A CRITICAL LOOK AT "CALIBRATION" IN COTTON QUALITY MEASUREMENT

J. L. Woo
Visiting Research Professor
College of Textiles, NCSU
Raleigh, NC

Abstract

Presented here is a serious, and by no means fault searching, re-examination of what has been known as "calibration" in cotton fiber testing. The calibration, being an essential pre-requisite for the measurement process, is in fact an inverse problem involving a process of identifying the performance of an instrument, arising from the direct causal relationship it represents. Effect of using an assembly which is non-constant and random, like a clamp of cotton, as the calibration standard on the possible magnitude of measurement errors is made explicit to recommend planned further studies on the subject in the hope of reducing the uncertainty of the cotton quality measurements.

Calibration - Definitions and Views

Definitions

A formal definition of calibration that might convey all the features of actual acts, effects and meaning involved seems an elusive one. A selection of different definitions from two textbooks on hand, hardly any specific one to be more satisfactory or representative, are as follows:
"*Calibration* is the act of turning data into information. This is achieved by comparison with some agreed measurement standard and the result is to give *meaning* to the symbolism inherent in the signal" (Sydenham, etal., 1989). "*Calibration* is the process of determining and recording, with appropriate uncertainty, the relationship between the values indicated by a measuring instrument and the true value (or conventional true value) of the measured quantity" (Barney, 1988). A cut & pasted version might read: "*Calibration* is a process of deliberately subjecting a measuring instrument to a series of inputs, *of known standard values and level of traceability*, to *identify* the input-output relationship of the instrument for use in the subsequent measuring process."

The Old-fashioned Good Practice

On the other hand, it is well to recall what 'calibration' was meant to a good student of cotton testing in the 'pre *calibration cotton*, pre *computer-integration* era'. It was even not to think of meddling with the device on the basis of 'flimsy', 'dubious' and inconsistent fluctuations arising from the variations inherent to cotton fiber as a biological product, but it was meant more to address the procedural and human bias of systematic nature on the strength of the freshly gained information from the check test results. The thing that has to be wary of was the bad luck of catching the behavior known as "hunting" or alike, and a reasonable instruction given to a test operator to remedy such bias has been "If, (a given person) with a given instrument, 'reads' consistently below or above the known value, then a constant amount can be added to, subtracted from, or multiplied by, the measurement to give an adjusted or corrected value" (Steadman, 1997).

Thanks to the Instrument Makers and USDA

The current calibration procedures are so conveniently built into the instrument that there is no more of the need to worry about manually adding, subtracting, multiplying, etc., to correct the result. Displayed on the screen are, however, result of a series of manipulative signal processing applied to the raw data, the output from the sensor. As the results, to an average operator or even to the serious student, there is no way she or he could follow through how much of the variation is raw, and does not help to reduce the chronic instrument-phobia quite common among typical textile graduates.

Knowing that the force transducers used for the fiber strength measurement are calibrated with known standard weights additional to the screen-guided routines for the calibration (ASTM D5867-95), for example, and which indeed is comforting to know, one is tempted to ask how much of those calibration procedures appearing in the ASTM Designations are really essential from the cost-benefit viewpoint ? Are we not over-calibrating in scope or in frequency?

Fundamental Nature of Calibration

Let x be the input to a cotton quality measurement system, K, causing an output y. Then we might write it symbolically

$$y = Kx \;. \tag{1}$$

From the direct causal relationship (1), two inverse problems can arise: one is that tries to infer the 'causation' or the unknown input x, given K and y, and is nothing other than the process of measurement. Another is one that attempts 'identification' of K, given x and y, and is what we know as the process of calibration (Fig. 2). Dealing with a problem of calibration is not a simple task, though it might be quite challenging to some, even before paying our attention to the mathematicians' warning that the solutions to inverse problems in general are known for lack of uniqueness and instability. (For example, Gladwell, 1986; Groetsch, 1993).

Calibration in the Classical Real World

We calibrate a measuring device in order to keep result of a measurement on an identical specimen as consistent as possible at a traceable standard value, and the act of calibration is taken the time points where the device is

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1631-1633 (1998)
National Cotton Council, Memphis TN

presumed or considered liable to be offset by various real and assumed reasons to bring back the calibration curve to the original location, say, the dotted line *X* represented by the calibration standard *X* in Fig. 3.

That is to say, every time we calibrate the mechatronic device, using a calibration standard *X*, we are resetting the hardware's input-output relationship K by an amount corresponding to the displacement of the current calibration line to the dotted line *X*.

