WinCamD Series Diameter Accuracy, Precision & Resolution

At Issue: Customers and Reps/Distributors ponder, and sometimes ask, the following apparently reasonable questions:

i) What is the beam measurement accuracy/error of WinCamD/WinCamD-UCM?

ii) How can the datasheets justify listing accuracy values smaller than the pixel size?

iii) How does the accuracy depend on the beam size?

They may feel frustration when the answers are not always totally clear-cut and unambiguous. Why the uncertainty? Why is every answer qualified by: "… depending, of course, on the actual beam." ?

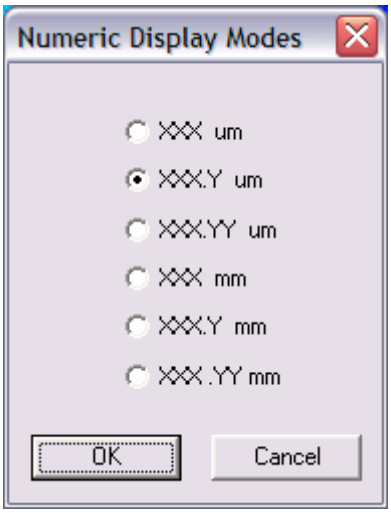
1. Definitions - Accuracy versus Precision versus Resolution

The **Accuracy** of a reading describes how close the reading is to the Absolute value of the parameter being measured. The Absolute value is the value that would be read by a perfect measurement system in perfect calibration with zero errors.

The **Precision** of an instrument refers to the Repeatability of the value obtained. An otherwise perfect measurement instrument that was incorrectly calibrated could be described as *Inaccurate* but *Precise*.

The **Resolution** of an instrument refers to the smallest increment (i.e. above the noise level) that the instrument can measure.

Readout Resolution is the smallest increment that may be read on the screen or via the software interface. DataRay software offers several **Numeric Display Modes**. The default is **XXX.Y μm**. The user may choose other options, but, *simply choosing a higher Numeric Display Mode resolution option does not make Accuracy higher*.



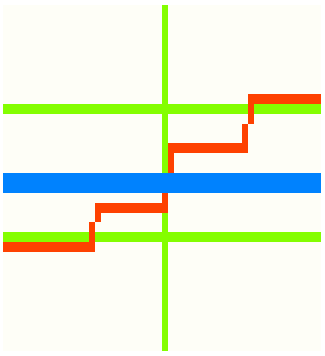
2. Pixel size / pitch quantization?

The pixel dimension (actually the pixel pitch, since the fill factor is never 100%) is 4.65 μm for WinCamD, 6.7 μm for WinCamD-UCM. With TaperCamDs the effective pixel size is even larger. [In fast mode the pixel dimensions are twice as large]

The casual observer might conclude that all measurements must be 'quantized' in terms of the pixel dimension. As shown below, this is not the case.

3. Beam Diameter based on clip level

WinCamD measures the outer diameter at the clip level. It must achieve this whether or not a pixel is at the specified clip level intensity. To do this it relies upon inter-pixel linear intensity interpolation.



The magnified orange profile portion, shown against the light green grid, shows the profile intensity (y-axis) versus position (x-axis) for the left hand edge of a profile. There are pixels above and below, but not on, the blue line indicating the requested clip level.

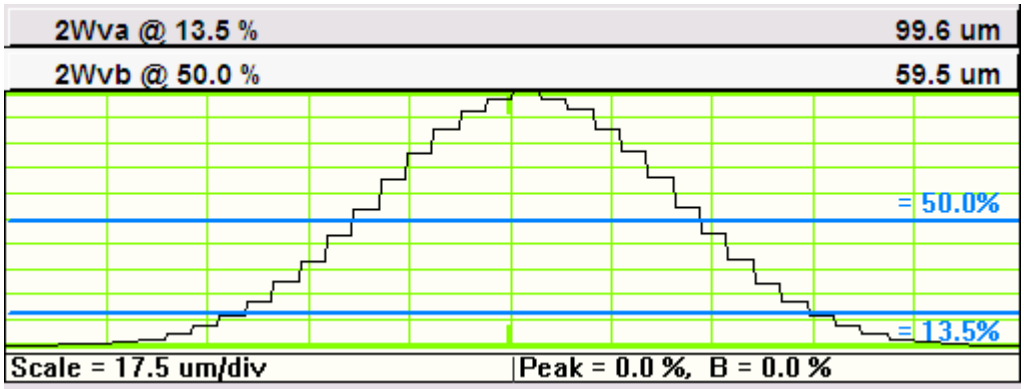
Rather than simply taking the outer pixel as a diameter basis, WinCamD determines the position of the two (adjacent) pixels above and below the requested clip level, and performs a linear interpolation between these two values.

I.E., the software determines the position where the profile *would have crossed* the clip level if the imager pixel size were infinitely small. It then makes the same determination for the right hand side of

the full profile. The difference between these two interpolated position values determines the diameter for the specified clip level.

Since these interpolated values are not quantized by the pixel location, the measured beam diameter is not quantized by the pixel size.

Smallest beam size.



Understanding this inter-pixel intensity interpolation leads to an understanding that accuracy will degrade as we move to smaller beams.

The profile of a 100 μm Gaussian beam shows well that even with 4.65 μm pixels, the validity of linear interpolation starts to break down as we go to smaller beams. This is because the two adjacent pixels start to lie on a curve rather than a straight line segment.

It is for this reason that the normal advice is to use a smallest beam diameter limit of about 10 times the pixel size. DataRay errs on the conservative side and suggests limits of 50 μm for WinCamD, and 70 μm for WinCamD-UCM.

A user may *choose* to measure smaller beam diameters, but should be aware of these accuracy limitations.

4. Second Moment Diameter

The Second Moment Diameter of an image is based upon an area integral weighted by the square of the distance from the beam centroid. As such it does not include a specific clip level. *See the WinCamD series manual for a full description and the formulae*.

Since Second moment diameter is a total image based calculation, then, at least to a first order, it is not subject to pixel dimension quantization limits.

In accordance with the ISO 11146 standard, DataRay cuts off the calculation at 99% of the included energy. For a pure Gaussian beam 99% of the energy corresponds to curtailing the calculation at a clip level of 1.45%, corresponding to a beam diameter 1.29 times greater than the 13.5 % clip level diameter. For a typical beams that are not pure Gaussians these numbers would be different.

5. Centroid

The Centroid (Xc,Yc) of an image is the intensity weighted arithmetic mean position of all pixel intensities *above the centroid clip level* (default value 13.5%). It is the 'Center of Gravity' of the beam.

As noise moves pixels above and below the centroid clip level, and hence in or out of the centroid calculation, the centroid value may change by an amount lower than the pixel size. For large beams the 'quantization' is barely visible. For smaller beams, it may become significant.