West Coast Lumber Inspection Bureau

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ASSESSING THE COMPARABILITY OF NDT SYSTEMS USING STANDARD PRACTICES

A Challenge to NDT Development

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ABSTRACT

Nondestructive testing (NDT) technologies may differ markedly in both the process and in the output, even though the goal of the technologies is the same. Implementation of varying technologies requires 1), standardized techniques to assure repeatability; 2), control of bias against a standard; 3), relevance to an end-use performance requirement; and 4), cognizance of applicable cultural issues. Two well known NDT technologies are used to explore these factors. One example is “machine grading”, a generic term for NDT processes that vary from mechanical bending to vibration - all with the intent of estimating mechanical properties to meet a commercial objective. Another example is moisture meters, the variety of which use differing physical measurements to estimate the moisture content of wood. As NDT technologies near final development, these 4 factors should be addressed in preparation for implementation.

INTRODUCTION

Differing NDT technologies can have similar applied goals. To relate to the end-use, most technologies utilize predictive algorithms, simple or complex. Consequently, physical measurements may differ, precision and bias may differ, and the resulting predictive capabilities may vary between the NDT technologies, even if the goals are the same. While each of the “competing” technologies may be practical and relevant in a commercial or laboratory application, the user will need methods for standardization and calibration in order to assess equivalent value. Implementation of the technology is aided if these concepts are addressed during the development of the basic technology.

Modern systems may be complex, using a variety of measurements and complicated algorithms, yet have relatively simple output. This complexity, and the high throughput rate of product in a dynamic system, can be a major challenge to assessing the mechanical and electrical performance of the elements that comprise these systems. The classic concepts of standardization and calibration should be applied but may be very difficult or essentially impossible in the production mode.

As the use of NDT technologies is spreading world-wide, the technologies interface with many different cultural practices when they are applied in commerce. These cultural differences range from standard practices to the industrial environment. Understanding of cultures and sensitivity to how the application may be affected can be important.

The application of standardization and calibration to NDT technologies is explored using examples from lumber grading and moisture measurement commonly applied in the United States. Cultural issues are briefly explored with the assistance of a recent survey of these factors.

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RECONCILING DIVERSE TECHNOLOGIES

To illustrate the fundamental need for standardization and calibration technologies in reconciling diverse technologies, it is useful to use examples of two technologies that differ fundamentally; but, which have identical goals - the products of both technologies serve the same market. The examples chosen are two methods of mechanical grading of lumber and two methods of moisture measurement.

Machine Grading

Nondestructive lumber grading can be done by a number of methods. Dynamic bending and wave propagation are prominent examples of mechanical systems. Both are used to predict the static modulus of elasticity and bending strength of lumber in an edge-wise orientation; neither NDT method make that actual measurement. The dynamic bending devices measure stiffness by deflection under a load or by load to a standard deflection in a flat-wise orientation (Galligan and McDonald 2000). In the dynamic wave propagation methods, a wave may be induced by impact or through a transducer (Pellerin and Ross 2002). The commercial user is only interested in the quality of the prediction of the non-measured property, not the technology nor the intricacy of the algorithm that is applied. An important part of the NDT challenge should be applying standard methods to these dissimilar processes to assess how well the user's goal is being attained. This requires output monitoring of the product.

Moisture Measurement

Another example is moisture measurement. Two technologies that differ in fundamentals are used for many commercial moisture meters. Although the science is complex and the nomenclature often over-simplified, these meter systems are classed as "conductance" and "capacitive-admittance" (Galligan 2008). In many conductance meters, the measurement is made between two closely spaced electrodes - a small sample of wood in which the measurement is heavily influenced by the highest moisture in contact with the electrode. In the capacitive-admittance meters, the response to the presence of moisture is measured in an electrical field between electrodes, often circular and several centimeters in diameter. Most often, the user of these instruments is not interested in the measurement within the area of influence of the electrodes, but in inferences about the larger piece of wood to which the meter was applied, or several pieces of which this one piece is only a sample. How well these inferences can be attained must be aided by standard methods that can be applied to both technologies; yet, the inferential nature of the problem requires technology beyond either meter measurement.