Once the device is in calibration with an appropriate calibration standard *X*, measurement on a specimen proceeds as straight forward as below: with the specimen mounted on the device, starting at the read or indicated output value *Y* on the vertical axis in the figure, tracing horizontally to meet the calibration line *X* at p, from which vertically downward to meet with the horizontal axis at X_0, which is the estimate of the so far unknown value of the specimen.

Calibration in the Real World of Cotton Testing

When a calibration standard is a stochastic entity rather than an object with a constant standard value, it is likely to possess the following properties as we could easily see in our calibration cottons.

(a) the standard value *X* for a calibration standard *X* is no longer a constant but is a random variable *X*.

(b) the random variable *X* takes on a range of values, say, within a region of tolerance as shown in Fig. 3, dependent on the prevailing sampling conditions.

(c) as the result, a packet of a calibration standard bears a standard values: MCI average and standard deviation (McNabb, 1995) from which an appropriate 'decision rule' for the calibration control needs to be devised.

In Fig. 3, the measurement system or the device K is represented not by a solid line but a band of breadth d, so that an unknown *X*= X_0 is to produce an output Y_0_η, or between Y_1 and Y_2, depending on which location the latest calibration has brought the device to. What is more, there will never be a calibration curve but a calibration band whose central location shifts up and down in the region by chance. This represents the possible range of the instrument's response to the single input X_0. To help the understanding, it is reminded that the output's unit is more often not identical to that of the input. It follows that our measurement, i.e., the estimate of the unknown input, will take a value between X_1 and X_2, and not the clear cut X_0. , thus we ends up with a possible estimation error of

$$\delta = \pm \mu \;/(dY/dX)_{X=X_0} \quad (2)$$

where $\eta \cong d$, $(dY/dX)_{X=X_0}$ the sensitivity of the measuring device at $X=X_0$. The quantity controllable by the USDA authority in the course of preparation for the calibration cottons, by the way it is admirably kept small, is the tolerance applicable to the indicated outputs rather than input, the true values of the screened cottons, and thus, the measurement error will be proportional to the tolerance allowed in the calibration cottons, and the proportionality constant is the reciprocal of the device's sensitivity. The approach is only an elementary one and hardly be novel, but it may be used in estimating or comparing the quality of measurement between competing alternatives.

Conclusions

1. The unavoidable amount of measurement (or estimation) error, resulting from the use of cotton as the calibration standards, tends to be proportional to the tolerance allowed in Calibration Cottons, however well kept small, and inversely proportional to the sensitivity of the device. (And, it is well not to ignore the fact that a small, even non-stochastic, difference at an initial stage could lead to the fluctuations known as "chaos.")

2. Under the present system of calibration, a frequent calibration is analogous to leaving the not inexpensive mechatronic systems to 'physically' fluctuate under the whims of random sampling and of an irregular variation that is intrinsic to cotton. This description seemingly echoes well with some reported positive signs of 'over-calibration.'

3. Being stochastic masses, properties of the Calibration Cottons are not only non-constant but also subjected to the chance effects of sampling. Considering the recognized fact (Ramey, Jr., 1995), that the use of more than one calibration system creating confusion, an in-depth re-examination of the pros and cons of using cotton as the calibration standard, as a part of the calibration system, may prove to be beneficial.

4. Efforts to minimize or optimize the frequency of calibration is justified under the present system of cotton marketing, and attempts to develop more efficient decision rules for the calibration control scheme, e.g., Cusum control technique, are also well justified under the present circumstances. [For example, Suh, 1990; 1993; 1994).

5. The variational feature of the measurement processes, especially with the use of the stochastic Calibration Cottons, is no doubt an aspect to be properly understood by means of statistical science, but its effects on the instrument performance of

deterministic nature, including the *accuracy*, may be better understood only through engineering insight.

Recommendation

It is advisable to undertake two in-depth studies on calibration.

One is a simulation study on the convergence (or divergence) behavior of the calibration-related measurement errors (Woo, 1997) to elucidate effects of present system of calibration on the quality, and hence on the rationality and economics, of cotton quality measurements.

Another is a series of straight comparison experiments between testing schemes with two different calibration materials: one using calibration cottons, and other using non-stochastic calibration material, i.e., an alternative to cottons, to help assess thresholds of cost-effective calibration requirements.

References

P.H. Sydenham, etal., *Introduction to Measurement Science and Engineering*, Wiley (1989).

