Solutions for Process Weighing and Force Measurement | Handbook TC0010

An Overview of Calibration Methods and Procedures for Process and Inventory Weigh Systems

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An Overview of Calibration Methods and Procedures for Process and Inventory Weigh Systems

Overview

Electronic weigh systems are often used in the process industries because they offer a non-intrusive, highly accurate, and reliable measurement of mass within a process vessel or inventory silo. Properly installed and calibrated systems routinely achieve accuracies of 0.02% with a measurement precision, or resolution, of one part in 50,000. These performance specifications compare very favorably against the best level (0.5%) and flow measurement (0.1%) technologies.

The changing industrial climate is placing increasingly greater emphasis on quality of product. Many of the most progressive manufacturers are pursuing official recognition of quality systems through ISO 9000 registration and the implementation of total quality programs within their enterprises.

These changes are resulting in a greater awareness of "weight" as a preferred process variable and the importance of properly installing, servicing, and calibrating electronic weighing systems. It is now becoming more and more important to not only accurately and properly calibrate, but also to document the calibration.

There are several ways to calibrate an electronic weigh system that range from a simple electronic simulation to a multi-point applied deadload calibration. The proper method to use is largely a function of the required accuracy, traceability, and perhaps most importantly, the method that is most practical, given time, budgets, and physical configuration of the system.

For example, calibration of a freestanding inventory silo containing a low-cost material can be cost-effectively calibrated using an electronic simulation method. However, at the other extreme, a pharmaceutical process reactor with connected piping and subjected to validation review by the FDA may need to be calibrated using deadweights to full scale capacity.

The range of calibration options available, where and how to apply them, the expected results, and case histories of actual results will be discussed. Where appropriate, structural issues and system specifications will be addressed. Finally, a chart will be developed that summarizes the methods, results, and applicability.

System Descriptions

A traditional system uses several load cells to fully support the vessel or structure being measured. The analog mV signal from each of the transducers is connected in parallel within a summing circuit that provides a single mV signal output corresponding to the average of the multiple load cell signals. This averaged signal is usually connected to the input of a weight transmitter/indicator device where it is conditioned, digitized, scaled, and displayed and/or retransmitted (Figure 1).
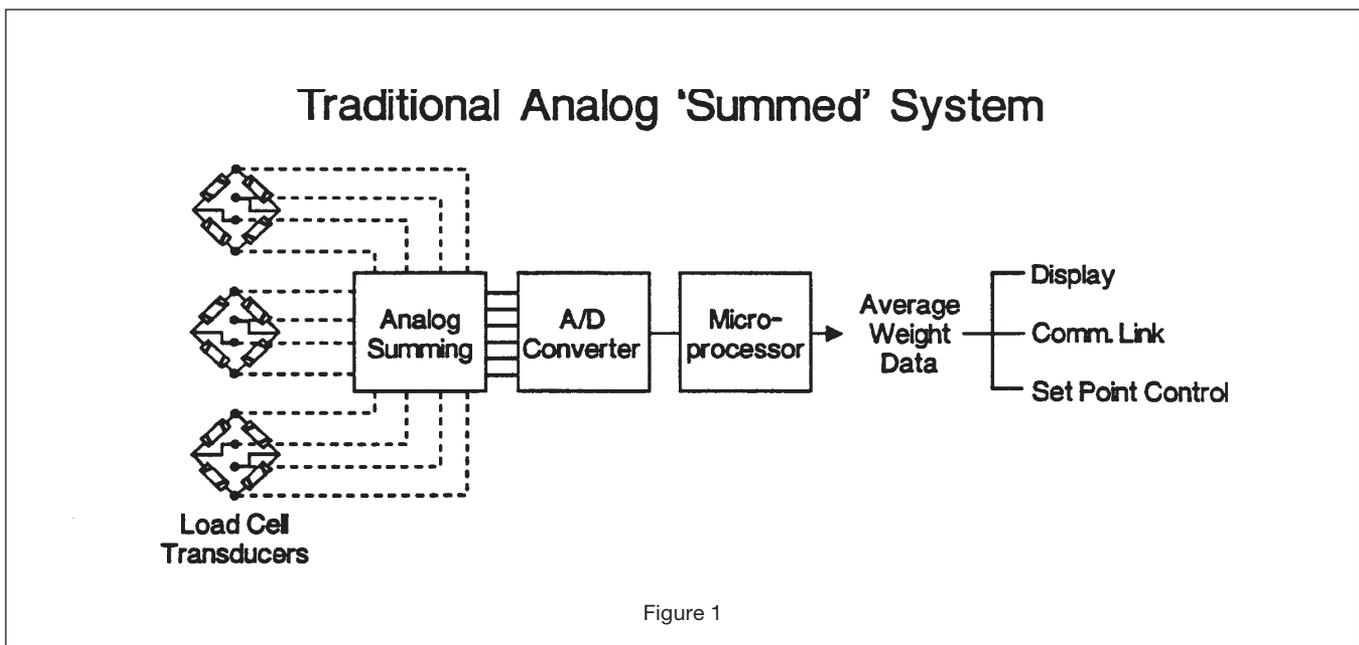
Figure 1

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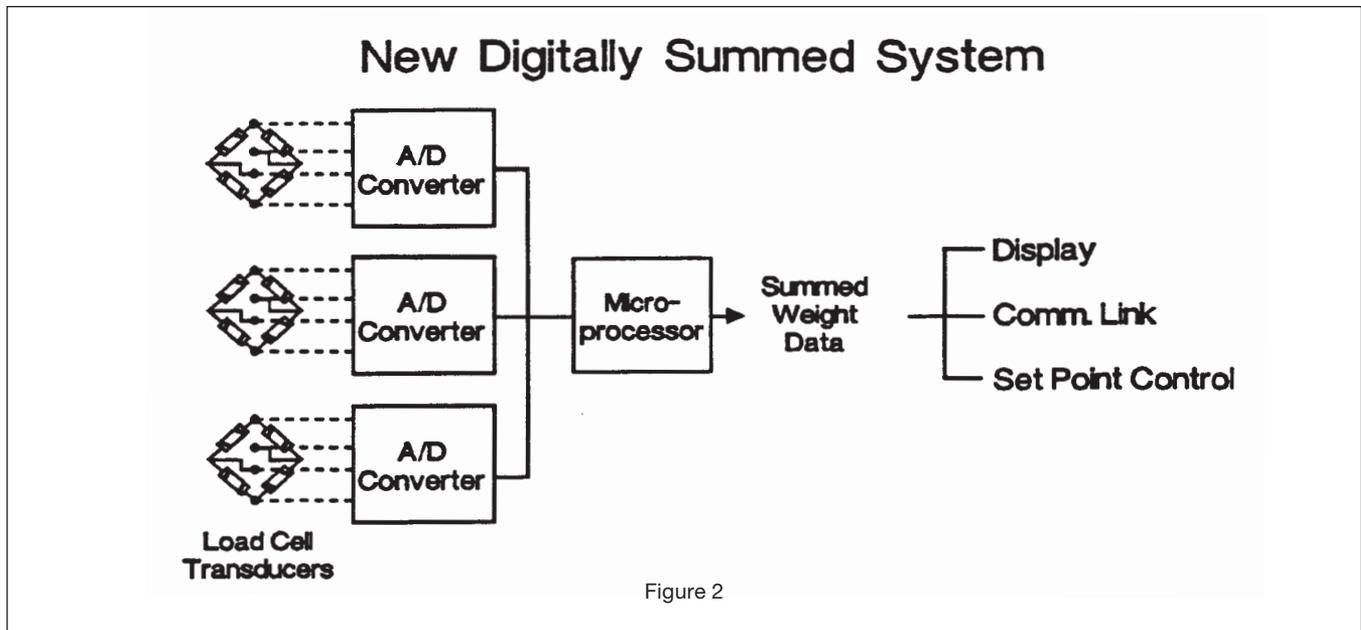
Figure 2

