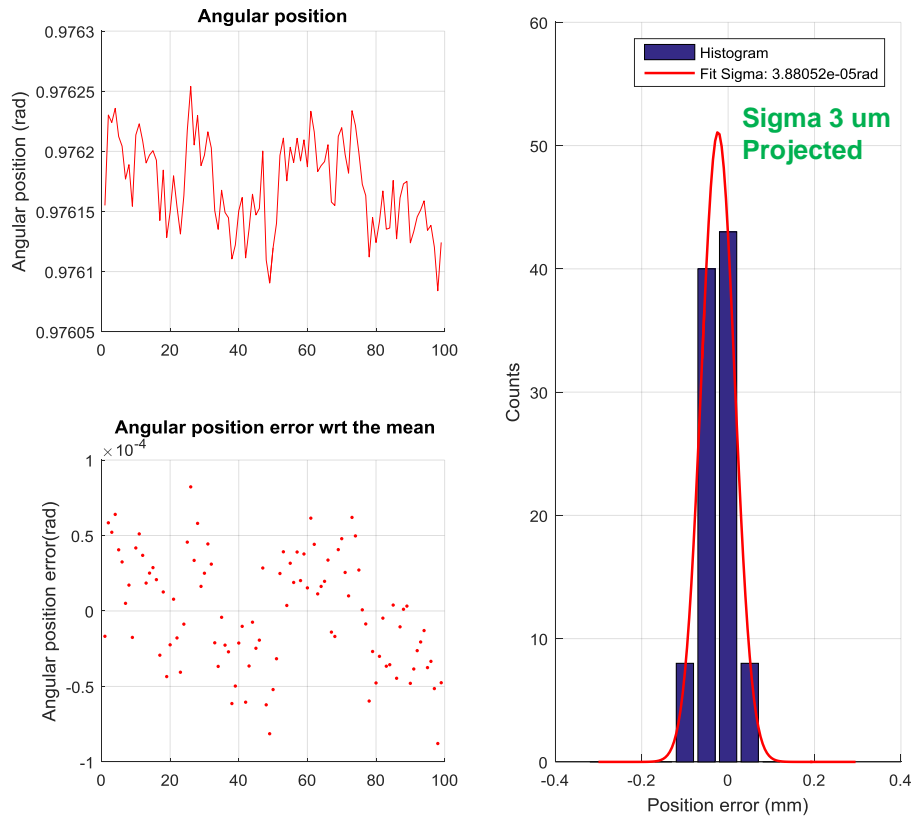


# 3. The Calibration Bench

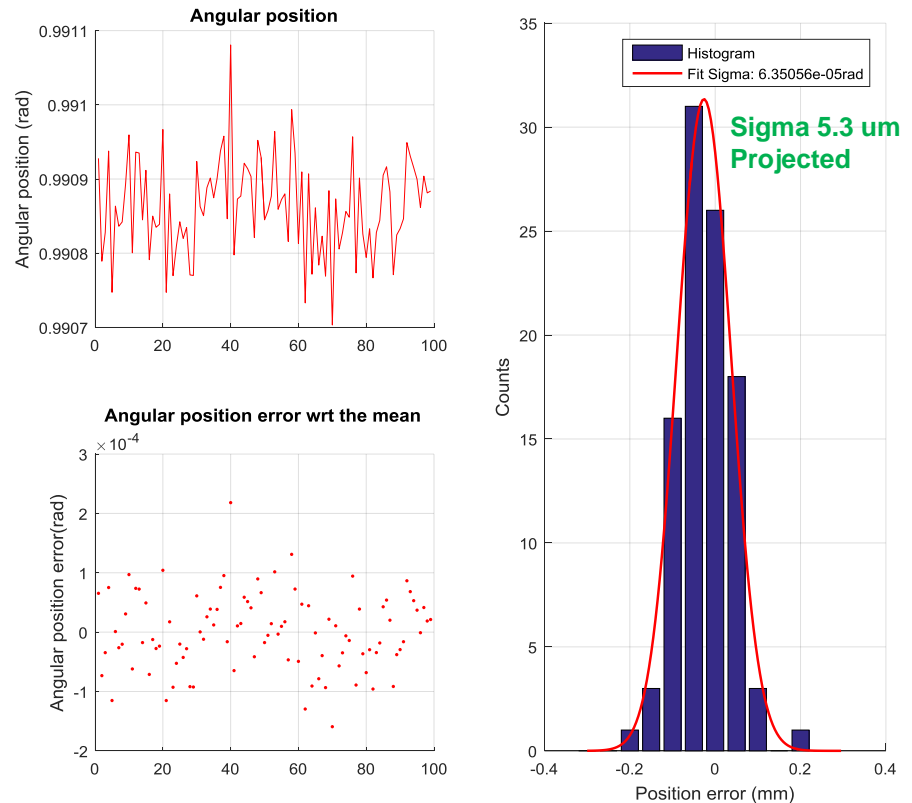
## 3.3 Findings when performing single position scans

