Load Cell Based Scales Tutorial and Trouble Shooting Guide

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Table of Contents

1. Overview

This document describes the theory of operation, and troubleshooting of typical electronic scales consisting of multiple strain gauge load cells. It is intended to provide sufficient information to allow a scale technician to identify and repair problems with the scales.

There are many different types of scales and load cell configurations on the market today. While they may have slight differences from manufacturer to manufacturer, they generally work on the same principle. This troubleshooting guide is not intended to be manufacturer specific and thus deals in general terms when describing the characteristics of a scale. This guide will be most useful when used in conjunction with the manufacturer's specifications.

2. Typical Electronic Scale Configuration

This section describes how a typical scale is configured for the purposes of establishing a common terminology and understanding:

A. **Platform/Hopper** – Whatever it is that the scale is supposed to weigh, there has to be a method of supporting or holding the item to be weighed so all of the force of gravity on the item is transmitted to the load cells. Typically either a steel platform (say for trucks) or a hopper (for bulk materials) is used. The platform or hopper is totally mechanically isolated from all surrounding structures so that it is totally supported by the load cells. It is important that there are no mechanical connections to the surrounding structure, other than through the load cells.

B. **Load Cells** – One or more load cells is used to measure the force on the scale. Typically 3 or more load cells are used in a heavy capacity scale. If less than 3 load cells are used then some sort of mechanical checking arrangement is used to stop the scale from tipping over, which will cause in-accuracies unless it is a very small scale. Each of the load cells have a capacity rating in terms of the maximum load they are designed to measure, stated in pounds or Kg, which must be greater than the total weight of the platform/hopper plus the weight of the item being weighed. These load cells are wired to a weight indicator via a J-Box.

C. **Junction Box** – Each load cell has a 4 wire cable coming from it. Two of these wires are used to provide power to the load cell (excitation), and two return a voltage reading proportional to the weight on the cells (signal). All four cells are wired in parallel in a junction box located near the scale. From this junction box a single cable returns to a weight indicator.

