QUALIFICATION MEASUREMENTS OF THE EPFL WINDING WHEELS

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INTRODUCTION

- The width, length and position of the pins w.r.t. the thread are presented for winding wheels EPFL-1 to 4.
- The measurement is made on pictures using “on-screen” ruler (see slide 5).
- The width and position of the pins relative to the thread are used to align the fibres (i.e. the channels).
- Standard pin numbering:
  - Starting at the mat cutting groove, and increasing in the winding direction.
MANUFACTURER PIN DESIGNS

Pin design v1: R = 3 mm

Pin design v2: R = 3.5 mm
WHEEL EPFL-2
(BOMA 2017-5)
DEFINING THE SCALE AND ASSIGNING UNCERTAINTIES

- We measure the length of 10 steps (defined as one thread pitch of 275 μm) which we define as our scale $L_0$
- Measurements assume that the 275 μm pitch is correctly made, and that there is no uncertainty on this number
- $L_0 = 2750 \mu m \pm \sigma_x$
- The uncertainty on the start/end point of the measurement is estimated (based on thread pitch width) : 20 μm
- $\sigma_x = \sqrt{2} \cdot 20 \mu m = 28 \mu m$  1.0 % relative uncertainty from the scale
- The scale uncertainty is $1.07 \cdot \sigma_x$ for a typical pin with width $L = 2950 \mu m$
- The typical width of a pin is given by : $L = 2950 \mu m \pm 1.0 \% (scale) \pm \sigma_x \approx (2950 \pm 41) \mu m$
SCALE AND WIDTH MEASUREMENT (SOFTWARE : IMAGEJ®)

Scale definition

Width measurement
The wheel has 11 pins

Each pin’s width is measured in 3 different positions around the central axis

The average value for a single pin presents an uncertainty \( \sqrt{\left( \frac{28}{\sqrt{3}} \right)^2 + (29.5)^2} \mu m = 34 \mu m \)
When measuring, the ruler is not orthogonal to the thread but makes an angle $\theta$

The associated relative uncertainty is $\sigma_\theta = 1 - \cos \theta \approx \theta^2/2 = 1.23 \cdot 10^{-4}$

This uncertainty is neglected
CONSIDERING ALL MEASUREMENTS

- We consider all 33 measurements
- Maximum width is 2997 \( \mu m \)
- RMS is 21 \( \mu m \)
  - RMS includes in quadrature the resolution and the pin-to-pin variations.
  - RMS gives an upper bound on the uncertainty
- Nominal width (manufacturer): 3.00\( ^{+0}_{-0.03} \) \( mm \)

![Graph of Winding Wheel EPFL 2 - Boma 5](image)

<table>
<thead>
<tr>
<th>Width (( \mu m ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2900</td>
</tr>
<tr>
<td>2910</td>
</tr>
<tr>
<td>2920</td>
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<td>2980</td>
</tr>
<tr>
<td>2990</td>
</tr>
<tr>
<td>3000</td>
</tr>
</tbody>
</table>

Entries: 33
Mean: 2953
Std Dev: 20.98
MEASURING THE LENGTH

- Same scale as previously
- Only one measurement per pin due to the geometry
- We assume a measurement error \( \sigma_y = \sqrt{2} \cdot 26 \, \mu m = 37 \, \mu m \)
- The scale uncertainty is \( 2 \cdot \sigma_x \) for a typical pin with length \( H = 5500 \, \mu m \)
- The typical length of a pin is given by: \( H = 5500 \, \mu m \pm 1.0 \% (scale) \pm \sigma_y \approx (5500 \pm 67) \, \mu m \)
LENGTH RESULTS

- RMS is 29 μm
- Nominal length (manufacturer) : 6.71 mm
- Observed lengths do not correspond
- They are closer to the 1st pin design : 5.66 mm
WIDTH AND LENGTH PER PIN