Once Disk holder “finds a comfortable position for each speed”...

Calibration 55 rs



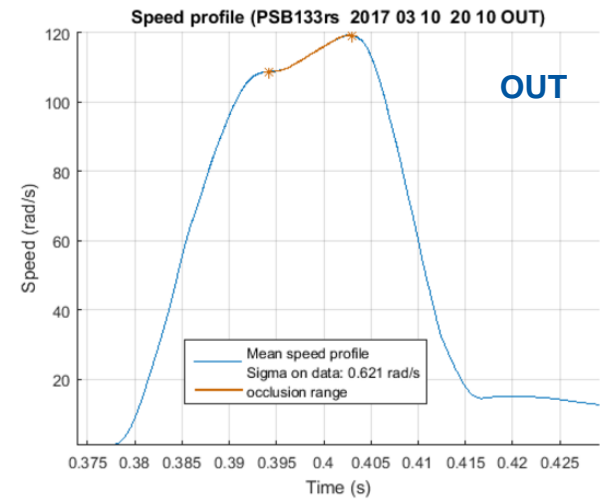
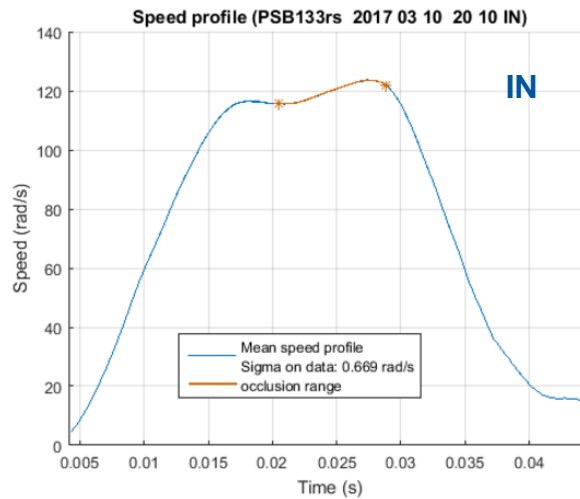
Calibration 133 rs



