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Certification and calibration of weighing devices

Introduction to the certification and calibration process and implications for high capacity precision weighing Equipment

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Abstract

High Capacity weighing equipment is frequently installed, serviced, and used by personnel generally not familiar with advanced measuring principles. These users have come to expect 0.1% uncertainty performance with 5 to 100 ton loads. How is this possible? What is the total system that is used to deliver this performance? The needs and practices of commerce have strongly influenced the high capacity weighing industry. This paper explores the certification, installation and routine calibration process used by the weighing industry. The related issues of specification, sealing, and calibration intervals are explored.

Introduction

The majority of weighing is conducted by people we would not consider as metrologists. Depending on the application, these users expect a scale to be easy to use and to provide a reading with an accuracy exceeding 0.1% of reading.

These scales do not exist in a vacuum. There is a process of certification, installation, use, and periodic calibration. The rules governing these steps have been codified as handbooks [3] and laws[4]. These laws and rules codify conservative "best metrological practice." A network of laboratories and mass standards make it possible for the results in one country to relate to a similar measurement in another country. The high performance mentioned above would not be possible without this infrastructure.

In this paper I will detail the overall process of specification, certification, initial installation and ongoing calibration for high capacity precision weighing applications. I will describe "best metrological practice" in the weighing industry. As part of the presentation I will explore limiting factors in initial and ongoing performance and show that some of these limits are inherited from the legal-for-trade arena.

The State of the Art

In the beginning, a designer has limitless possibilities in defining a product. It's very exciting! Then reality sets in. As each aspect of a design is addressed the real world and its constraints restrict these choices. Some of these restrictions may be given by nature, such as simple physics or the properties and costs of materials. Other restrictions may stem from available infrastructure, legal, or customary practice.

The weighing industry is one of the oldest, with influence extending to almost every area of human activity. As such, legal and customary practices exert a powerful influence in scale design. The use of scales to regulate trade has generated considerable regulatory influence in what features and performance is acceptable. In all countries a government office of weights and measures is a standard feature. Some countries, Canada for example, require special markings for all scales that are NOT legal-for-trade.

The use of scales to regulate trade has brought a high degree of perfection in the industry long before the discovery of electricity. Electronic weighing devices have only recently approached the simplicity, accuracy and reliability expected in mechanical weighing devices available long before the turn of the century. The calibration infrastructure to support this level of performance has developed in tandem with the scale industry.

Weighing devices have helped define measuring as we know it today. The basic concepts of graduations, accuracy, resolution, and calibration adequacy were developed and refined long before the first aircraft flew. Modern concepts such as characterizing and expressing uncertainty of reading are just beginning to be widely introduced to the weighing industry. There is an element of resistance to the introduction of these concepts to the weighing industry as a whole. Many lay people feel a certain apprehension in being presented a bill for goods that has some specified degree of uncertainty.

In the following discussion I will mention many private and government agencies. If you are new to the weighing industry please refer to appendix A, "The players."

Design and Specification

Let's say a company designs a new scale product with some design goals and features in mind. The basic issues are well understood, but to achieve a state of the art product many subtle and thorny problems have to be resolved. For an excellent description of the issues encountered in designing a scale see Kroll [1]. The author Arthur C. Clarke is quoted as having said that "any sufficiently advanced technology is indistinguishable from magic." Electronic weigh scales have been at this level of performance for many years.

After construction of a prototype the company may verify function and accuracy with an internal testing program. When the company is satisfied that the product will meet its design goals it may be sold as a measuring instrument. We would like to think that the advertised specifications are derived from the aforementioned testing program.

A customer may examine the advertised specifications and determine if the scale meets their requirements. Then they engage in the usual tradeoffs between needed features, price and comfort level with the company offering the product for sale.

This scale may be used for most purposes, but not all.