Reconciling Differing Measurements with Common Objectives

Reconciliation of the output of these lumber grading and moisture measurement technologies with the objectives of an end-user requires methods of standardizing and calibrating each technology to their common goal. In this paper, the exploration of these requirements will reference US standards and procedures; application in other countries, geographic areas or for other products must address the relevant standards of practice and/or ISO standards where applicable. Parallel examples can be made for other NDT technologies.

It is important to separate measurement capability (the NDT response and related algorithm) from the end-use inferences desired by the user. For example, estimating the characteristic strength property of a population of lumber from the NDT output is a statistical inference based heavily on sampling and less on the NDT measurement. Inferring the moisture content of a piece of lumber, or even a package of lumber, from a measurement with a hand-held moisture meter has similar requirements. The combination of the NDT measurement and its use is a comprehensive process that cannot be separated from critical elements of statistics and related sampling when inferential outputs are required (Galligan and Kerns 2002, ASTM D 7438-08 2008).

This paper addresses whether NDT devices can be treated as classic "measuring instruments", each of which produces an output for which interpretation is required. While this may seem intuitive for hand-held moisture meters, it may not for a massive production line machine used for grading lumber. To achieve a stable, relevant process it is desirable to apply standardization and calibration techniques. Discussion will suggest, however, that the ability to apply these principles varies by technology; complex proprietary equipment poses difficulties that require the user to rely on process control based on testing, especially if the process is dynamic rather than static. The expense of implementing these principles also is an important factor; however, it is not addressed in this paper, since it must be evaluated on an individual mill basis.

IMPLEMENTING STANDARDIZATION AND CALIBRATION

Standardization

The term "standardization" is used in the context of assuring repeatability of the testing device. This requires a standard against which the measurement can be made. This is the first step in assessing the performance of the device. Note that "accuracy", in the sense of known bias, is not the objective in standardization, only the determination of the ability of the technology to maintain an acceptable repeatability against a standard. The notion of bias is addressed by calibration, which follows standardization.

As an example, to standardize a conductance moisture meter, a meter reading can be taken with a “standard” metal resistance element placed between the electrodes. This reading can be periodically repeated to assure that the repeatability is under control. With capacitive-admittance meters, a common practice is to take a reading with a reference material placed under the electrodes. The electrical properties of reference materials must be durable and stable under changes in both temperature and moisture content; chemical stability of a reference material is also critical to assure constant performance over time. It is assumed that the standardization process - the material and the method - is applicable within the range of applicability of the meter (ASTM D 4444-08 2008).

Standardization of dynamic NDT technologies can be much more complex than that of a hand-held moisture meter. Grading/sorting systems for lumber, veneer and paper are prime examples. Under static conditions - a non-operating condition - metal bars, dial gauges, and other standardized instruments can be appropriately applied and the repeatability of the machine response to applied loads can be measured with relative ease. However, the desired objective is to have the stability measured under the dynamic production environment of normal operation. The production NDT device - viewed as a measuring instrument - must operate under the challenges posed by production-line damage or time-related degradation under the process load.

The use of static standardization for a very dynamic process assumes that the static response is mechanically the same as the dynamic response and retains that relationship over time - not always a sound assumption in these complicated devices. Consider for example that lumber grading machines now exist that can operate at speeds of 100 meters/second or more. Devices for measuring dimensions and moisture content also function at high product throughput.

Although in a laboratory, high speed analysis equipment can be applied to assess the repeatability of dynamic processes, this is a challenge for production quality assurance. The practice of passing test pieces through the system repeatedly is sometimes used; however, these pieces usually are not “stable”standards in the general sense. Proprietary instrumentation is sometimes available from vendors; however, these systems are not normally available for daily quality assessment. As a result, in many production environments, the repeatability of dynamic NDT measurement is assessed not by a standardization tool, but by QC sampling and analysis (for example, ASTM MNL7A-EB 2002, Shelley 1995, Leicester 1995). These are not uniformly “standardized” processes in the wood product industry of North America.