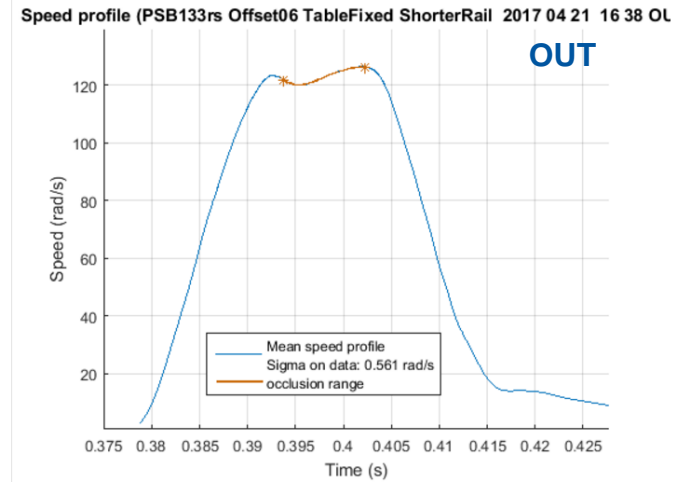
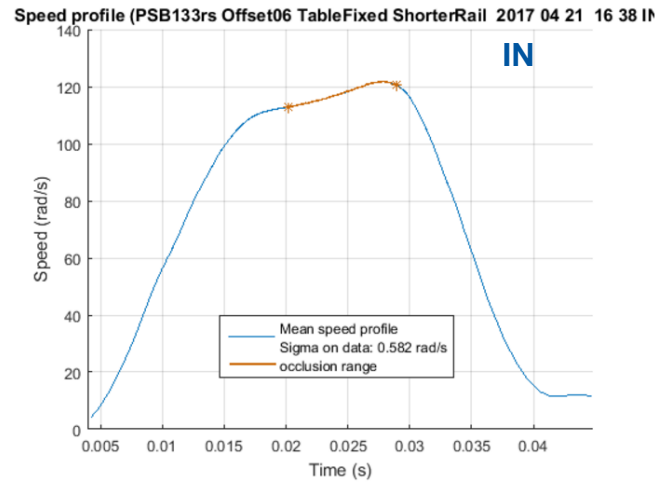
# 3. The Calibration Bench

## 3.4 Speed Profiles

Speed Profiles  
