An investigation into the use of diffraction for sieve calibration

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Test and Measurement Conference
Tuesday 30 September 2014

Your measure of excellence
Sieves

• A sieve or strainer is an important part of most industrial processes

• Used extensively in
  • pharmaceutical
  • coating
  • painting
  • food
  • civil engineering among other industries

• Two main types of sieving uses
  • safety screening (safety screening removes any oversized unwanted particles/ contamination)
  • grading (quality screening ensures a similar particle distribution, for example, in pharmaceuticals; screening will ensure similar particles in making pills)

• It is therefore important that the sieve hole-sizes are known
• The calibration for sieves is normally by optical microscope or video image analysis (ISO 3310-1:(E))

• In South Africa, the optical method is the most common one

• This method is very laborious and time consuming
Alternative methods used to calibrate sieves:

- **Particle sizing** - use of particles of known sizes is employed
  - particles are passed through the sieves, shaken and the size of the particles that pass through each sieve in the stack are noted
  - method is very cumbersome and reference particles need to be purchased at high cost and these cannot be used to test many sieves

- **Combination** of the particle sizing, inspection and optical method
• Before calibration, sieves must be inspected by eye to check that there are no obviously large holes and that there are no sediments stuck between the wires.

• If sieve is damaged, appropriate steps must be taken
ISO Requirements

• Currently, the technical requirements for testing sieves stipulates through ISO 3310-1:(E) that the average aperture size of the sieve should be reported

• These should be measured in both warp (horizontal) and weft (vertical) directions

• The ISO standard prescribes that an average aperture size must be reported for a minimum of 15 readings in each direction for a sieve of up to 200mm in diameter
• According to the standard, no aperture shall exceed the nominal size, \( w \) by more than \( X \)

\[
X = \frac{2w^{0.75}}{3} + 4w^{0.25} \quad \text{where } X \text{ and } w \text{ are in } \mu \text{m} \tag{1}
\]

• The average aperture size \( \bar{w} \) shall not depart from the nominal size \( w \) by more than \( \pm Y \)

\[
Y = \frac{w^{0.98}}{27} + 1.6 \quad \text{where } Y \text{ and } w \text{ are in } \mu \text{m} \tag{2}
\]

• From this, we can see that, say for a 63 \( \mu \text{m} \) sieve size, a single hole size can be up to

\[
X + w = 26 + 63 = 89 \ \mu \text{m} \tag{3}
\]
• For a 63 µm sieve size, the average aperture size should be within 3.7 µm and the maximum hole size can be as high as 89 µm

• A typical 63 µm sieve has more than 2 million holes and an average reading for 30 holes does not give the correct representation of the sieve hole sizes
Sieve calibration using diffraction

• Looked for a method that could:
  • increase speed
  • calibrate more holes
  • calibrate more accurately

• Diffraction address all these as:
  • there will be an increase in speed and ease at which the sieves are calibrated
  • more apertures than the required 30 holes per sieve can be measured, giving a better representation of the aperture sizes of the sieves
  • the accuracy of the measurement will be improved, with higher resolution and better uncertainty
  • diffraction is a first principle method and the calibration method has a shorter traceability route to the SI unit and therefore is more accurate
• NMISA already has a history experimenting with diffraction

• They developed a wool fibre meter to measure wool fibre thickness

• Over the last few years this technique was refined and further developed by a consortium to a commercial system which is now available on the market.

• The system is very cost effective and can achieve the required accuracies using the principle of diffraction

• System can measure wool fibre thicknesses in the range 15 to 25 μm with an accuracy of better than 0,8 μm
Properties of light

- Light has various properties which have been exploited for different reasons in science.
- Light manifests itself in two forms, i.e., the wave-particle duality of light.

In particle form:

\[ E_{\text{photon}} = h\nu \]

- For a photon with a wavelength of 700 nm (1.77 eV), the maximum velocity is approximately \( 6.22 \times 10^5 \) m/s.
- For a photon with a wavelength of 550 nm (2.25 eV), the maximum velocity is approximately \( 2.96 \times 10^5 \) m/s.
- For a photon with a wavelength of 400 nm (3.1 eV), the maximum velocity is approximately \( 6.22 \times 10^5 \) m/s.