The scale may not be used as a measuring device to regulate trade application. That is, you cannot buy or sell across the scale. Before this can happen the scale must be examined and found correct for the intended application. More plainly, the government wants to examine the device to verify that it is suitable. When the scale is examined and found correct, a National Type Evaluation Program (NTEP) "Certificate of Conformance" is issued. These are issued by an agency of the United States government called the National Institute of Standards and Technology (NIST) through the Office of Weights and Measures (OWM).

Even if you think that you are not at all interested in the legal-for-trade market, consider this: without this testing, there is no independent testing to verify that a manufacturer's claims are true. In most technical fields it is common for the sales departments of competing companies to engage in a battle of specifications. Without evaluation by an independent party you have nothing but the manufacturer's claims to use for evaluation. This can be dicey at best. Even if you have no specific requirement for a legal-for-trade scale, an NTEP listing insures that a product has been examined by an independent third party and found correct.

The NTEP listing shows the measured accuracy as 'nmax', in divisions. More divisions are preferred. This is the opposite of the usual percentage error specification, where a smaller number is better. Generally, if a device is listed it meets all of the requirements of NIST handbook 44, "Specification, Tolerances and Other Technical Requirements for Weighing and Measuring Devices"[3]. If some characteristic has not been tested the device will get a provisional certificate with an explanation of what has not been tested.

Certification

Obtaining an NTEP Certificate of Conformance (CoC) goes something like this: a manufacturer starts the process by filling out paperwork and submitting said paperwork and a technical file on the device to the National Type Evaluation Program (NTEP) program coordinator.

The NTEP program is the established system that examines weighing equipment and determines that it does or does not meet the requirements of NIST handbook 44 [3]. Please note that this does not constitute an endorsement or approval of any piece of equipment. The equipment is either "correct" or "not correct" in meeting the requirements of NIST handbook 44 as defined by the tests and checklists expressed in NCWM publication 14, “National Type Evaluation Program: Administrative Procedures, Technical Policy, Checklist, and Test Procedures”[11]. If this all sounds terribly “correct” and fussy, please keep in mind that the government is just a referee concerning the weighing industry. They are not to favor the manufacturer or the user concerning weighing equipment.

The NTEP program coordinator assigns the equipment to a participating laboratory.

This laboratory will run through procedures found in the “Pub 14 checklist,”[11] as it is known in the industry.

The sorts of things that are inspected includes features that make it possible for non-metrologists to install and use very accurate measuring devices, features that reduce the possibility of fraud, and the actual performance of the device, under both normal weighing conditions and under adverse environmental conditions.

The results of the evaluation are sent back to the NTEP program administrators in Gaithersburg, MD. A device that is found to be correct is issued a Certificate of Conformance that is listed in NIST publication 5, “National Type Evaluation Program: Index of Device Evaluations”[10]

Initial Installation

A non-legal-for-trade instrument may be examined by the metrology department of the purchasing company, sealed, and put into use. The reference force may be generated with dead weights or a calibrated load cell. The metrology department is on the hook to verify that the reference force is of suitable accuracy, and that the results support the application.

Please note that in the non-legal-for-trade markets it is considered good practice to set the initial calibration interval based on some factory or industry recommendation. This interval will be adjusted based on the results of the results of periodic calibration. This flexibility does not exist in the legal-for-trade market.

In a legal-for-trade setting, a government inspector and a scale distributor or company representative meet to test and seal the device. The reference force is always generated with dead weights. The state inspector witnesses the testing of calibration of the device. For initial installation a device is tested to “acceptance tolerance.” This is usually half of the normal tolerances established for a given device. If the inspector is satisfied that all of the applicable requirements are met he will affix a seal good for some legally specified interval. This interval tends to be quite conservative.

Ongoing Calibration

At some interval, usually once a year for a weighing device, an authorized technician tests and re-seals the device. Generally, if the device meets its specified tolerances, no adjustment of the device is performed.

Please note that most metrological departments have provisions for notifying the customers if a device is Significantly Out Of Tolerance (SOOT). The user may elect to repeat critical weightings if a SOOT report on a given scale may have brought the readings into suspicion. This is a good reason to record scale unit or serial numbers with a measurement.