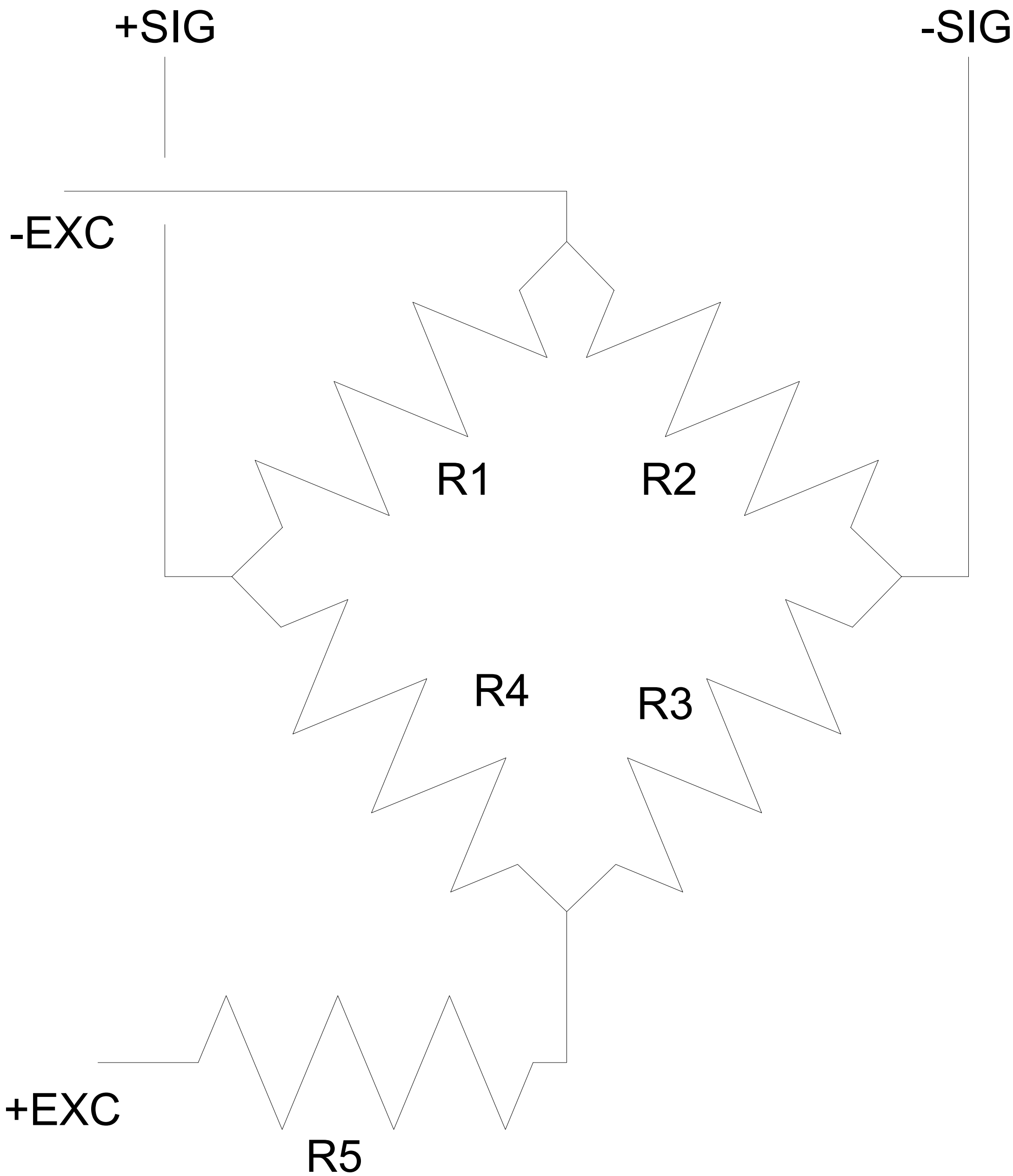
D. **Weight Indicator** – This generally mounted remotely from the scale itself, in an area where the weight can be viewed on the indicator display. A Six conductor cable from the load cell junction box connects to the Excitation, Sense and Signal leads on indicator. The Sense leads are jumpered to the Excitation leads either in the junction box, or at the indicator to allow the indicator to correct for Excitation voltage changes. The purpose of the Indicator is to digitize the low level signal voltage from the load cells and convert it to a displayed weight, and to optionally communicate that weight to other devices such as PLCs or remote displays.

3. Theory of Operation Load Cell

This section describes the theory of operation of load cells and the weight indicator.

A. Each load Cell consists of block of steel specially machined so that as force is applied to it a section in the center of cell (the strain web) deforms a very specific amount for each pound of force applied to it.

B. In the strain web four strain gauges are glued to the metal. They are arranged electrically in a bridge. In addition a 5th resistor is typically used for calibration at the factory.



C. R1-R4 are the strain gauge resistors glued to the metal strain web. Each is approximately 350 ohms (certain load cells may be 750 ohm or higher, refer to your manufacturer's spec sheet) , and setup so that when there is no pressure on the load cell all four resistors are equal in value. As pressure is put to the load cell, thus deforming the metal slightly, the resistance of the strain gauge resistors changes slightly.

D. The strain gauges are configured so that as force is applied to the cell R1 and R3 slightly increase in value, and R2 and R4 decrease in value (by less than 1 ohm).

E. The excitation voltage applied to the bridge causes current to flow from +EXC thru the strain gauges to –EXC. As long as R1-R4 are all equal, then there will be no voltage difference between the +SIG and +SIG legs (the unloaded condition of the load cell).

F. As force is applied to the load cell, and the strain gauge bridge becomes slightly un-balanced, then a voltage will appear between the +SIG and –SIG legs.