PSB System →



Speed Profiles  
LAB System →



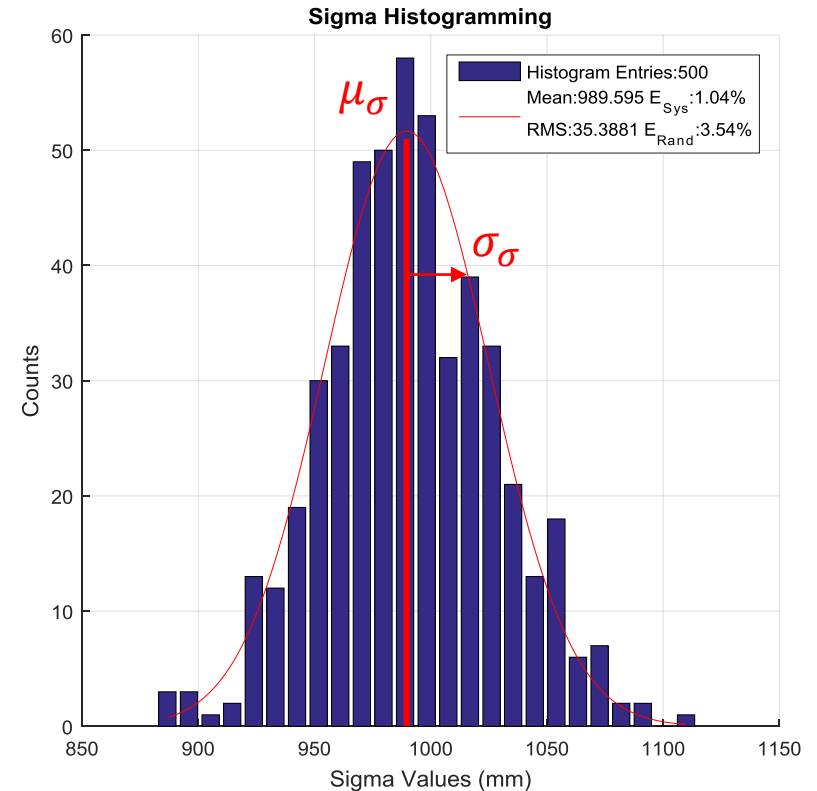
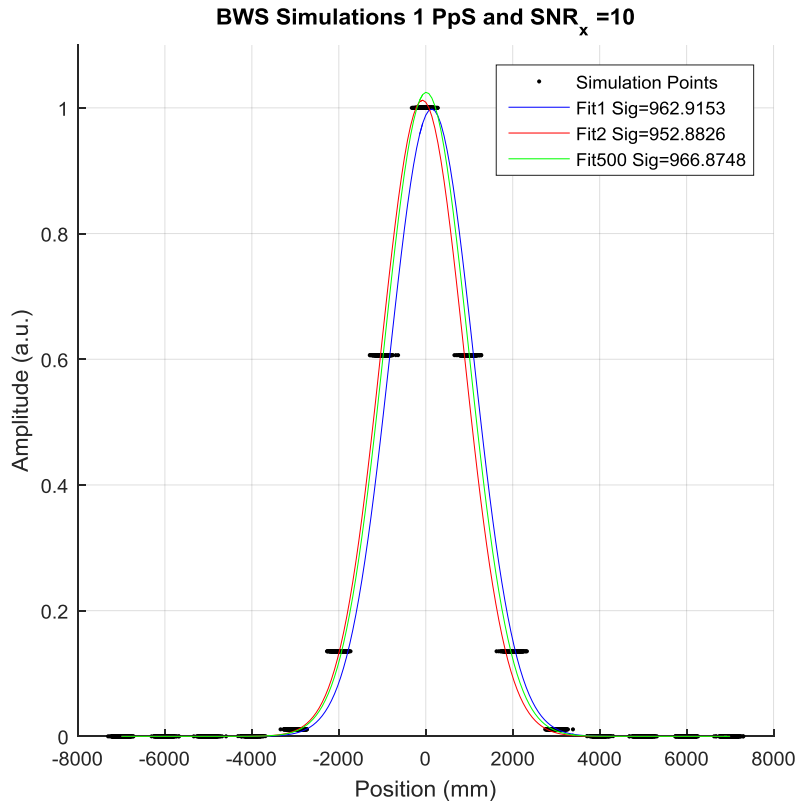
## 2. The Calibration Bench