More recent technological advancements have resulted in digitally summed systems that operate somewhat differently (Figure 2). In a digitally summed system, the individual load cell output is digitized, therefore providing a known or calibrated measurement of each vessel support point. This digitization can take place in either the load cell itself, or in a separate transmitter device. The output of each transducer is communicated on a simple local area network to a display or re-transmission device where the digital values are added or summed together.

Typical Component and System Accuracies

Strain gage technology based load cells consist of a strain gage sensor mounted on a metallic structure that deforms under load. The metallic structure is design to operate as a very linear and repeatable "spring". Additional passive components within the load cell sensing circuit compensate for temperature effects over a wide range of operating conditions. The performance of these transducers is normally states as a percentage of rated load, or full scale output. Typical performance specifications are:

KIS Load Beam Performance Specifications

Combined error	0.02% rated output
Repeatability	0.01% rated output
Temperature effects	0.0008% / °C
Creep	0.02% rated ouput (5 min)

Instrumentation for load cell systems typically provide very good performance with resolution capabilities of better than on part in 50,000 and non-repeatability of less than 0.01%. The highest quality devices have temperature effects as low as 2 ppm/°C. Other components of the system include cabling, etc., which through the use of remote sensing, have negligible effects.

The tried and true method to calculate expected system accuracies is to assume that all errors are random and to use the RMS method to determine the maximum "probable" error:

$$\text{Probable Accuracy} = \sqrt{\frac{(\text{Combined Error})^2 \bullet (\text{Temp. Effects})^2 \bullet (\text{Repeatability})^2}{\text{Total Number of Load Cells}}}$$

This approach has been applied to weigh systems for over 30 years, and has proven to be a reasonable, but conservative, predictor of actual installed performance. The following printout is a spreadsheet program zdeveloped by BLH Nobel to automatically perform the RMS calculation and tabulate system accuracies in several formats (Figure 3).

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```
File:SYStemCALCulations          VERSION 3.52          6/12/94
------------------------------------------------------------------
BLH DXP-40 and KIS-3-5  System Error Analysis          09-Nov-94

Enter Customer Name            -------> SAMPLE
Enter Project Reference        -------> HIGH ACCURACY SYSTEM EXAMPLE
Enter Instrument Model Number  -------> DXP-40
Enter Load Cell Model Number   -------> KIS-3-5
Enter Excitation Voltage       ------->      10  Vdc
Enter Number of Load Cells     ------->       3
Enter Vessel Dead Weight       ------->     300  Lbs
Enter Vessel Live Weight       ------->   3,000  Lbs
Enter Temperature Variation (+,-) ----->      5  Degrees F
==================================================================
Load Cell Capacity                            1,124 lbs
System Capacity                               3,372 lbs
Gross Weight                                  3,300 lbs
------------------------------------------------------------------
LOAD CELL SPECIFICATIONS

Creep ------------------------------------------     0.01 % RO
Zero Temperature, % RO/Degree F ------------------   0.0008 % RO
Span Temperature, % RO/Degree F ------------------   0.0008 % RO
Combined Error, (Non-Linearity + Hysteresis) -----   0.02 % RO
Non-Repeatibility --------------------------------   0.01 % RO
------------------------------------------------------------------
SYSTEM SIGNAL LEVELS

Load Cell Rated Output                        2.0394 mV/V
Signal at System Capacity                     20.394 mV
Dead Weight Signal                            1.814 mV
Live Weight Signal                            18.144 mV
------------------------------------------------------------------
SUMMARY

Digital Accuracy
    Load Cell(s) Error (RMS)                  0.163 lbs
    Digital Resolution                        0.020 lbs
    Maximum Probable System Error             0.183 lbs
    Maximum Probable System Error (% Live Weight)    0.006 %
    Maximum Probable System Error (% System Capacity) 0.005 %

Analog Accuracy
    Load Cell(s) Error (RMS)                  0.163 lbs
    Analog  Resolution (Live Weight)          0.020 lbs
    Maximum Probable System Error             0.183 lbs
    Maximum Probable System Error (% Live Weight)    0.006 %
    Maximum Probable System Error (% System Capacity) 0.005 %