G. The magnitude of this voltage is based on load cell design, and is rated in Mv/V (milliVolts of signal per Volt of Excitation) at full load. A lot of load cells are rated at 3mv/V, which means that for every volt of excitation we will get 3mv of signal if the load cell is loaded to capacity. Other load cells may be rated at 2mv/V.

H. The calibration resistor (R5) is approximately 50 ohms, and represents a combination of calibration resistors that are installed at the factory to adjust the mv/V specification, and to compensate for temperature changes.

I. Placing an Ohm Meter across the signal leads (with all other leads disconnected) you will measure approximately 350 ohms (+/- 5 ohms). Placing the meter across the Excitation leads you will measure 395 ohms (+/- 5 ohms). Placing the meter across a signal and excitation lead you will measure less than 300 ohms.

J. The load cell cable also has a shield wire that is attached to ground at the indicator end. You should never be able to measure any resistance between an Excitation or Signal wire and the shield.

K. The primary calibration specification for load cells is how much the mv output of the cell changes per pound of load applied. This is factory calibrated to be within .03% accuracy. The output with no load is roughly factory calibrated (since this gets zero'd out during calibration anyway), and is specified to be within 1% of full scale output with no load (around +/- 1mv in most applications).

3.1 Parallel Connection of Load Cells

Since most scales have more than one load cell, and the scale indicator only has one input channel, a method of connecting multiple load cells to one input has been devised. The load cells are connected in parallel in the junction box, and the resulting output is wired to the Indicator. The following section describes some of the concepts of parallel connection:

A. The resistance of the excitation, or signal leads of a parallel combination of load cells is equal to the parallel combination of their individual resistances. As an example, with the signal lead resistance being 350 ohms, four load cells in parallel would give us 88 ohms (measured at the signal leads on the indicator with the wires disconnected from the indicator so there is no voltage). On the excitation leads (400 ohms for a single cell) we would see approximately 100 ohms.

B. When powered on the excitation voltage is applied to all cells. Indicators typically output somewhere between 5vdc and 15vdc for excitation. In this example let's assume that the excitation is 10vdc, so each cell will have 10 volts on it's excitation leads.

C. When connected in parallel, each load cell will contribute a fraction of it's output to the total signal, with the fraction being the inverse of the number of load cells. If there were four load cells, then each load cells signal output will contribute ¼ of it's stand alone value to the sum of all 4 cells. As an example, if the output of each load cell was measured while it's signal leads were disconnected from the Junction box, and the outputs were: Cell 1=5mv, Cell 2=10mv, Cell 3=8mv, Cell 4=6mv, then when connected together the signal level measured will be: (.25x5)+(.25x10)+(.25x8)+(.25x6) = 7.25mv.

D. If one load cell's signal leads were disconnected from the rest, leaving three load cells, then each will contribute 1/3 of it's output. If the scale were exactly mechanically balanced, and the load applied equally to all cells, then the calibration would stay exactly the same if one or more load cells were disconnected. Note that this is almost never the case, so disconnecting a load cell will cause the scale to go out of calibration.

E. In most cases the mechanical arrangement of a scale means that the load is not equally distributed between the cells, and they will all output different values, and how this load is distributed to each cell will change with time, and even with the amount of weight in the scale. This is ok because the load cells are precisely matched, and thus it doesn't matter which load cells are actually measuring the weight. The important thing is that the output of the sum of the cells is correct.

F. All scales have what is known as a Dead Load – This is the weight that we are not interested in, such as the weight of the platform/hopper, dust build up on the scale, the no load zero balance output of the load cell, etc. The dead load will be different from scale to scale, thus a comparison of the dead load between scales doesn't tell much. However, if the dead load on a particular scale is recorded at calibration time, then a change in this over time can indicate a problem. The dead load is compensated for when the scale is zero'd during calibration.