The photoelectric effect is observed when potassium is illuminated with light of energy greater than 2.0 eV, necessitating the ejection of electrons.
Light in wave form
Refraction

- Bending of light when passing from one medium to another

Reflection

- Light strikes and object and bounces off
Diffraction
• Bending of light around barriers

Interference
• Adding up or cancelling of diffracted light
Diffraction

“the process by which a beam of light or wave is spread out as a result of passing through a narrow aperture or across an edge, typically accompanied by interference between the waveforms produced”
Calibrating sieves using diffraction

- Sieve wires act as the barrier around which light is bent
- The ‘bent’ light interferes and produces a pattern on the screen

- Horizontal wires produce vertical pattern
- Vertical wires produce horizontal pattern
Calibrating sieves using diffraction

From small angle approximation:
\[ \tan \theta \approx \sin \theta \approx \theta = \frac{y}{D} \]

Condition for minima:
\[ a \sin \theta = m \lambda \]

Sieve hole size \( a = \frac{m \lambda D}{y} \)
Sieves calibrated

200 μm

125 μm

63 μm
## Results

<table>
<thead>
<tr>
<th>Sieve hole size (µm)</th>
<th>Diffraction Measured value (µm)</th>
<th>Optical Measured values µm (standard deviation calculated over 10 holes measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>63,25</td>
<td>62,2 (3,6)</td>
</tr>
<tr>
<td>125</td>
<td>125,74</td>
<td>124,6 (3,9)</td>
</tr>
<tr>
<td>212</td>
<td>213,01</td>
<td>214,8 (4,6)</td>
</tr>
</tbody>
</table>
## Errors

<table>
<thead>
<tr>
<th>Distance from minima to maxima $y$ (µm)</th>
<th>Calculated aperture size (µm)</th>
<th>Difference in aperture size from nominal (µm)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>9500</td>
<td>213,005</td>
<td>0</td>
<td>Actual</td>
</tr>
<tr>
<td>9510</td>
<td>212,781</td>
<td>0,224</td>
<td>10 µm error on $y$</td>
</tr>
<tr>
<td>10000</td>
<td>202,355</td>
<td>10,650</td>
<td>500 µm (0,5mm) error on $y$ results in 11 micron error in measurement result</td>
</tr>
</tbody>
</table>

Sieve hole size $a = \frac{m\lambda D}{y}$
### Uncertainty Budget


<table>
<thead>
<tr>
<th>Description:</th>
<th>Calibration of</th>
<th>Type:</th>
<th>Relative Uncertainty Value ( U(X) )</th>
<th>Probability Distribution ( N, R, T, U )</th>
<th>Divisor Factor</th>
<th>Sensitivity Coefficient ( C_i )</th>
<th>Relative Uncertainty Contribution ( U_i ) ( (y) )</th>
<th>Length (mm):</th>
<th>Expansion coeff. ( (\text{um}(\text{mm}.\text{K})^{-1}) ):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>Source of Uncertainty</td>
<td></td>
<td>Constant</td>
<td>Length dependent</td>
<td>( \text{(Unit)} )</td>
<td></td>
<td></td>
<td>Constant ( \text{(um)} )</td>
<td>Length dependent ( \text{(um/mm}^{-1}) )</td>
</tr>
<tr>
<td>Std</td>
<td>wavelength</td>
<td></td>
<td>6.00E-06</td>
<td>um</td>
<td>( \text{Normal k=2} )</td>
<td>2.00</td>
<td>3.365E+02</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>uncertainty in D</td>
<td></td>
<td></td>
<td>1.00E+03</td>
<td>um</td>
<td>( \text{Rectangular} )</td>
<td>1.73</td>
<td>6.700E-05</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>uncertainty in y</td>
<td></td>
<td></td>
<td>1.25E+02</td>
<td>um</td>
<td>( \text{Rectangular} )</td>
<td>1.73</td>
<td>2.242E-02</td>
<td>1.62</td>
<td></td>
</tr>
<tr>
<td>REP</td>
<td>Repeatability</td>
<td></td>
<td>1.00E-01</td>
<td>um</td>
<td>( \text{Normal k=1} )</td>
<td>1.00</td>
<td>1.000E+00</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>Constant</th>
<th>T-dependent ( \text{(um.mm}^{-1}) )</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Combined</td>
<td>1.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expanded</td>
<td>4.30</td>
<td></td>
</tr>
</tbody>
</table>

**Total - combined (um):** 1.62  
**Total - expanded (um):** 4.30
Monte Carlo Simulation

Equation:

\[ a = \frac{m \lambda D}{y} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distribution</th>
<th>Nominal</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>Normal</td>
<td>0.6330000000 μm</td>
<td>0.0000006000 μm</td>
</tr>
<tr>
<td>Distance</td>
<td>Normal</td>
<td>31968000000000 μm</td>
<td>100000000000000 μm</td>
</tr>
<tr>
<td>y</td>
<td>Normal</td>
<td>950000000000000 μm</td>
<td>125000000000000 μm</td>
</tr>
</tbody>
</table>
Discussion of results

• Accurate results depend heavily on the accurate determination of y

• Uncertainty using optical method ranges from 3.6 μm to 4.6 μm

• Uncertainty on diffraction method can be improved by using a camera to detect diffraction pattern
Conclusion

• We have investigated diffraction as an alternative way to calibrate sieves
• Diffraction is faster and more holes can be calibrated, giving a better representation of the sieve hole sizes
• It provides a shorter traceability route to the national standard
• Further investigation is needed into use of camera for detection of diffraction pattern and improvement of uncertainty
Thank you

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