Limits of Accuracy for High Capacity Weighing Equipment

Specification of Accuracy

Before we begin it is useful to define just what we mean with our accuracy terms.

In a weigh scale application, errors are more properly expressed as:

± (Percentage of applied load), or ± (a specified division),

Whichever is greater.

The first term, span error or percentage of applied load, is derived by assuming that a weighing device may be used anywhere through its range, so the specification must be expressed as a percentage of reading. Some spectacularly good calibration figures on load cells are achieved by only considering the full capacity load. For a high quality load cell, I would expect to see a figure of about 0.007% at full scale. This same cell specified from 10% to 100% of its capacity may only rate as 0.025% of reading.

The second term is zero error. This is constant throughout the weighing range.

Most of the error factors in a scale may be characterized as a zero or span term. Please refer to figure 1 to see the difference between span and zero error.

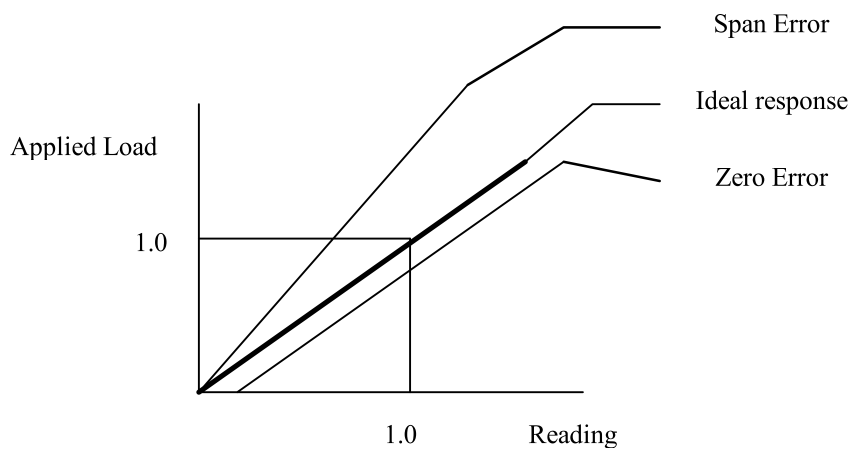

Figure 1.

Measurement and specification of these error terms are relatively easy. It is usually good manufacturing practice to leave some error margins to ensure that all production items will continue to meet the specifications established with the prototype items.

The method of selection of graduation or division size is called out in a fairly complicated fashion in NIST handbook 44[3]. Selecting the correct division size is most important at the lower weight readings. In general, it turns out that correct division size is about two to three times larger than the zero error term in the measured characteristics. Selecting a resolution much smaller than hardware is capable of performing does not make sense in a metrological sense.

You can think of a division as a range of possible values of a measurement.

Please refer to figure 2. The applied load is about 7 units, and the measuring device is registering it internally as 12 units.

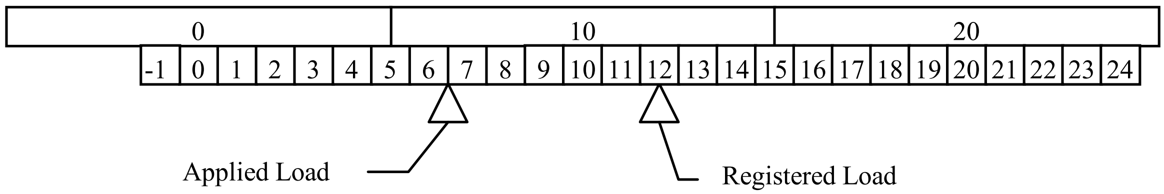

Figure 2.