G. The other component of a scale's output is the Live Load, which is the weighing of the material we are interested in. When we add live load to a scale, the millivolt output of the load cells will change. When we span the scale during calibration, we are telling the Indicator how many pounds of change equal 1mv. It is the CHANGE in millivolt output that is important in calibration, not necessarily the actual mv output.

4. Scale Trouble Shooting

This section is dedicated to describing trouble shooting procedures for the weighing portion of the scale. It does not attempt to address failures of the scale indicator, nor communications with other devices. There are two basic situations where trouble shooting of scales may be required:

1) The scale is weighing (weights displayed on the indicator display), and the weights are questionable. Section 4.1 will cover this situation.

2) The scale is not weighing at all (no weight on the display), or the weights displayed are clearly bad (like a large negative weight or positive weight outside of the normal operating range). Section 4.2 will cover this situation.

4.1 Questionable Weights

This section covers the testing to be done if the weights are in a reasonable range, but are questionable in accuracy.

The first step is to determine if the weights are accurate or not. This is a two part process, the first of which is a cornering test, and the second is a gross calibration test.

4.1.1 Cornering Test

The purpose of this test is to determine if the scale weighs the same no matter where the weight is placed. This will help identify mechanical binds or bad load cells.

A. Arrange for the availability of test weights near the scale. These should be as large as possible, but small enough that they can be applied to different sections of the scale.

B. Empty the scale, and let it stabilize.

C. Record the displayed weight on the indicator.

D. Place the test weights as near as possible on one corner of the hopper/platform structure.

E. Record the new weight displayed on the indicator. It should be greater than the weight recorded in step C by the amount of the test weights, +/- .3% of the test weight amount. Note that sometimes as you apply the weights to the scale you can cause a zero shift due to the mechanical impact of the weights. Repeat this step at least twice to make sure you get an accurate reading.

F. Remove the test weights and make sure that the scale weight returns to that recorded in step C, +/- 2 divisions (a division is the smallest amount of weight change the indicator can measure, which is set up during calibration)

G. Repeat steps C thru F on all corners of the scale.

H. All corners should respond the same when the test weights are applied. It is possible that all weigh the same, but not exactly the amount of the test weights, in which case the scale needs calibration (see test in section 4.1.2). If the corners are inconsistent in their weights then see the troubleshooting section in 4.2.

4.1.2 Gross Calibration Test

The purpose of this test is to determine if the scale is consistently weighing correctly with each application of weight. It will help determine if a re-calibration is needed, or if there are other problems with the scale.

A. Arrange for the most amount of test weights that can be loaded on the scale. Ideally this should be a minimum of 20% of the normal weighing range of the scale. The weights should be applied near the center of the scale or evenly distributed on the scale.

B. Empty the scale and re-zero the scale using the zero button on the scale indicator.

C. Apply the test weights to the scale.

D. Record the weight now showing on the scale indicator. This should be equal to the test weight amount +/- .1% of the test weight amount (for legal for trade scales). Non-legal for trade process scales will normally have wider tolerances that may be as much as .5%.

E. Repeat steps B-D at least twice to test for repeatability. If the scale is in error, but repeatable, then re-calibrate it as described in section 5. If the scale is not repeatable in it's weights, then see the troubleshooting section 4.2.

4.2 Scale not Weighing

This section describes what to do if the scale is not weighing at all, or failed the cornering or Gross Calibration test. In this case there is something wrong with the scale either mechanically or electrically, and the objective is to identify it and correct it.

A. Inspect the platform/hopper for mechanical interference. The scale cannot touch any mechanical structure other than through the load cells. If the scale is of a nature that control cables or hoses attach to the scale, make sure that they are flexible and have loops in them to minimize the forces they can apply to a scale. Note that an air hose can exert several pounds of force on a scale, and fixed conduit can exert hundreds of pounds if run vertically to the scale.

B. Check all load cells to make sure that their mounting arrangement is correct, and that the weight is transmitted through the load cells without interference. Common problems are interference from self jacking screws, load pins, or suspending rod.