NOTE: Calculations represent system capability. Actual performance may
be degraded by installation conditions. Weigh System Handbook is
available to provide guidance in achieving system capability.
```

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Applications Review

Process and inventory vessel weigh systems bear very little in common with platform and truck scales. Vessels tend to be supported on three or four support points and are almost always connected into the process with pipes or conveyors. Depending on the material being processed they can also be subjected to continuously changing load distributions.

Attached Piping

Piping connected to a vessel being weighed can, if improperly designed or installed, create three basic contributors to system errors:

1. Shunting of load resulting in non-repeatabilities and non-linearity.
2. Horizontal forces resulting in load distribution changes that appear as drift.

3. Vertical thrust forces that cause significant changes in the measurement under pressurized process conditions.

Well designed systems will use horizontally connected pipes with either sufficiently unsupported lengths to minimize vertical forces, or in non-pressurized system, flexible sections to allow free vertical movement. Systems expected to encounter large thermal changes may also need to incorporate expansion loops to minimize horizontal thrust loads. Typical load cells combined with support system structure deflection is less than 0.25 in. Consequently, a piping design that allows for that amount of vertical movement, with minimized piping reaction, will produce a linear and repeatable measurement (Figure 4). The following formula (Figure 5) has been used to estimate the negative effects of connected piping given the pipe K factor. Vertical piping, with or without flexes or bellows-type fittings should be avoided.
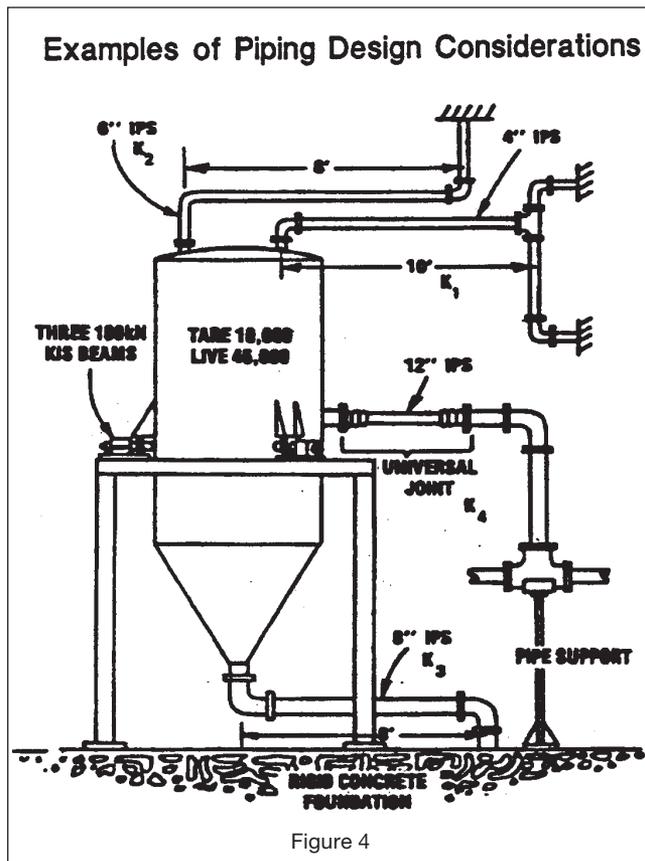
Figure 4

Rule of Thumb For Systems with Piping

$$\text{Estimated Accuracy} = \frac{\text{Vertical Pipe Loads}}{\text{Live Load}} \times 0.10$$

To calculate vertical piping loads:

$$V = K(D)$$

Where

V = Vertical Pipe Load (#)
K = Spring Rate of Pipe (#/in.)
D = Deflection of Pipe (in.)

Figure 5

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Spring Rates for Schedule 40 Steel Pipe

NOTE: Spring rate obtained from the chart above should be derated by 0.42.
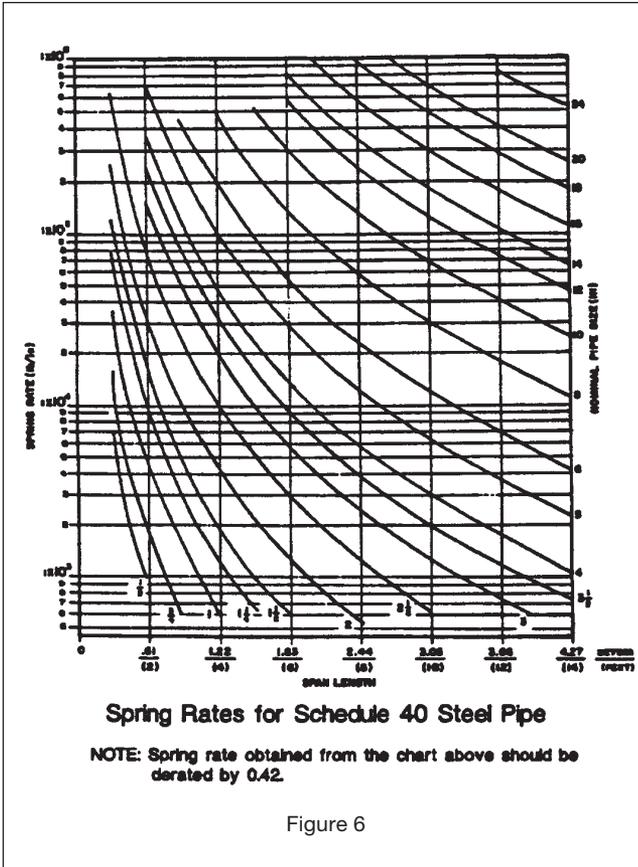
Figure 6

Structural Considerations

Three point support systems are desirable from a start-up and calibration point of view because they tend to be self-leveling – three points define a horizontal plane. In systems that use four or more points of support, each point must be measured independently during start-up and calibration to make sure that the load is evenly distributed. If it is not well distributed for reasons other than a truly unbalanced load, the system will need to be shimmed to achieve an even distribution. A general rule of thumb is to achieve balance within 20-30% (difference between highest and lowest reading).

Non-uniform or excessive support deflection can also cause changes in load distribution as the vessel is loaded. It is always desirable to have uniform support deflection. Maximum overall deflection should not exceed 0.5" or result in an out of plumb condition of more than 0.5 deg.

