Weighing System Accuracy Tutorial

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1. Introduction

This document is intended to provide a practical, and applications oriented discussion of the issues involved in weigh system accuracy, and how to estimate the accuracy a particular system might achieve. These discussions are specific to full electronic load cell systems (not lever systems), with state of the art Digital Weight Indicators, as used in automatic batching systems.

Components of weighing accuracy fall into three categories:

- Weighing Apparatus Accuracy - This is the ability of the load cells, and the weigh hopper to produce a signal that corresponds to the weight of material in the hopper.
- Digital Weigh Indicator Accuracy/Resolution - This is the ability of the weight read-out to convert the load cell signal to an accurate and precise digital reading.
- Automation Repeatability - This is the ability of the automatic control system to feed a specified weight of material into the weigh hopper, as measured with the digital weight indicator.

All three of the above components must be considered when calculating the accuracy of a weighing system, and each will be discussed in more detail below.

The scales used in batching applications consist of the same equipment used in Legal for Trade applications, where government Weights and Measures organizations approve the scale's accuracy. While the method of stating, and measuring accuracy varies from Government to Government, the generally accepted concept is that the scale should be accurate to .1% of applied load, plus 1 displayed division. In some applications, when the scale is first installed it has to be accurate to .05% of applied load. While batching system scales are not approved for legal for trade, the same accuracy specifications do apply.

2. Weighing Apparatus Accuracy

The weighing apparatus consists of the following components:

- The load cells, which convert force to a voltage output.
- The weigh hopper, which both holds the material to be weighed, and transmits the force to the load cells.
- Dead to Live connections. These are unwanted, but necessary mechanical connections between the active part of the scale, and surrounding structures (wiring, plumbing, etc.). Properly designed, these connections act as a spring, and the in-accuracy they impose can be mostly calibrated out.

The three items above make up the basic scale. The most important item relative to accuracy is the load cell. Various government agencies provide Type Acceptance testing for the accuracy of load cell arrangements.

2.1 Load Cell Accuracy

While different agencies state accuracy in different fashions, most test certificate states the accuracy in terms of Maximum Number of Load Cell Intervals (also known as Displayed Divisions, or dd). This is a statement of the expected Weighing Apparatus accuracy using this load cell to weigh a single material, up to the calibrated capacity of the scale, over the entire temperature range of the load cell.

Most common load cells are rated at 3000 dd (note that the U.S. Certificate typically rates it at 5000 dd when used in a multiple cell system). This means that if you divide the calibrated capacity of the scale by the maximum displayed divisions, you will get the worst case accuracy of the weighing system. In legal for trade applications, the scale cannot legally be calibrated to any finer of a resolution that this, so as not to mislead those using the scale for transactions.

As an example, if three 5000# load cells are used in a system, and the scale is calibrated for 10000# capacity, the worst case accuracy would be 10000# divided by 5000 displayed divisions, or 2#. Note that this is .02% of capacity.

2.2 Load Cell Accuracy Related to Batching Systems

The test certificate accuracy specification needs to be interpreted for applications to Batching System accuracy for the following reasons:

- In today's batch house designs, the load cells are not subjected to the temperature extremes that are allowed under the specification. Thus the accuracy will be better.
- The practice of stating accuracy in displayed divisions is related to the concept of the scale being used to weigh a single commodity up to the capacity of the scale. This limitation represents the worst error possible in weighing a single commodity

of a weight equal to the scale capacity. It does not address expected accuracy of weighing smaller amounts.

In practice, when Weights and Measures organizations approve a scale installation, they do take into account it's accuracy in weighing small amounts. They will apply test weights to the scale in incrementally increasing amounts. The error they allow is a percentage of the load on the scale (approximately .05% on a new installation).

Batching Systems that weigh multiple materials in a single weigh hopper re-zero the scale at the start of a new material. Thus the expected accuracy of weighing a single material is a percentage of the weight of that material added to the scale (similar to weights and measures testing a scale with small loads).

An analogy to the incremental accuracy concept would be an automobile speedometer. If the speedometer has an accuracy of 5%, and is currently reading 100 Km/hr, then the automobile's actual speed is between 95 and 105 Km/hr - a possible error of 5 Km/hr. If the automobile's speed is increased until the speedometer reads 105 Km/hr, the accuracy of measuring the CHANGE in the automobile's speed is 5% of 5Km/hr, or .25 Km/hr, not 5% of 105 Km/hr. Obviously the precision of the speedometer will have an effect on our ability to measure this change in speed to this accuracy, and precision (or resolution) is our next topic.

3. Digital Weight Indicator Resolution

Another component of a scale's accuracy is the ability of the Digital Weigh Indicator to resolve the load cell output into a usable reading. There are several factors involved in this:

- Indicator Sensitivity - This is an indication of the smallest change in load cell output voltage that the Indicator can reliably detect. State of the art indicators have sensitivities better than .1 micro volt. Load Cells typically output 30 millivolts full scale, so a state of the art indicator can resolve the load cell rated capacity into 300,000 parts. The sensitivity determines the smallest displayed division size that the scale can be calibrated in.

- Filtering - This is the ability of the Indicator to remove unwanted variations in load cell output due to mechanical vibrations, or electrical noise. State of the art indicators use digital filtering techniques based on Discrete Fourier Transforms, or other digital implementations of analog multiple pole filters. These provide remarkably stable readings in high resolution scales. Typical industrial applications can be calibrated to 20,000 or more displayed divisions (i.e. .5#dd in a 10,000# capacity scale), and still provide a stable read-out. The filtering quality determines the smallest displayed division size that the scale can be practically calibrated in.

- Indicator Accuracy - This describes how well the Indicator Weight Read-out corresponds to the Load Cell voltage coming in. State of the art A/D designs provide better than .01% accuracy in this area - much better than the weighing apparatus itself.

In summary, as long as the scale is calibrated to be above .1 uV/dd, and 20,000 or less displayed divisions, the effect of the Digital Weight Indicator on accuracy will be negligible.

4. Automation Repeatability

The ability of the automatic control equipment to be repeatable in weighing up a specified weight, within tolerance, is dependent on several issues:

- The digital weight indicator needs to be calibrated in a high enough resolution, so that the displayed division size is smaller than the desired Tolerance. It is desirable that the Tolerance be at least 4 times the division size, although it can be as low as twice the division size in certain circumstances.
- The quality of the material handling feeders, and the flow ability of the material. Vibratory feeders have shown to provide excellent flow control, and predictable cutoff characteristics for most materials.
- The speed at which the material needs to be weighed up. The faster the weighup, the less repeatable the system will be. If it can be slowed down sufficiently, extremely repeatable weighups can be expected.

In a properly configured and tuned control system, a repeatability of +/- 1 displayed division can be achieved in 95% of the weighups. For materials where accuracy is not as important as speed, this repeatability would be +/-2 displayed divisions.

5. Summary

Weights and Measure agencies approve the types of scales used in batching systems for accuracy's of .02% of Capacity, or .05% of applied load. Even with the additional dead to live connections found in automated systems, accuracy's of .1% or better are achievable, although without proper scale installation the dead to live connections can degrade the accuracy considerably.

The ability of state of the art weight indicators to achieve stable readings at 20,000 displayed divisions, coupled with highly repeatable control systems, allow accurate weighments of materials in weights as small as 10% of scale capacity.

5.1 About the Author

Mark Weihs has over 20 years design experience in the weighing industry, and holds several patents on weighing apparatus. His range of experience includes extensive work with Weights and Measures organizations, the development of several load cell test systems, and the design of Digital Weight Indicators, and Load Cells.

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