If I tell you that a measuring device is reading in 1 unit divisions, and the applied value is 7 units, you may reasonably conclude that the actual readout should be anywhere between almost 6 and almost 8. If the starting point is between two divisions, say just between 6 and 7, and then you might expect the reading to be either 6 or 7. The same would be true if the starting point was between 7 and 8. Then you would expect a reading of 7 or 8. Nothing here would lead you to believe that the reading should be 12 units. You would have to conclude that 12 is an erroneous measurement.

If I specify that the division size is 10 units and the reading is 10 units, you may conclude that the value is anywhere from 5 units to 15 units. An actually reading of 12 units falls well within this range. A scale with a resolution smaller than the accuracy can be very deceiving. Any company that would offer such a product is demonstrating that they do not understand metrology.

The Force Transducer

The state of the art in electronic readouts is good enough so that, for all practical purposes, it does not contribute to the errors found in a modern weighing device. As such I will only consider the force transducer element(s).

Most of the transducers in use on high capacity weighing equipment are of the strain gauge / elastic element load cell design. Strain gage technology in one form or another has been used since the late 30's, and bonded strain gauges started in the late 50's The design is deceptively simple. Resistive strain gauges are bonded to an elastic element, that is, a spring. Please see Hannah and Reed [2] for a nice treatment of this process.

Strain gauge / elastic element load cell based designs have dominated the transducer market since the 70's. The properties of the spring that make up the elastic element define the limits of performance of this cell. These properties are widely known and can be examined in any materials properties handbook. Please see Kroll [1] for a description of the properties and magnitude of these limits.

Generally, the simpler the device, the closer it comes to the ideal properties of the parent spring element. The properties of cell geometry and temperature compensation are well understood and the treatments are straight forward. When you consider a more elaborate system, such as a hydraulic load cell, you must include the properties of the pressure transducer, itself a spring / strain gauge device, the coupling fluid, and the mechanical properties of the containment vessel. These added elements make for more complicated modeling, with more error terms to control. While such a design may make for simple manufacturing, the performance limits may be a considerable drawback.

A high quality uncalibrated load cell is good for about 1.0% to 0.5% performance. This includes all error terms.

After simple calibration a cell may achieve a performance of about 0.1% of reading.

This figure does not include linearity, sensitivity to creep, side load and hysteresis. In high capacity weighing, the vehicle is generally applied for a relatively short time. This minimizes the effects of creep. The hysteresis does not come into play because the loads increase to some value and stop during the measurement cycle. The side load sensitivity can be as much as 1% to 2% of applied side load. This can be minimized by careful design or usage restrictions.

Different cell designs minimize some of these error terms, but no cell design is the clear cut winner in bringing all error terms to zero at the same time; usually there are some tradeoffs. Naturally, the careful designer selects the cell design that best fits the intended application.

To extract maximum performance from a load cell the ASTM E74-95 practice [7] comprehensively deals with most of the undesirable properties of a load cell. The cell under question is subjected to a regime of at least 30 test loads with specified loading conditions and schedules. A polynomial curve is fitted through the measured points. This curve is taken to be the true response of this particular cell. Using simple calculations an uncertainty figure can be developed for a given cell. The end products from an E74-95 calibration are a curve and an uncertainty figure in force units. For a 50 ton cell it is not uncommon to see an uncertainty figure of 7 lb. (3.2 kg), and I frequently see cells with an uncertainty figure of 3 lb. (1.36 kg) or better.

The preceding items would seem to indicate that performance in excess of 0.1%, possibly as well as 0.003% of full scale is possible. This is one of those tricky full scale numbers. The same 3 lb (1.36 kg) of uncertainty at the 10% loading point, 5 tons, gives an uncertainty of 0.03%.

Let’s move on to the next part of an installed system.