It is also important to take into account the relationship between total vessel and support deflection and deflection of attached piping support. It is good practice to anchor piping supports to the same structure that the tank is on so that the deflection will match (Figure 7).

Data Communications

Weigh systems are capable of repeatabilities of 0.01% and measurement resolutions of 50,000 counts. (Some systems provide up to 4 million counts.) Analog data communication is commonly limited to 12 bit or 4096 counts of resolution in order for a host computer based control system to benefit from all of the performance a weigh system can offer. It is necessary to use either a high resolution (16 bit) analog output, or to incorporate a digital communication technique.

Examples of Possible Support Deflection Problems
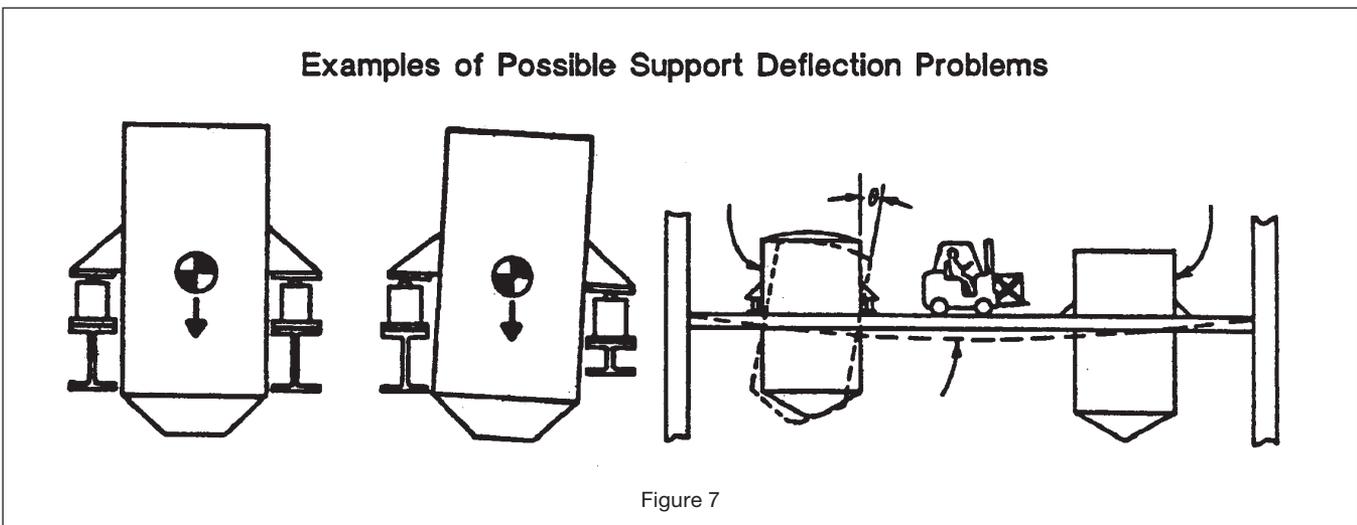
Figure 7

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Calibration Methods

Basic Procedures: Before beginning an actual calibration, it is always necessary to inspect the vessel/weigh system for structural, piping, or other mechanical deficiencies. It is also important to independently measure the output from each load point to determine balance and to shim if required. These independent measurements can be made manually with a high resolution DVM, or automatically with some of the newer digitally summed instrumentation systems.

Calibration Standards: Traceability of calibration standards is an important issue before beginning any calibration. Traceability is in essence an unbroken chain linking the measurement to a recognized standard. In the case of standards for calibrating weigh systems, the recognized standards organization is NIST (National Institute for Standards and Technology).

In simplified terms, there are four levels of standards traceability:

1. NIST Standards – The physical standards that are in place at NIST.

2. Primary Standards – Deadweight lifting machines in a controlled environment and precision voltage standards.

3. Secondary Standards – Portable deadweights, master bridges (load cell simulators), and voltage measurement standards.

4. Working standards – Transfer standards such as calibrated load cells, digital volt meters, and portable load cell calibrators.

Total system uncertainty is calculated using the RMS of the uncertainties of each standard in the traceability chain:

Summation of Uncertainties (Probable Error)

$$U_T = \sqrt{\frac{(U_1)^2 + (U_2)^2...(U_n)^2}{N}}$$

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MV Simulation

The output from a load cell is an analog mV signal proportional to applied force. If we assume that the load cell calibrations are correct, either because they are new or have recently been calibrated as a component, it is possible to calibrate the indicator/transmitter device by applying a known millivolt signal that would correspond to the applied force (Figure 8).

Applications: Uniformly loaded vessels with minimal piping restrictions.

Accuracy: 0.25 to 1.0% depending on calibration accuracy of mV source and accuracy of load cell calibration specifications.

Benefits: Low cost, ready availability of mV source.

Deficiencies: Does not prove mechanical characteristics of entire system or calibration of the load cells.

Equipment: mV source, DVM, load cell calibration specifications.

Procedure (Analog Summed Systems)

1. Disconnect one load cell from summing unit. Install in its place one "dummy" Wheatstone bridge with the same impedance of the load cell that was removed.