Average width per pin

Length per pin
<table>
<thead>
<tr>
<th>Pin number</th>
<th>Width a [µm]</th>
<th>Width b [µm]</th>
<th>Width c [µm]</th>
<th>Average Width [µm]</th>
<th>Length [µm]</th>
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<tbody>
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<td>3</td>
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<td>2946</td>
<td>5497</td>
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<td>10</td>
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<td>11</td>
<td>2971</td>
<td>2951</td>
<td>2925</td>
<td>2949</td>
<td>5533</td>
</tr>
</tbody>
</table>

$\sigma_{x}^{RMS} \approx 21 \, \mu m$

$\sigma_{x}^{Estimation} \approx 34 \, \mu m$

$\sigma_{y}^{RMS} \approx 29 \, \mu m$

$\sigma_{y}^{Estimation} \approx 67 \, \mu m$
PIN POSITION RELATIVE TO THE THREAD

- We measure the distance between the right edge of the pin and the 2\textsuperscript{nd} thread pitch after the left edge.
- Again we average over three measurements ($\sigma = 39 \mu m$).
- The 11 pins seem to be aligned with the thread by less than one pitch (checked during fibre winding).
- $d = (3573.3 \pm 11.8) \mu m$
- $\chi^2_{dof} = 0.45$ \quad p-value $= 92.2\%$
Nominal depth (manufacturer) : 2.50 mm

The pins widths were also measured using precision blocks and are compatible with the pictures’ measurements
  - Confirmation of the absolute scale

However, it is more useful as upper limit than as proper measurement due to the pin’s geometry which hinders the measurement
WHEEL EPFL-3
(BOMA 2017-4)

MODIFICATIONS OF THE PROCEDURE RELATIVE TO EPFL-2 WRITTEN IN BOLD
We use 38 steps to define our scale $L_0$

$L_0 = 10450 \, \mu m \pm \sigma_x$

$\sigma_x = \sqrt{2} \cdot 20 \, \mu m = 28 \, \mu m \quad \Rightarrow \quad 0.27 \% \text{ relative uncertainty on the scale}$

The typical width of a pin is given by: $L = 2950 \, \mu m \pm 0.27 \% (scale) \pm \sigma_x \approx (2950 \pm 29) \mu m$

Average value for a single pin presents an uncertainty $\sqrt{\left(\frac{28}{\sqrt{3}}\right)^2 + (8)^2} \, \mu m = 18 \, \mu m$
CONSIDERING ALL MEASUREMENTS

- Maximum width is 3010 μm
- RMS is 17 μm
  - RMS includes in quadrature the resolution and the pin-to-pin variations.
  - RMS gives an upper bound on the uncertainty

<table>
<thead>
<tr>
<th>Width [μm]</th>
<th>Events</th>
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<td>2930-2940</td>
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<td>3030-3040</td>
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<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
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<td>Entries</td>
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<tr>
<td>Mean</td>
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<tr>
<td>Std Dev</td>
<td>17.39</td>
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LENGTH RESULTS

- We assume a measurement error of $\sigma_y = \sqrt{2} \cdot 26 \mu m = 37 \mu m$
- The typical length of a pin is given by: $H = 5500 \mu m \pm 0.27\% (scale) \pm \sigma_y \approx (5500 \pm 40) \mu m$
- RMS is 25 $\mu m$
WIDTH AND LENGTH PER PIN

Average width per pin

Length per pin

Winding Wheel EPFL 3 - Boma 4
<table>
<thead>
<tr>
<th>Pin number</th>
<th>Width a [µm]</th>
<th>Width b [µm]</th>
<th>Width c [µm]</th>
<th>Average Width [µm]</th>
<th>Length [µm]</th>
</tr>
</thead>
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<td>5601</td>
</tr>
</tbody>
</table>

\[ \sigma_x^{\text{RMS}} \approx 17 \mu m \]
\[ \sigma_x^{\text{Estimation}} \approx 18 \mu m \]
\[ \sigma_y^{\text{RMS}} \approx 25 \mu m \]
\[ \sigma_y^{\text{Estimation}} \approx 40 \mu m \]
We measure the distance between the right edge of the pin and the 1st thread pitch after the left edge.