C. On the back of the indicator, locate the connector for the load cell input, and have ready a Volt-Ohm meter for the tests to follow.

4.2.1 Combined Load Cell Resistance Test

The following test will check the overall wiring and load cell configuration to determine if the cabling or individual load cells need to be tested. This is a passive resistance test of the parallel combination of the load cells.

A. Unplug the load cell connector from the back of the indicator, and perform the following measurements on this connector while it is disconnected.

B. Measure the resistance between the +E and –E terminals of the connector. This should be the specified excitation resistance divided by the number of load cells. For a four load cell system with 400 ohm cells, you should see 100 ohms +/- 3 Ohms. If it is not, then proceed to the individual load cell resistance test in section 4.2.3. Note that if you don't measure any resistance at all (open), then you probably have a problem with the cable between the indicator and the Junction box.

C. Measure the resistance between the + SIG and –SIG terminals of the load cell connector. This should be the specified signal resistance divided by the number of load cells. For a four load cell system with 350 ohm cells you should see 88 Ohms +/- 2 Ohms. If it is not then proceed to the individual load cell resistance test in section 4.2.3. Note that if you don't measure any resistance at all (open), then you probably have a problem with the cable between the Indicator and the Junction box.

D. Measure the resistance between the shield and each of the individual wires on the load cell connector. You should measure over 1 Meg Ohm of resistance. If there is any substantial continuity between the shield and a load cell wire then you have a problem either with the cable between the indicator and the Junction Box, or with an individual load cell. You can test each individual load cell at the junction box (section 4.2.3) to determine which. This must be corrected or the scale will not weigh properly.

4.2.2 Combined Load Cell Signal Test

This test will measure the power to the load cells as well as their output to determine if there is problem that may be attributable to an individual cell.

A. Plug the load cell connector back into the indicator, and have a volt meter that can measure in both Volts and Millivolts.

B. Set the meter to a DC range that can handle 20volts.

C. Measure between the +E and –E terminals on the load cell connector while it is plugged into the indicator. You should read the excitation voltage specified in the indicator manual within 1VDC.

D. If the Excitation does not read as specified, then unplug the load cell connector from the indicator and measure it again on the indicator. If it still is out of spec then there is a problem with the indicator. If it reads correctly with out the load cells plugged in, but incorrectly with them plugged in, then you may have a cable or load cell problem (however this should have shown up in section 4.2.1). Inspect all cables for shorts, and try plugging the load cell connector into another indicator to see if you get similar results. This will determine if it is the Indicator or a Load Cell problem

E. If you believe it is a load cell problem, you can disconnect the load cells one at a time in the junction box to isolate the problem (make sure you disconnect both the signal and excitation connectors).

F. Calculate what the full load output of the load cells should be. You can do this by multiplying the excitation voltage output of the indicator times the specified mv/V output of the load cells. As an example, if the indicator had a 15vdc excitation, and the load cells were 2mv/V, then the full scale output would be 30mv.

G. With the load cell connector plugged into the indicator, and the voltmeter set to a scale that can read millivolts, measure between the +SIG and –SIG of the load cell connector.

H. As a rule of thumb This should be approximately equal to the dead load of the scale, divided by the total load cell capacity, times the full scale output of the cells (as calculated in Step F). If it is outside of this range then there is a possibility of either a bad load cell or a mechanical problem with the scale. Note that it is possible to have a load cell with a large zero offset that can cause this value to be outside this range, but still weigh correctly (see next step), but it is a symptom of something that needs to be looked at. If the signal is significantly outside of this range (either negative, or over 20mv then there is most likely a problem than needs to be corrected. The actual change in this signal in proportion to weight is the most important measurement. The steps below will help determine this.

I. Empty the scale and measure between +SIG and –SIG and record the millivolt reading.

J. Arrange to put the test weights on the scale and record the millivolt reading again between the +SIG and –SIG pins on the back of the indicator.