2. Connect mV source in parallel with signal leads on the "dummy" bridge.

3. On system indicator/transmitter, acquire a "zero" calibration point.

4. With a DVM, measure the excitation voltage. Calculate a known mV span point by multiplying the excitation voltage by the desired force vs. mV/V span point on the load cell calibration sheet:

$$\frac{\text{Live Load or Calibrated Range}}{\substack{\text{Total System} \\ \text{Capacity}}} \times \substack{\text{Rated Output} \\ \text{of Load Cells}} \times \text{Excitation} \times \substack{\text{Millivolt} \\ \text{Value}}$$

5. Dial in an mV signal that corresponds to a known force span point. Acquire/adjust this span point in the system indicator/transmitter.

6. Reconnect the load cell and acquire a new zero point. Calibration is now complete. Check calibration by applying a known weight.
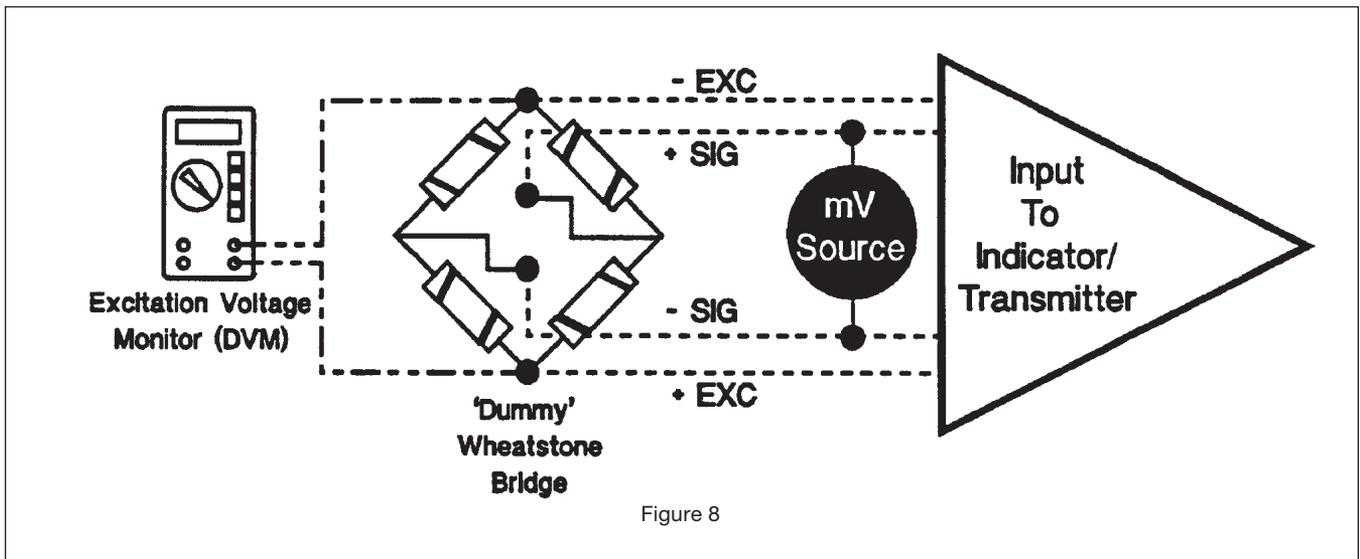
Figure 8

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mV/V Simulation

Load cell outputs are normally stated as an mV/V signal output vs. applied load. This unit of measure simple means that there will be X mV of output at full capacity for every volt of applied excitation. Load cell manufacturers often offer special calibrators that electrically simulate the Wheatstone bridge circuit and are adjustable in discrete segments to provide a range of mV/V outputs. Since many load cell instrumentation systems use a ratiometric gain circuit, the use of an mV/V calibrator is preferred over an mV signal source (Figure 9).

Applications: Uniformly loaded vessels with minimal piping restrictions.

Accuracy: 0.10 to 1% depending upon calibration accuracy of mV/V source and accuracy of load cell calibration specifications.

Benefits: Low cost.

Deficiencies: Does not prove mechanical characteristics of entire system or calibration of the load cells.

Equipment: mV/V calibrator load cell calibration specifications.

Procedure: (Analog Summed Systems)

1. Disconnect one load cell from summing unit.
2. Connect mV/V simulator in its place. Set the output at zero mV/V.
3. On system indicator/transmitter, acquire/adjust a "zero" calibration point.
4. Calculate the required mV/V value to use for a span calibration point using the following formulas:
   a. 4 Load Cell System, 2000 lb. Capacity Each
   b. 2 mV/V = 2000 lb on each load cell
   c. In analog summed system, 2 mV/V = 8000 lb.
   d. Calibrate for max. 4000 lb. live load
   e. (4000/8000) X 2 mV/V X 4 = 4 mV/V or 4000 lb.
5. Dial in the mV/V signal that corresponds to a known force span point. Acquire/adjust this span point in the system indicator/transmitter.
6. Reconnect the load cell and acquire/adjust a new zero point. Calibration is now complete. Check calibration by applying a known weight.

*An interpolation procedure may be required if the actual mV/V setting is not selectable on the calibrator.
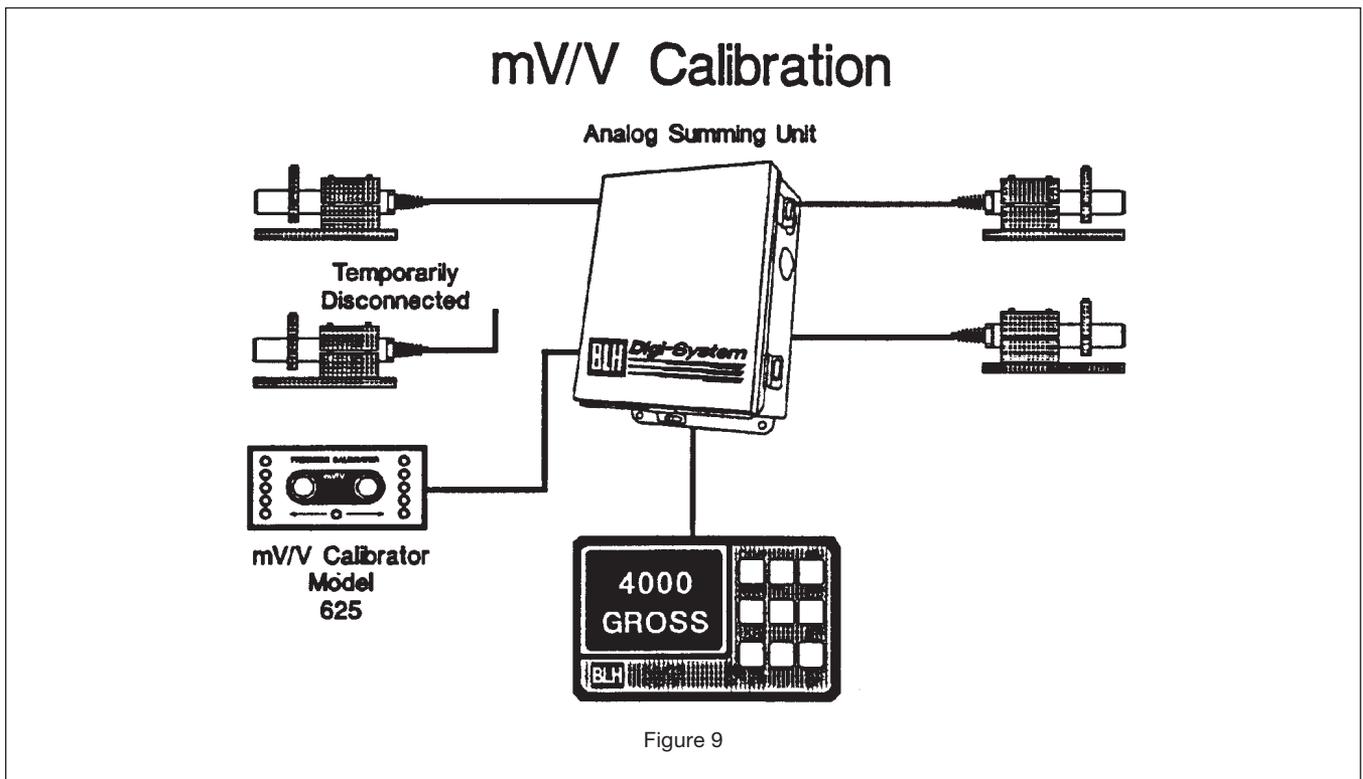
Figure 9

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Pushbutton or PROM Calibration

Systems that use technologies that individually digitize and then sum each load cell value often are equipped with an mV/V reference within the instrumentation device. This embedded reference is used to establish a relationship between the mV/V output of each load cell and individual force. Depending upon the manufacturer of the system it may be possible to establish this relationship by reading calibration data from a PROM. In the load cell, or by entering the load cell calibration data through a keypad (Figure 10).