### 2.3 Possible sources of uncertainty on scanner precision assessment

PSB BWS Numeric Summary (Precision results)			
Speed (Rad/s)	Eccentricity Correction (um)	Absolute Calibration (um)	Single position Calibration (um)
55	0.43	5	3
133	0.46	11	5

# 3. Position Incertitude VS Beam Sigma Incertitude

## 3.1 Numerical Simulations



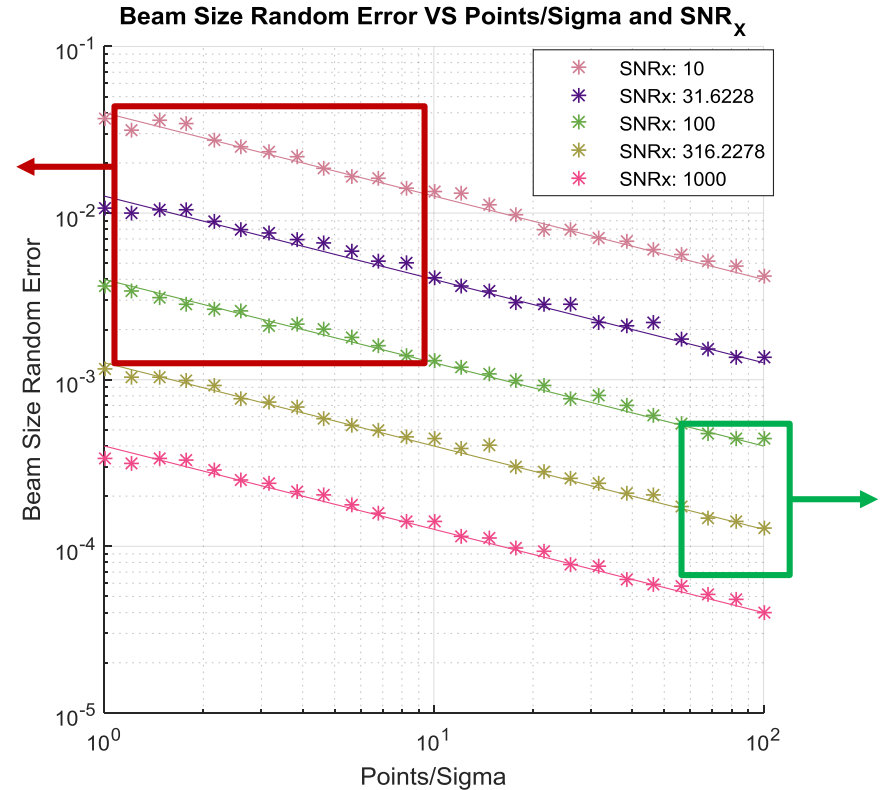
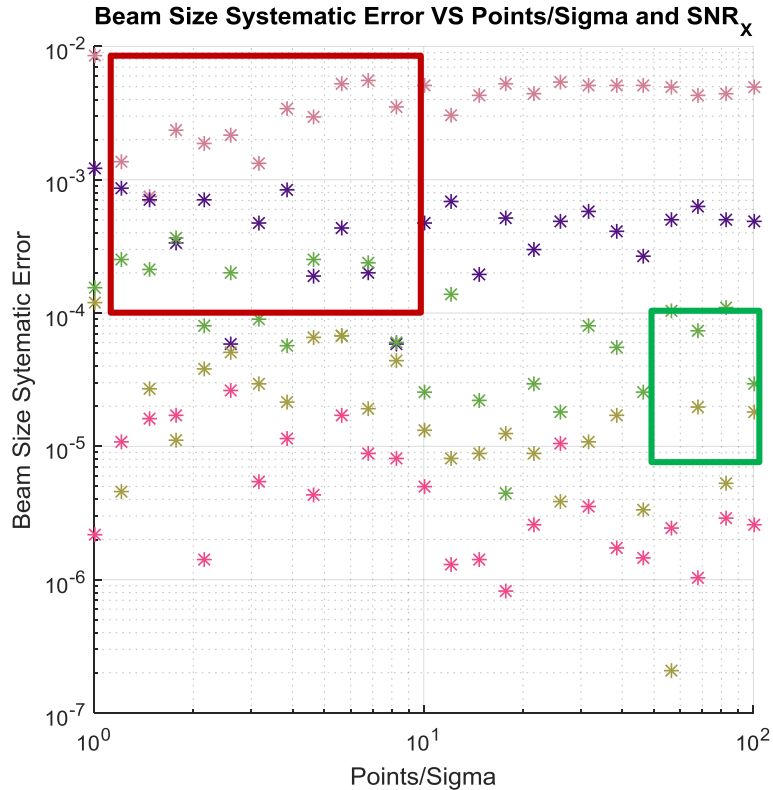
- Gaussian profile with variable # points per sigma
- Generation of 500 measurements in centered in each position with variable incertitude:

$$\sigma_i = c = \frac{\sigma_{beam}}{SNR_x}$$

$$\epsilon_{systematic} = \frac{\sigma_{beam} - \mu_\sigma}{\sigma_{beam}} \quad \epsilon_{Statistic} = \frac{\sigma_\sigma}{\sigma_{beam}}$$

# 3. Position Incertitude VS Beam Sigma Incertitude

## 3.1 Numerical Simulations: Results



Machine	Beam Size	PpS @ 20ms-1	Uncertainty	$SNR_x$
<b>PSB</b>	1.5 - 9 mm	46 - 281	11 $\mu$ m	136 - 820
<b>SPS</b>	0.2 - 5 mm	0.4 - 10	11 $\mu$ m	18 - 454

Typical Examples:



# 3. Position Incertitude VS Beam Sigma Incertitude

## 3.1 Numerical Simulations: Outcome and conclusions

### Requirements for Rand Err < 1% on SPS @ 20ms-1:

$$\epsilon_{Statistic}(SNR_x, PpS) = \frac{0.4}{SNR_x \sqrt{PpS}}$$

#### Sigma 200 um

PpS = 0.4, SNRx needs to be >63

Pos Incertitude required better than 3 um

#### Sigma 5000 um

PpS = 10, SNRx needs to be >13

Pos Incertitude required better than 380 um

### Comments

#### **Specifications:**

- Bernd's Document → Position measurement accuracy of the order of 1 μm

#### **Conclusions:**

- For PSB beams: System is within specifications in terms of beam size error (< 0.1%).
- For SPS beams: For small beams, accuracy needs to be improved or speed reduced.
  - Analitical approx diverges for PpS < 1 maybe intertitude > 3 um can be allowed for small beams.

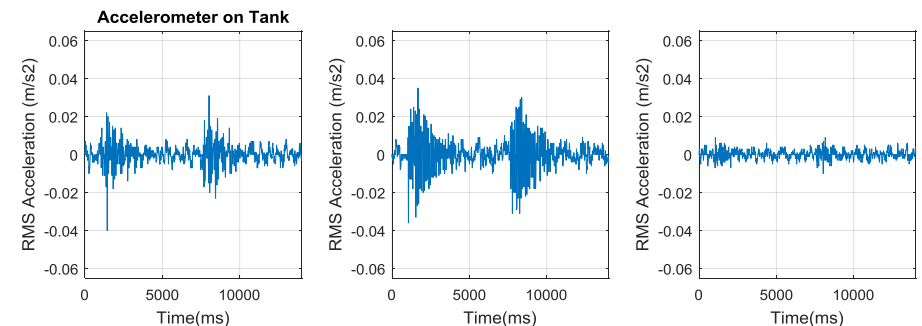
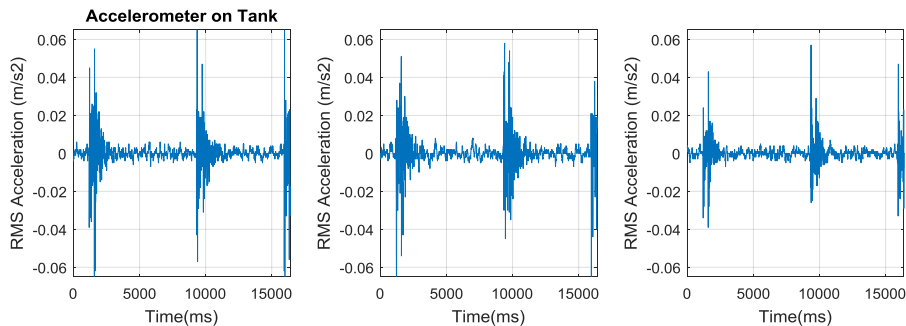
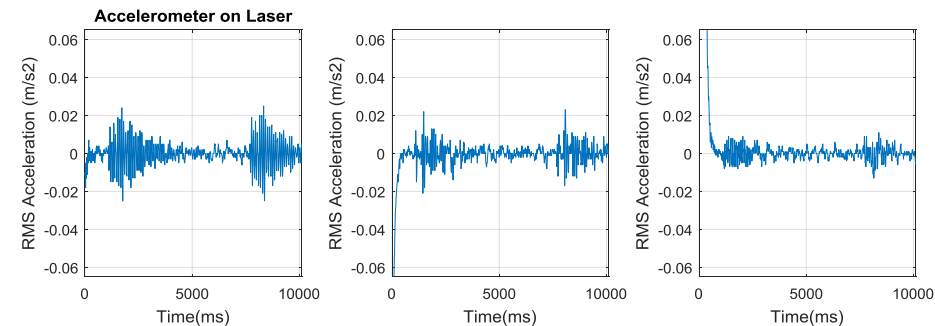
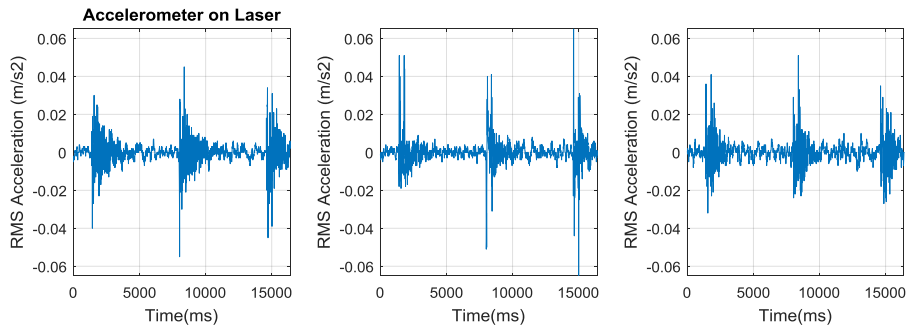
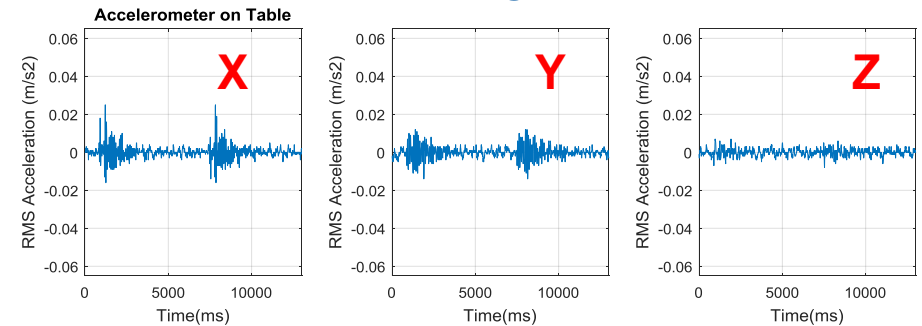
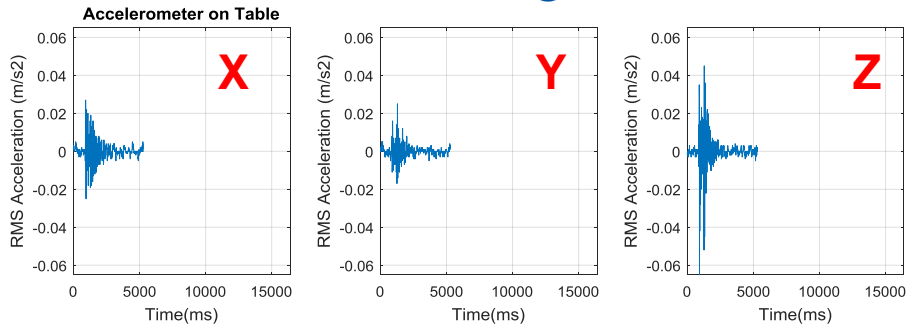