Again we average over three measurements ($\sigma = 18 \, \mu m$).

Pins stay in the same thread (but pins 3 & 4 are slightly displaced).

$$d = (3295.2 \pm 5.0) \, \mu m$$

$$\frac{\chi^2}{dof} = 5.24 \quad \rightarrow \quad p\text{-value} = 9.6 \cdot 10^{-8}$$
To ensure that the discrepancy seen in pins 3 & 4 is real we measure the distance from the left edge of the pin to the 1st thread after the right edge

- This is the opposite direction
- Effect still present
WHEEL EPFL-4
(BOMA 2017-2)

MODIFICATIONS OF THE PROCEDURE RELATIVE TO EPFL-2 WRITTEN IN BOLD
NEW SCALE AND UNCERTAINTIES

- We use 35 steps to define our scale $L_0$
- $L_0 = 9625 \, \mu m \pm \sigma_x$
- $\sigma_x = \sqrt{2} \cdot 20 \, \mu m = 28 \, \mu m$ $\Rightarrow$ 0.29 % relative uncertainty on the scale
- The typical width of a pin is given by: $L = 2950 \, \mu m \pm 0.29 \% (scale) \pm \sigma_x \approx (2950 \pm 29)\mu m$
- Average value for a single pin presents an uncertainty $\sqrt{\left(\frac{28}{\sqrt{3}}\right)^2 + (9)^2} \, \mu m = 18 \, \mu m$
PIN POSITION RELATIVE TO THE THREAD

- We measure the distance between the right edge of the pin and the 1st thread pitch after the left edge
- Again we average over three measurements ($\sigma = 19 \mu m$)
- Pins stay in the same thread (but pins 7 & 8 are slightly displaced)
- $d = (3295.2 \pm 5.0) \mu m$
- $\frac{\chi^2}{dof} = 5.24 \quad \Rightarrow \text{p-value} = 9.6 \cdot 10^{-8}$
CROSS-CHECK FOR PINS 7 & 8

- To ensure that the discrepancy seen in pins 7 & 8 is real we measure the distance from the left edge of the pin to the 1st thread after the right edge
  - This is the opposite direction
- Effect still present
The magnitude of the misalignment is different between the two previous plots.

- This is due to some uncentered pins.

- We sum both values.
  - The structure is similar to the width plot, as expected (see next slide).
COMPARISON BETWEEN WIDTH AND ALIGNMENT SUM

Winding Wheel EPFL 4 - Boma 2

Average distance (μm)

Pin Number

-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100

Winding Wheel EPFL 4 - Boma 2
WHEEL EPFL-I  
(BOMA 2016-2)  
MODIFICATIONS OF THE PROCEDURE RELATIVE TO EPFL-2 WRITTEN IN BOLD
NEW SCALE AND UNCERTAINTIES

- We use 35 steps to define our scale $L_0$
- $L_0 = 9625 \mu m \pm \sigma_x$
- $\sigma_x = \sqrt{2} \cdot 20 \mu m = 28 \mu m$  $\rightarrow$ 0.29% relative uncertainty on the scale
- The typical width of a pin is given by: $L = 2950 \mu m \pm 0.29 \%(scale) \pm \sigma_x \approx (2950 \pm 29)\mu m$
- Average value for a single pin presents an uncertainty $\sqrt{\left(\frac{28}{\sqrt{3}}\right)^2 + (9)^2} \mu m = 18 \mu m$
WIDTH PER PIN

![Graph showing width per pin for Winding Wheel EPFL 4 - Boma 2.](image-url)
PIN POSITION RELATIVE TO THE THREAD

- We measure the distance between the right edge of the pin and the 2\textsuperscript{nd} thread pitch after the left edge
- Again we average over three measurements ($\sigma = 19 \, \mu m$)
- Pins stay in the same thread
- $d = (3570.9 \pm 5.7) \, \mu m$
- $\chi^2/dof = 1.19 \rightarrow p\text{-value} = 29.49\%$