Applications: Vessels with minimal piping restrictions.

Accuracy: 0.05 to 0.5% depending on calibration accuracy of mV/V reference and accuracy of load cell calibration data.

Benefits: Low cost, no special calibrators required.

Deficiencies: Does not prove mechanical characteristics of entire system or calibration of the load cells.

Equipment: Load cell calibration data sheets or load cells with data stored in PROM.

Procedure

1. Either automatically (PROM based) or manually enter individual load cell calibration data.
2. One system indicator/transmitter, acquire adjust zero.
3. Calibration is complete. Check with known deadweight.

Special note: This method and procedure is only valid on systems that digitize each load cell independently. Analog summed systems with single channel instrumentation that is equipped with mV/V reference will have reduced accuracies, particularly when load distributions change.
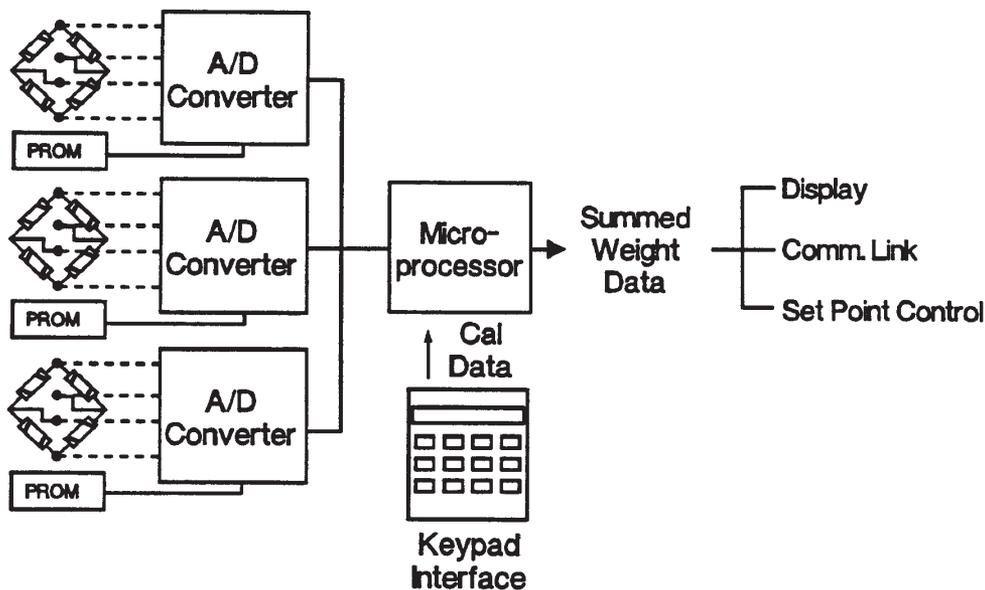
Figure 10

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Hydraulic or Mechanical Force Application

Pulling down, or lifting up on a vessel with a known force will change the force on each load cell (Figure 11). If the application of the applied force accurately models the load distribution of the weigh system, it is possible to demonstrate the calibration reliability of the entire system, inclusive of the load cells, piping, and structural influences. Some systems are designed from the outset to incorporate either individual lifting lugs or hooks on the vessel structure to apply the force. Specialized single and multi-point hydraulic force calibration systems can be fabricated or purchased and equipped with load cell transfer standards. Specialized instrumentation systems are also available to apply and precisely measure the force application at each load cell point simultaneously.

Application: Systems equipped with a force application attachment point.

Accuracy: 0.25 to 1.0% depending on accuracy of transfer standard and the ability to properly model the actual force application and distribution.

Benefits: Less expensive than deadweight methods. Proves mechanical and electrical characteristics of entire system.

Deficiencies: Requires design forethought to include force application provisions and specialized force application and measurement equipment.

Equipment: Force transfer standard consisting of at least one load cell and readout device, hydraulic or mechanical force application equipment.

Procedure

1. Install the transfer standard in series with the force application equipment. In some cases, this will be a tension type load cell installed on a hydraulic ram to pull up or down on a central attachment point on the vessel. In other scenarios, individual compression type load cells mounted on top of lifting rams will be used to lift up simultaneously on each load cell support point.

2. Remote all material from the vessel and acquire/adjust a new zero point in the system instrumentation.

3. Apply a known force, through the lifting or pulling system with the transfer standard, and acquire/adjust a span point in the system instrumentation. It is usually desirable to perform a 5 point calibration in order to compensate for any non linearities that occur.

4. Remove the force application equipment, the calibration is complete.