# 2. The Calibration Bench

## 2.3 Possible sources of uncertainty on calibration bench: Vibrations

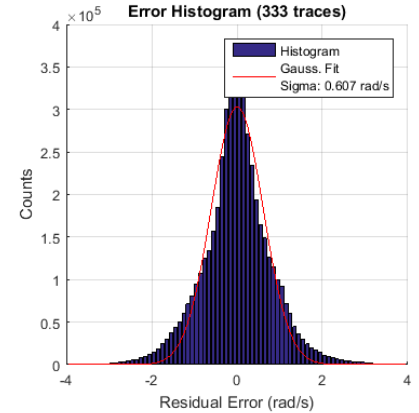
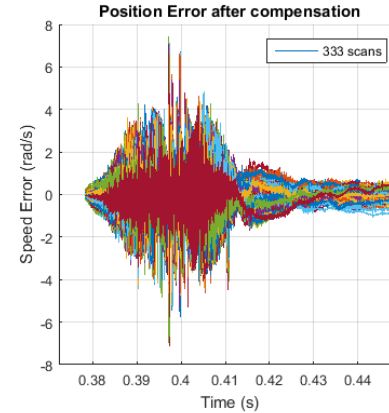
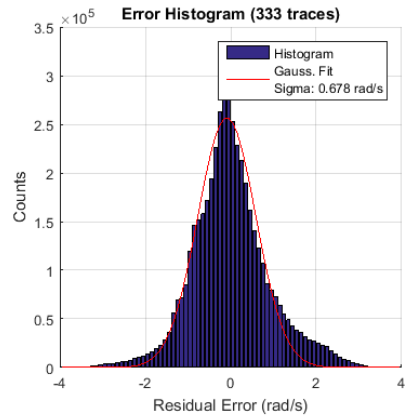
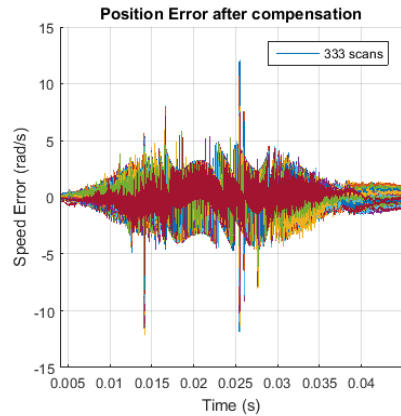
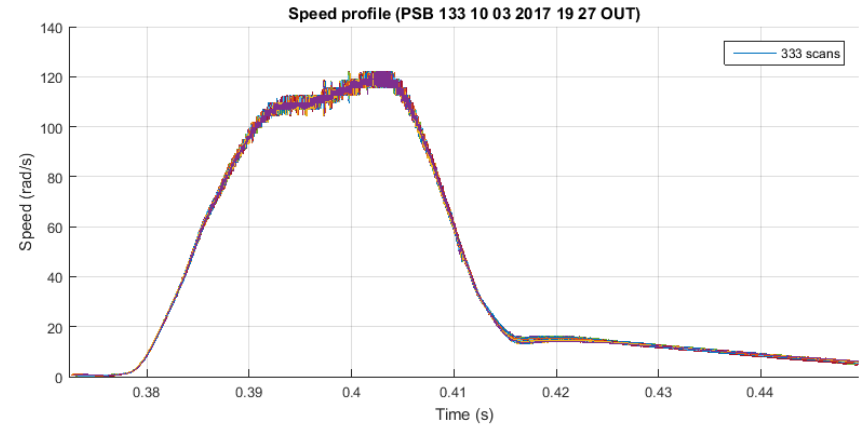
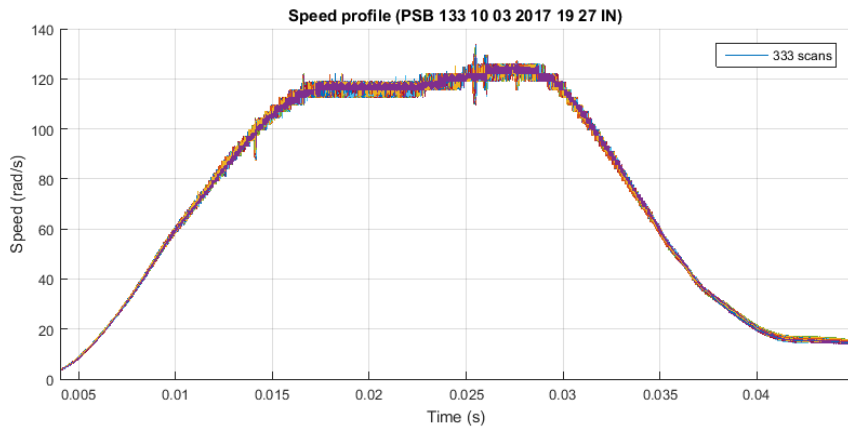
### Calibration @ 133Rad/s

### Calibration @ 55Rad/s



# 2. The Calibration Bench

## 2.4 Scan-to-Scan Speed Variations (133 Rad/s)



# 2. The Calibration Bench

## 2.4 Scan-to-Scan Speed Variations (55 Rad/s)