K. The signal reading should change (subtract the reading in I from the reading in J) by the amount calculated as follows: Divide the amount of test weights applied by the total load cell capacity in the scale, and multiply by the full scale output calculated in F. Note that voltmeters are not nearly as accurate as the indicator, and this is only a rough reading to see if the scale is basically doing what it should. If this reading is within 10% of what it should be it is ok. If it is not then either there is a bad load cell or a mechanical problem with the scale. See section 4.2.4 for individual load cell tests.

4.2.3 Individual Load Cell Resistance Tests

This section describes how to test the resistance of each individual load cell, which can help identify a bad load cell or wiring problem. This test should be done if the combined resistance test in 4.2.1 was out of spec, or if there are other reasons to suspect a bad load cell.

A. Locate the load cell junction box. All load cells terminate here, and a single cable leaves this box and goes to the weight indicator.

B. Inside this junction box is normally a circuit board with terminal strips that should be clearly labeled as to which load cell connects to which, and which terminals are signal and excitation.

C. Have read a voltmeter set to read ohms.

D. Disconnect the 4 wires coming from load cell 1 from the terminal strip in the junction box, and identify the signal and excitation leads (refer to your load cell specification sheet for the color codes as they can be different depending on the manufacture)r.

E. On the removed excitation wires, measure the resistance between them. It should be 390 Ohms +/- 10 ohms for a typical load cell (but check your load cell specification sheet to verify).

F. Measure the resistance on the removed signal wires. It should be 352 Ohms +/- 2 ohms for a typical load cell, however verify as above.

G. Measure the resistance between each of the four wires, and the shield. It should be greater than 1 meg ohm.

H. Repeat steps D through H for all load cells.

I. If any of the resistances are outside the specified range, then the cabling or load cell may be bad.

4.2.4 Individual Load Cell Signal Test

This test will help determine if one of the load cells is outputting an incorrect signal. Because the loading of the load cells is rarely symmetrical (one cell may support more of the load than the others), the test may not provide conclusive results. This test should be performed if the combined load cell signal test in 4.2.2 was out of range, or a bad cell is suspected for other reasons. This test will also help point out mechanical problems with the scale.

A. Locate the load cell junction box. Make sure all wires for the load cells and the cable to the indicator are connected to the terminal strips with the EXCEPTION of the signal wires from each load cell (those need to be disconnected from the junction box terminals).

B. Have a Volt meter ready that can read millivolts, and the test weights used in 4.2.2.

C. With the scale empty, record the millivolt reading on each of the load cells signal leads. Each load cell should read about the same as what was measured in step 4.2.2 G (with all load cells hooked together). A variation of more than 25% between the reading in 4.2.2 G and any of the load cell readings is cause for suspicion, and may warrant a check of the load cell or mechanical structure.

D. Apply the test weights to the scale in a fashion that they are either in the center of the scale, or evenly spaced around the scale so that the load on each corner is similar

E. Record the millivolt reading on each of the load cell signal leads

F. Calculate the change in millivolts on each cell from step C to step E. For each load cell this reading should be about the same as the change calculated in 4.2.2 K (with all load cells hooked together). A variation of more than 25% between each load cell's change and that measured in 4.2.2K may indicate a problem with that load cell or the structure.

G. When the change in output voltage from the cells was measured between empty and full you will see some cells change differently than others. If there is a wide variation between the cells, and the average is incorrect, then it is possible that there is either a mechanical bind or a bad cell. Usually the cell with the low output change is the one with a problem.

H. You can also do a quick bench test of a load cell that is not in service by temporarily hooking it directly to an indicator, or alternately hooking the excitation leads to a 15vdc supply. With no load on the cell it's signal output should be between +/- 1mv. Any reading substantially outside this range would indicate that the cell has been damaged. Note that you can also do the resistance tests on the cell as described above. Note that these tests are not conclusive, as the cell can pass these and still be bad. The only sure test is put the cell under a range of known loads and check it's output.