Special notes: If a multipoint force application is used, it is vitally important that the forces be applied and measured evenly and simultaneously. Uneven application will cause load shifts that can significantly affect the calibration accuracy.
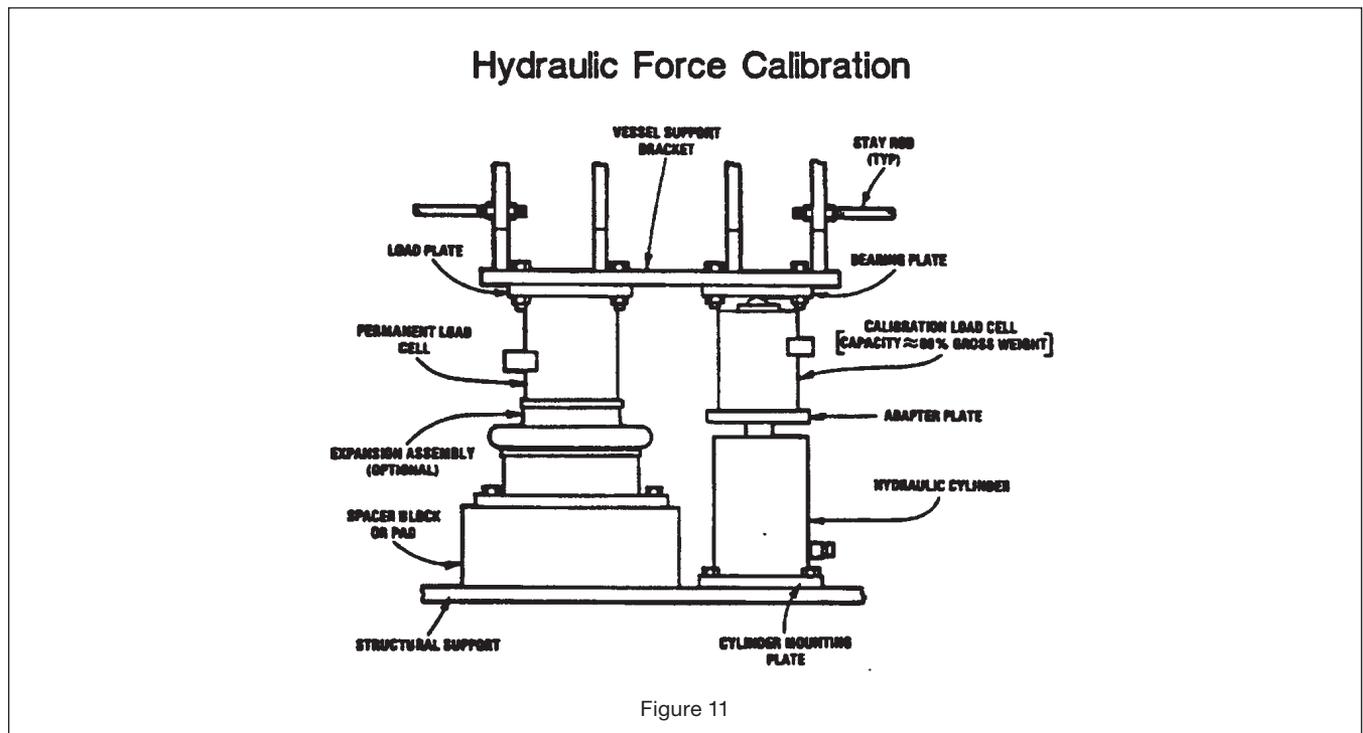
Hydraulic Force Calibration

Figure 11

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Mass or Volumetric Flow Calibration

Even though electronic weigh systems have accuracy potentials that exceed most flow measurement technologies, it is not uncommon to use flow measurement as a transfer standard to calibrate a weigh system (Figure 12). This is usually done on systems that cannot be practically calibrated in any other way because of mechanical/structural issues. It is possible for a volumetric flow calibration technique to achieve good accuracy results if temperature and pressure variables are held constant and monitored and corrected for. Therefore the equipment required must include not only a premium flow meter, but also temperature and pressure measuring devices. When using mass flow meters, it is not necessary to monitor temperature/pressure variables.

Application: Vessel configurations that prohibit the use of weights or force application techniques.

Accuracy: 0.25 to 1% depending upon the flow meter accuracy.

Benefits: Convenience, especially where flow meters are already installed in the piping. Accurately models mechanical characteristics of the system.

Deficiencies: possible accumulation of errors, turn-down errors possible.

Equipment: Volumetric flow meter with temperature measurement or mass flow meter, plumbing/piping connections into the vessel, Timing device or flow totalizer, density information of material being added.

Procedure

1. Empty vessel and acquire zero point in system instrumentation.

2. Initiate flow of material into vessel. Stop flow and totalize at approximately 20% of capacity intervals. Calculate mass that was added and acquire/adjust five span points into the system instrumentation.

3. On applications using volumetric flow, monitor temperature and pressure and correct the mass calculation as required. To minimize flow turndown effects, use three way valves to turn flow on and off without flow interruption.
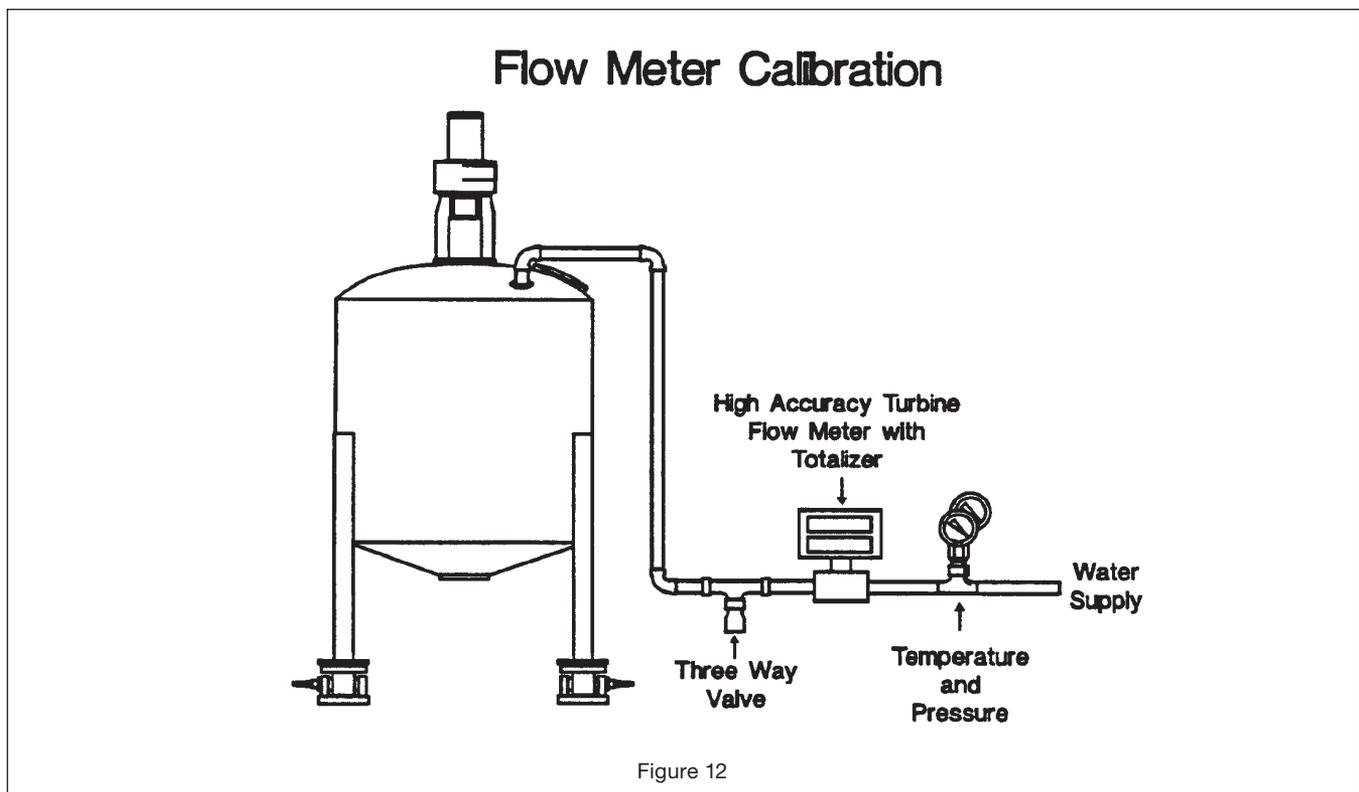
Figure 12

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Partial Applied Deadweight

Load cells are very linear devices and therefore it is often possible to set a calibration slope with a small portion of the actual system capacity (Figure 13). On systems with connected piping that may affect linearity throughout the calibration range, it is desirable to recheck the slope at several points to verify linearity. Bear in mind that the smaller the check weight is in proportion to the calibrated range, the less precise the check of the slope will be. For example, in a system with a range of 50,000 lb counting by one pound in checked with a weight of, say, 500 lb, a slope error of 0.2% would not be detected.

Applications: Virtually any weigh system.

Accuracy: 0.5 to 2% depending upon the size of deadweight in relation to calibrated range.

Benefits: Low cost, ease of implementation, can detect large system non-linearities throughout span.

Deficiencies: Relatively low accuracy, will not identify small to moderate slope errors.

Equipment: Partial capacity deadweight or transfer weight (i.e. person weighed on another scale).

Procedure

1. Remove material from vessel and acquire zero point in system instrumentation.