In summary, classic standardization is not commonly measured on the instrumental parts of the dynamic NDT systems in current use; statistical analysis of periodic samples of product output is used to estimate repeatability, often of the specification variable, not the controlling process variables.

Calibration

All measurement systems exhibit bias against a standard target. Calibration is the step in which this bias is quantified so that the system output may be adjusted or the bias may be accommodated when the product is applied to the end-use. Further, in wood product NDT it is often necessary to not only make a device measurement but also to make additional inferences about concomitant properties or end-use function. Examples are measuring stiffness but estimating strength or measuring conductance for moisture level but judging the ability to bond an adhesive. These latter issues are really ancillary to the principal task of calibration; however, they are often combined in the thought process of researchers and users. In this paper, the distinction is made between calibration of an NDT device as an instrument against a standard and the calibration of the device against a specific end-use.

Calibration As An Instrument Against A Standard. Calibration against a standard requires a standard testing procedure, a standard method of analysis and a standardized goal, which may be a test value determined by that test. An example is a moisture meter reading taken on a selected, conditioned wood sample, where the selection, conditioning and measurement are all made following standard processes. This same sample is then oven-dried and weighed (the standard test method), the moisture content calculated (the standard calculation methodology) and the difference between the meter and the oven-dry method are used to determine the bias (ASTM D 4442-07 and D 4444-08 2008). Since this is a relatively static process, this "classic" calibration is relatively straight-forward; but, the calibration strictly applies only to the wood sample within the test area (see discussion in ASTM D 4444-08 2008). Other issues, such as moisture gradients, which result from commercial drying and handling processes, are realistic commercial concerns but are addressed as measurement "practice" issues and not considered "standard calibration" of the NDT device. This "commercial" calibration includes process effects which must be clearly understood by the user to make this calibration effective (ASTM D 7438-08 2008).

Classic calibration against a standard can be very difficult for mechanically dynamic processes like "in-line" moisture detectors or lumber grading machines. Often multiple NDT readings are processed by proprietary algorithms and presented as one or more outputs to represent each specimen. In some devices, the algorithm output may only be a mark which indicates the specimen quality or "grade" - with no individual outputs to indicate the contributions of the various measurement components that comprise the algorithm output. As was discussed for standardization, these more complex processes confound the ability to employ a simple test of a specimen to verify the dynamic measurement capability of the NDT device. In mechanical grading, this is further confounded by the complexity of dynamic response of the wood specimen under test loadings. The complexity of these measurements is demonstrated by Bechtel (2007) for tests of lumber in bending and for transverse vibration by Murphy (1997, 2000).

Often, the industrial solution has been to side-step the issue of "classic" standardization and calibration in the dynamic mode and go immediately to quality control sampling and analysis for a remedy - still based on subsequent static laboratory measurement and utilizing the increased information of the quality control (QC) analysis but incorporating the error contributions of multiple measurements, proprietary algorithms, and dynamic response within the analysis. This unintentional but realistic incorporation of error contributions complicates using quality control tests to optimize the NDT system, and troubleshooting of production problems.

Not all properties predicted by the NDT technology are nondestructive. An example is the strength properties of lumber which are an algorithm-based output of a complex, dynamic measurement that must be assessed by a destructive test. The test results then are processed through a regression or similar method based on separate samples. A recent paper on use of measurement-uncertainty protocol, using a chemistry example, describes the complexity of the quality assessment sequence for instruments whose application depends on regression (Vanatta 2007). In this process, the notion of "calibration" against a standard target value is lost and adjustment of an industrial NDT device to meet a standard for a strength property is dependent upon the sequence of qualification testing, property assignment procedures (e.g., ASTM D 6570-04 2008), and QC sampling and analysis, as noted previously.

Calibration Focused On Performance In Application. The difficulty of applying the concepts of classic standardization and calibration to complex industrial NDT equipment has led to performance-related specifications that link the claimed output to a specific need. A prime example is the recognition that while both visually graded and mechanically graded lumber have a coefficient of variation (COV) of stiffness for design, the COV for the mechanically graded is smaller than that of the visually graded, thus affording some benefit in column design, such as in residential wood frame walls (DeVisser, et al 1993, Galligan, et al 1994, WCLIB 1993).