5. Scale Calibration

The procedure for calibrating a scale is very dependent on the nature and structure of a scale. Often the instruction manual for the scale will give suggestions on the best approach for that type of scale. In addition, the exact keystroke procedure on the indicator is completely dependent on the indicator type, and the manual for the indicator must be referred to.

The general procedure is to empty the scale, and tell the indicator that it is empty at which time the indicator will acquire the current load cell output as it's zero reference. Then a known and calibrated weight is applied to the scale, and that amount of weight is typed into the indicator keyboard at which time the indicator will measure the change in millivolt output from no load to test weigh load, and calculate the millivolts per pound ratio (span), which it will use from then on to convert the voltage output of the load cells to a displayed weight.

The calibration process requires certain selections and decisions to be made. Some of the more important ones, and related terms are as follows:

A. **Capacity** – This is the maximum amount of weight that is intended to be put on the scale, generally limited by the scale design. Specifying the capacity generally has an effect on two things: 1) Overload indication – The scale indicator will show an error when the weight exceeds this amount; 2) Full Scale Counts – the total number of different weights the scale can display (see below for further discussion).

B. **Graduation Size** – This is also referred to as the Increment Size or Displayed Division (dd). This is the smallest amount of weight change that the indicator can display, and is always some variation of 1,2, or 5 with decimal places to the left, or fixed zeros to the right. The smaller the graduation size the more precise the scale, but also the more unstable it will be.

C. **Test Weight Amount** – This is the amount of known test weight applied to the scale to span the scale. Several schools of thought abound on the proper test weight amount. Some say it should be equal to the capacity of the scale, others say it should be equal to the normal amount the scale is used to weigh. The answer depends on how the scale is used. If it typically weighs the same amount each time, then it should be calibrated at that level. If it is used to weigh a large range of weights then a test weight that is in the middle of the weighing range will provide the best linearity over the entire range. In all cases the scale should be tested at the maximum and minimum ranges after calibration.

D. **Motion Detection** – This is a setting used by the weight indicator to determine when it has settled. This is used mostly in legal for trade applications and prevents the scale from performing certain functions until it has settled. These functions typically are Tare, Push button Zero, Printing, and Auto Zero Acquisition. A typical legal for trade setting would be 3 displayed divisions.

E. **Zero Range** – This specifies the total percentage of the capacity of the scale that can be zeroed using the front panel push button. For legal for trade applications this is typically limited to 2%, however in process applications it can be set much higher, and 20% is not unusual.

F. **Auto Zero Maintenance Range (AZM)** – Most scale indicators have a feature that allows them to automatically re-zero themselves (same as push button zero) if they are stable, and close enough to zero. This setting determines how close to zero the scale has to be before it will automatically "push the zero button". Typically this is set for less than 3dd. In process weighing (such as batching) this feature is usually turned off as it can cause in-accurate weighing.

G. **Full Scale Counts** – This value is internally calculated by the indicator after calibration, and is equal to the specified capacity divided by the graduation size. Basically this represents the total number of different weights the scale can display (similar to the number of ticks on your ruler). For legal for trade applications this is usually limited to either 3000, or 5000 – However in process applications this can be over 20,000 with the right indicator. The larger this number the more precise the scale, but also the more unstable it is likely to be.

H. **Micro Volt Build** – Also termed uv build, relates to the signal sensitivity of the indicator. Since the indicator converts the load cell voltage to a number it has to be able to distinguish between small voltage changes. The smallest voltage change that can be measured by the indicator is called its Sensitivity, and is measured in micro volts. The Micro Volt Build is the voltage change represented by one graduation of the scale. This can be calculated by dividing the graduation size by the total load cell capacity of the scale (sum of the name plate rating of all load cells), and multiplying by the full scale voltage output (calculated earlier). Generally a build of less than 1 micro volt may cause an unstable scale.

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