Calibration

Low capacity applications are calibrated using dead weights. The accuracy performance of these weights is called out in NIST handbook 105[5] or ASTM E617-91[6]. Generally, these weights are calibrated to an accuracy of 1 part in 10 000, or 0.01%. In the early days of metrology is was customary practice to make the calibration standard ten times better than the machine being calibrated. In modern terms, this would be expressed as a test uncertainty ratio (TUR) of 10:1. The new rule of thumb dictates an arbitrary 4:1 TUR. While this makes it possible for an untrained person to determine that a standard will produce acceptable results, an arbitrary TUR can be counterproductive. In advanced metrology circles it is possible and desirable to determine the actual required TUR. A skilled metrologist can establish and defend smaller Test Uncertainty Ratios. It is not uncommon to see a TUR as low as 1:1 in some areas of metrology.

For a high capacity aircraft scale the use of deadweights presents certain problems. A 1 000 lb (454 kg) test weight is about 15” x 15” x 20” (38 cm x 38 cm x 51 cm). A layer of four of these weights is about 30” x 30” x 20” (76 cm x 76 cm x 51 cm) tall. This is only 4 000 lb. (1 816 kg). To apply the rated capacity of 30 tons you would have to stack these weights to a height of 25 feet (7.6 m). This presents serious practicality and safety issues.

The are about 30 high capacity (in excess of 20 tons) dead load machines in various states of repair in the Unites States at this moment. Of these machines, some are currently out of commission and some are located in a captive situation were they are not able to accept outside work. This leaves about 10 available for the average customer as a resource. Time on these machines is scarce and fairly expensive. Accuracy on these machines can be as good as 5 parts per million or 0.0005%. For a variety of reasons, a dead weight machine may be of much lower accuracy. The “102 000 lb. machine” at the Navy lab in Pomona, CA is quoted at 0.01% of applied load.

Because of the scarcity of high capacity dead weight machines, it may be necessary to use a load cell and indicator as the calibration source for portable high capacity weighing equipment. Assuming that the master cell is calibrated at the NIST facility on one of those 0.005% machines, the accuracy limitation of the cell defines the master cell performance. This would get us back to the 0.03% figure mentioned above. If this is used to calibrate the end user device, and we use a 4:1 TUR, then we are back to the 0.1% accuracy for the end user device. If a manufacturer claims an installed accuracy of 0.05% of reading you must ask how this system will be calibrated to deliver this performance. The answer may be surprisingly expensive.

Appendix A

Meet the Players

These are the most common parties you will encounter in the weighing industry in the United States. Please keep in mind that this cast of players is usually duplicated with different names in each country or region. An example would be NIST in the United States, and OIML in Europe. They serve similar purposes, but serve different geographical areas.

NIST- National Institution of Standards and Technology. Formerly know as NBS, the National Bureau of Standards. This is a government agency under the Department of Commerce whose purpose is to deal with the technical issues that do not really fit into any other part of the government. You may wish to visit them at www.nist.gov to get a better picture of the many offices and programs that these people are involved with. They run the gamut from mundane issues such as regulating the features of the common berry basket to the truly exotic items such as verifying the correctness of computer programs and supplying calibrated leaks.

OWM - Office of Weights and Measures. This office is a branch of NIST Technology Services, which is one of eight major programs within NIST's Measurement and Standards Laboratories. The OWM administers programs such as NTEP, NCWM, and general laboratory metrology.

NTEP - National Type Evaluation Program. This program is the established system that examines weighing equipment and determines that it does or does not meet the requirements of NIST handbook 44. Please note that this does not constitute an endorsement or approval of any piece of equipment. The equipment is either "correct" or "not correct" in meeting the requirements of NIST handbook 44 as defined by the tests and checklists expressed in NCWM publication 14 [11]. A device that is found to be correct is issued a Certificate of Conformance that is listed in NIST publication 5 [10]. This is a vast improvement over what existed before the 1980's; each state had it's own separate approval process. They were all different.