Some lumber grading devices estimate a "low" cross section stiffness. This "low" value is often associated with enhancing the prediction of tensile strength, and early research showed an improved relationship with bending strength as well (Galligan and Kerns 2002); consequently, a production facility concerned with control of strength performance may emphasize monitoring the "low" area measurement performance of the NDT device in order to positively influence the performance of grades verified by test. If the grades are strength-limited, rather than stiffness-limited, this may aid increasing yield.

Some machine grading production facilities produce a variety of grades that extend from high strength levels for the tension laminations of beams, tension chords of I-joists and high truss grades to the lower grades that compete for market share in wood frame houses and more "commodity" applications. There often is a well established producer-buyer linkage for the higher grades with shared communication on test performance and application. Reputation and risk can be more critical in these "single member" applications than in structures with redundant members. NDT systems that can be adjusted and monitored closely, with output that can be tested for specific performance, permits emphasis within a production facility on specific grades/markets.

The use of specific application-oriented systems also applies to the moisture measurement example. In manufacture of glued-laminated beams where radio-frequency gluing is used, the moisture meter "in-line" scans for "wet spots" that are not acceptable. Static moisture meter standardization and calibration is insufficient. Even if a "wet" area can be verified and control limits established using the classic, static oven-dry procedure, how will the meter respond dynamically when the lumber moves at a high rate of speed? What size "wet spot" and level of

moisture will be rejected? A standard test method to measure this performance over a range of technologies is difficult, although the need has been defined (Galligan 2008).

QC: Specification Conformance versus Control of Process Variables

QC sampling and analysis techniques often have the specific objective of estimating and preserving the specification of the grade; however, this usually is not the same as assessing the process control variables or addressing the root causes of an upset in the NDT function. QC systems that address conformance to a specification are often dictated by a regulatory body or an auditing agency. QC systems that focus on the NDT function - the process variables - are most often chosen at the discretion of the producer of the product. Both are important in quality assurance and should be integrated in the producer's quality monitoring; however, the question of adequate standardization and calibration of a process is best directed to the process control QC, rather than to the assessment of conformance to a specification.

One example is breaking a sample of lumber to assure conformance to a strength claim. This strength test is an essential element in assuring that conformance; however, the breaking values provide limited insight into the NDT measurement of the stiffness, density, or visual characteristics that must be measured with consistent accuracy. The assessment and control of this accuracy ideally would be addressed by standardization and calibration concepts applied to those measurements.

Given the necessary emphasis on conformance to a specification and the regular auditing that accompanies that requirement, producers can lose sight of the more fundamental need for constant emphasis on control of the NDT process variables. The difficulty of applying classic standardization and calibration techniques to complex NDT devices complicates this task. Additional discussion of these issues may be found in the text and references of Galligan and DeVisser 2004.

REFLECTING CULTURAL REQUIREMENTS IN APPLYING STANDARDS

The increasingly global nature of the NDT industry is encouraging and challenging. Systems developed in one geographic area are being used elsewhere and/or the output of the systems is being marketed in other locations. This paper emphasizes technology-related issues; however, general cross-cultural issues are very important. These include governmental regulations and operating procedures, non-governmental codes and standards, legal systems, language (written translations, use of symbols, oral practices, etc.), regional customs and culture, geographical influences (climate, topography, etc). A recent document "International Consumer Product Testing Across Cultures and Countries" which, while focused primarily on testing of consumer products, provides some country-by-country summaries of cultural practices (ASTM MNL55 2007).

Contemporary Examples (personal experiences)

Perhaps one of the most common cross-cultural areas of interest is the translation of technology from one language to another. Words in one language may have no direct counter-part in another language; inferences in one language may be difficult to reproduce in another; reliance on a translator to produce the essence of the message may not be adequate when direct translation is not possible; and the translator may lack background in the details of a particular technology.