G.C. Barney, *Intelligent Instrumentation*, 2nd ed., Prentice Hall (1988).

R.G. Steadman, *Cotton Testing*, Textile Progress, Vol. 27, No. 1, The Textile Institute (1997).

ASTM D 5867-95, Standard Test Methods for Measurement of Physical Properties of Cotton Fibers by High Volume Instruments.

G.M.L. Gladwell, *Inverse Problems in Vibrations*, Nijhoff (1986).

C.W. Groetsch, *Inverse Problems in the Mathematical Sciences*, Vieweg (1993).

D.F. McNabb, Establishment of USDA HVI Calibration Cotton Values, Proc. 1995 Beltwide Cotton Conference, National Cotton Council, p.1172-1173.

H.H. Ramey, Jr., Universal Standardization of HVI Measurements, Proc. 1995 Beltwide Cotton Conference, National Cotton Council, p.1173-1175.

M.W. Suh, Statistical Precision Applicable to Calibration of HVI, Proc. International Cotton Conference, Bremen, p.49-56, 1990.

M.W. Suh, Sensitivity Analysis on CUSUM-Based HVI Calibration System, Proc. Sixth EFS Conference, p.86-100, Cotton Incorporated, 1993.

M.W. Suh, Improving HVI Calibration Decisions - New Recommendations, Proc. Seventh EFS Conference, p.159-172, Cotton Incorporated, 1994.

J.L. Woo, An Appraisal of Cotton Fiber Testing in light of Measurement Technology, Proc. Tenth Annual EFS Research Forum, Cotton Incorporated, 1997.

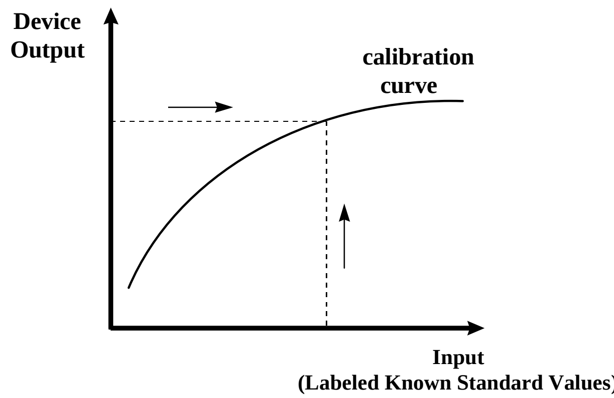

Figure 1. Calibration: Identification of Device Characteristics.

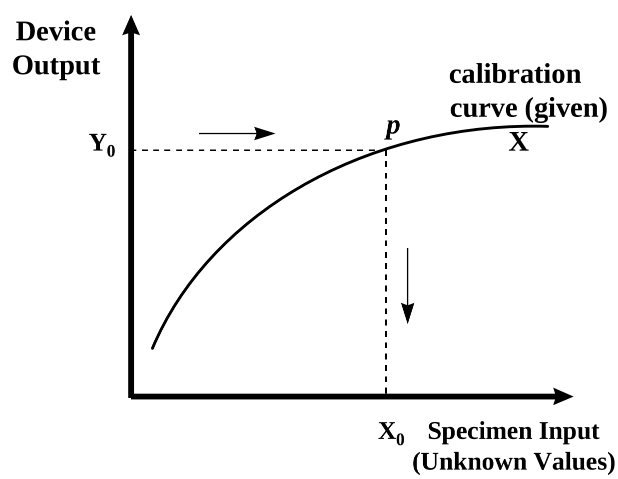

Figure 2. Measurement: Inference on Unknown Inputs.

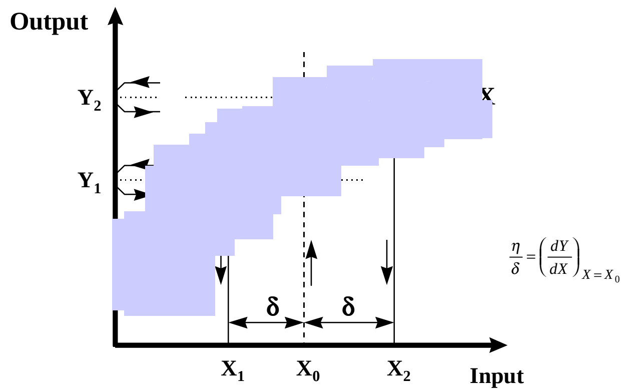

Figure 3. Measurement in the Real World of Cotton Testing.