NCWM - National Conference of Weights and Measures. This is a cooperative effort between industry and government. Membership is open to anyone with extra time on their hands. The membership (you guessed it, it's listed in a yearly publication [9]) is a veritable who's who of the weighing industry. A regular agenda is published in NCWM Publication 15 [12]. The contents of this agenda are established by proposals submitted to the various committee chairs. The results of the considerations of the interim spring time meeting are expressed in NCWM publication 16 [13]. The results of the main meetings are published in a series of special reports. The publications numbers of these special reports are selected at random, to get the report number of any given year contact the NCWM directly. The primary purpose of these special reports is to regulate the contents of various NIST and NCWM publications. This includes NIST handbook 44," Specification, Tolerances and Other Technical Requirements for Weighing and Measuring Devices" and NIST handbook 130, "Uniform Laws and Regulations in the Areas of Legal Metrology and Engine Fuel Quality." Considering that these two documents are directly adopted or called out in most states as the laws governing the regulation of legal metrology, the NCWM packs considerable clout.

ASTM - American Society for Testing and Materials. This is a private organization that, among other things, is the keeper of several key standards that are widely referenced in the weighing industry. The two that I see the most are ASTM, E617-91, "Laboratory Weight and Precision Mass Standards" and ASTM, E74-95, "Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines."

NCSL - National Conference of Standards Laboratories. This is another volunteer organization that serves metrologists. Part of the reward for joining is one of the most comprehensive information packets you could wish for if you work in a metrology lab. It is full of recommended practices and guidebooks. The chapter meetings and various projects can be great help to the weighing metrologist. I highly recommend membership and attendance of the local chapter meetings.

Selling Company - These companies try to determine the needs and methods of the customers. Then these companies produce the equipment that defines what performance is possible in the industry. Individual companies are usually directly involved with a host of alphabet agencies that constrain what may be offered for sale. These companies may produce and market equipment without any involvement with any of the various agencies that I am describing. The only problem here is that failure to participate may have severe impact on a company's ability to market their products. An example: many customers will not buy equipment that has not been tested by the NTEP program, even if they do not work in the legal-for-trade arena. This is quite understandable, as an NTEP listing indicates that the equipment meets a certain minimum level of performance, and that its characteristics have been verified by an independent third party.

Scale Distributor - Very few companies install and service all of their scales directly. In many cases a local Distributor actually installs the scales and maintains the periodic calibration services. This is particularly true when the scale involves the construction of footings and decks. These distributors are not necessarily metrologists, but the combination of factory training and rigorous adherence to the rules and laws set out by NIST handbooks 44 [3] and 130 [4] do a very good job of delivering a successful weighing system.

Buying Company - You know who you are. Depending on the organization, the purchasing department metrology department, end user, or some combination of the above conspire to purchase equipment that will perform the tasks at hand. It is the responsibility of the purchasing company to determine their own needs and sift through the various offerings to select a successful system. It is critical that the purchasing company determine the method and adequacy of calibration from the beginning.

Testing laboratories - The two that are most widely encountered in the United States are FM, "Factory Mutual" and UL, "Underwriters Laboratories." These are private companies that offer testing and listing services. A UL listing generally means that the equipment will not injure the user or itself. An FM "Explosion Proof" or "Intrinsically Safe" rating means that the equipment in question will be compatible with some specified hazardous location, such as fuel fumes or explosive grain dust.

Industry Oversight Agencies - In each specific area, some agency provides more or less oversight on the equipment employed by the end user. Some examples are the FAA for the aviation industry, or the Packers and Stockyards in the livestock industry. It is hard to generalize on these agencies; some directly dictate what the weighing equipment must do while others maintain a very loose rein on what is allowed.

Local State Government - This only applies to the legal-for-trade arena. Most SAWE members will never encounter this part of the weighing business. When it is required, the state provides the function of the metrology department found in some companies. The state inspector witnesses the testing or calibration of a metrology instrument. If the inspector is satisfied that all of the applicable requirements are met he will affix a seal good for some legally specified interval. These inspectors may "red tag" or remove from service any equipment that is out of tolerance. The powers of these inspectors are surprisingly broad and may include the power to seize equipment or arrest violators of the weights and measures laws.

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