Direct Translation. The authors's experiences include using a translator who was very experienced - but in electronic technology, not wood technology. In translating United States grading rules for laminating lumber for glued-laminated beams to Japanese, the word "laminations", was written "veneer".

In another instance, a translator was hired to translate lumber grading rules into Spanish. The traditional and complicated terms used to describe US visual grading practices proved a challenge to direct translation. This was further compounded by the need to reflect local Mexican Spanish (Español), rather than Castilian Spanish (Castellano).

Translations can be further complicated when the cultural differences include technological adjustments like measurement units. A broadly available, non-US test standard erroneously was translated into English with the incorrect metric units.

Inference. The effort to show inference, rather than direct translation, can be more difficult. In one instance, the intent was to indicate that the stated grade was "similar to" a Japanese "JAS grade" - meaning that the properties were essentially the same, but not necessarily identical, and could be evaluated appropriately. Attempts at a translation for "similar to" were reviewed several times between a translator and trading company representatives. The final selection was, once again, judged inappropriate by the next trading company visitor!

Incomplete Communication. The complexity of our NDT systems can cause communication problems, often with unexpected consequences. And selling a product through "middle-men" without buyer-seller contact can add to misunderstanding. In one example, a product fabricator in Japan was purchasing North American machine graded lumber to be re-graded to a JAS standard; however, the fabricator was upset because the lumber was "marked " with splashes of color. As is common in North America, the lumber had been color-coded for stiffness as part of the mechanical grading system. Once it was explained that the colors were evidence of the sorting by stiffness by the machine process, the fabricator was pleased to know that this additional inspection had been made.

Standards

Regions/Cultures. Standards reflect the cultures of their authors. Standards that originate in the United States or Canada reflect a heavy influence of wood frame construction; other regional standards may reflect experience with timber frame and other technologies. This influence extends even to conditioning of specimens for test. Standards that have originated in North America or in Europe may require wood specimens conditioned to a moisture content similar to indoor or outdoor exposure in the major regions of those countries. By standardizing wood conditioning to the same controlled conditions, comparability between products and regions can be achieved.

But what of countries/regions that seldom experience the conditions called for in the standard? At a recent international meeting, regional representatives questioned the relevance of a "standard" condition seldom found in that region. For design, the use of relatively irrelevant standard conditions places more technical emphasis on adjustments to test values, rather than on basic test results. As perspectives become more global, some of these traditional standards procedures may need to be revisited.

Procedural Differences. Standard procedures (test methods and analysis methods) are important in all cultures; however, there are marked differences in how these are developed and applied. Standard practices may reflect the originating organizations, the cooperative efforts of groups within the society, and the influence of governmental agencies. Some countries have government laboratories and agencies that authorize or judge adequacy and/or speak authoritatively for the government within a specific market. Other countries have less structured systems or no governmental spokesperson within a market. "Consensus" is often a base for standards development; however, the concept and practice of "consensus" varies within and between countries and regions.

Classic Cultural Challenges

Lastly, there are the classic examples of poor choices for nomenclature of products in a different culture, of ignoring subcultures in language and employment practices, of not anticipating the educational background required for workers, etc. Many of these are briefly examined and summarized for 17 countries in ASTM MNL55 2007.

RECOMMENDATIONS

Standardization and calibration should be addressed during development of NDT systems. For static measurement systems, these are essential elements in system implementation. Where possible for dynamic systems, building these elements into production equipment is highly recommended. The goal is for the producer of the product to be able to incorporate these tests in both their routine and their "rapid response" portions of their quality program.

Complex NDT systems that cannot be directly standardized and/or calibrated within the production format (i.e., extremely complicated, dynamically operating, regression-based, etc.) depend on sampling and analysis procedures containing associated errors and inherent mathematical assumptions. This adds uncertainty to the assessment of performance. Manufacturers of NDT systems should consider the needs of quality control applications as the systems are developed.

Global implementation of NDT systems requires attention to cultural influences on standards and their implementation - a global sensitivity and patience in adapting the standard practices, the equipment, and the ancillary communication to the cultures of the markets. The importance of cultural practices suggests that attempts to globally "harmonize" standards practices be tempered appropriately.

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