2. Apply partial deadweight and acquire/adjust a span point in the system instrumentation.

3. Remove dead weight and add material to vessel. Re-apply dead weight and observe change in measured value. It should be the same as the deadweight value, if it isn't, look for source of system non-linearity.

4. Continue to add material to vessel and check with deadweight throughout system calibrated range.

Partial Applied Deadweight Calibration
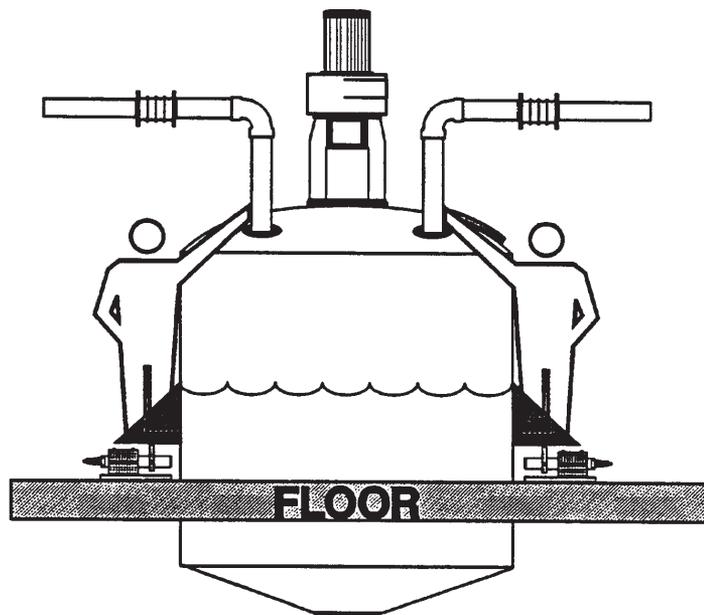
Figure 13

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Full Scale Build-up or Material Substitution

While it is not always practical to apply deadweights to full capacity on many vessels, it is possible to achieve the accuracy of a full deadweight calibration by using a build-up method (Figure 14). This involves applying a primary standard deadweight to the vessel, acquiring a span point, removing the deadweight and filling the vessel to the previously acquired span point, then reapplying the deadweight and entering a second span point, and then repeating the procedure until full capacity is achieved. This method will for all intents and purposes meet the accuracy of a full scale deadweight test.

Applications: Virtually any vessel.

Accuracy: 0.05 to 0.2%

Benefits: High accuracy, proves structural characteristics of system to full capacity.

Deficiencies: Time consuming, possible accuracy problems if small weights are used.

Equipment: Deadweights (minimum 10% of capacity), supply of water or process material.

Procedure:

1. Empty vessel and acquire adjust zero point in system instrumentation.
2. Apply deadweight and acquire/adjust initial span point in system instrumentation.
3. Remove deadweight and fill vessel until the entered span point is reached again.
4. Apply the deadweight again and acquire/adjust a second span point in the system instrumentation.
5. Repeat procedure until full capacity is reached.
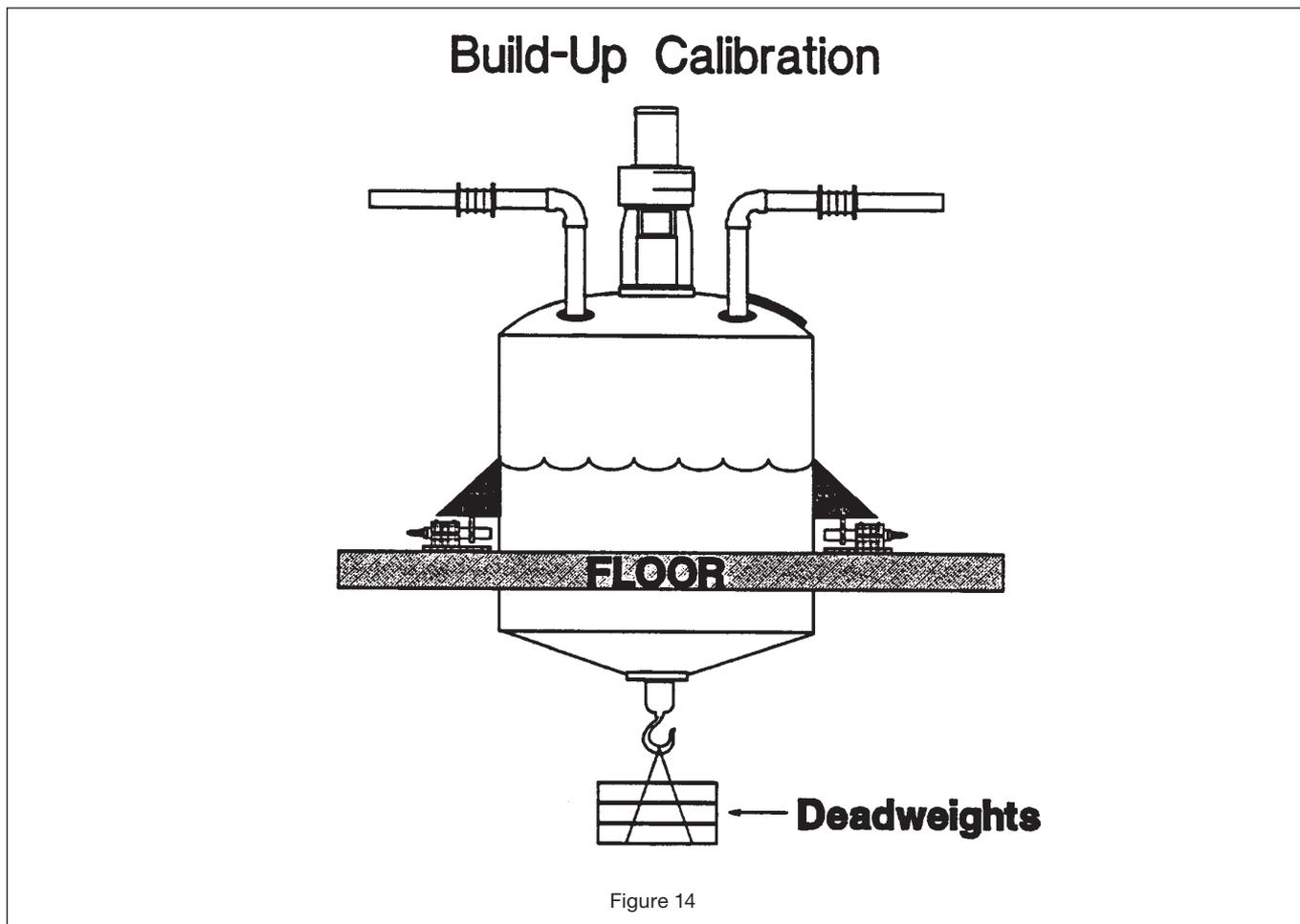
Figure 14

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Full Scale Deadweight

Probably the most accurate, or certain, way to calibrate a weigh system is to use deadweights that are primary or secondary standards traceable to NIST. On systems where the configuration allows for the uniform placement, or hanging of weights, this method is highly desirable (Figure 15).

Applications: Small to medium size vessels with uniform loading and facilities to hang or place deadweight.

Accuracy: 0.02 to 0.1%, depending on tolerance of weights.

Benefits: Superior traceability of standards, and if weights can be uniformly applied, the method will accurately model the mechanical characteristics of the system.

Deficiencies: Weights are often difficult to load and unload, and placement does not always properly model the actual loading of the vessel. Expensive and time consuming. Often times not possible because of vessel/structure configuration.

Equipment: Deadweights equal to full capacity of vessel weight attachment or placement points on vessel.

Procedure:

1. Remove all material from vessel and acquire/adjust zero point in system instrumentation.

2. Apply a quantity of deadload equivalent to approximately 20% of vessel capacity. Acquire/adjust a span point in the system instrumentation.

3. Repeat procedure until full capacity is reached.

4. Reverse removal of deadweights and check span points for accuracy.

5. Calibration is complete.
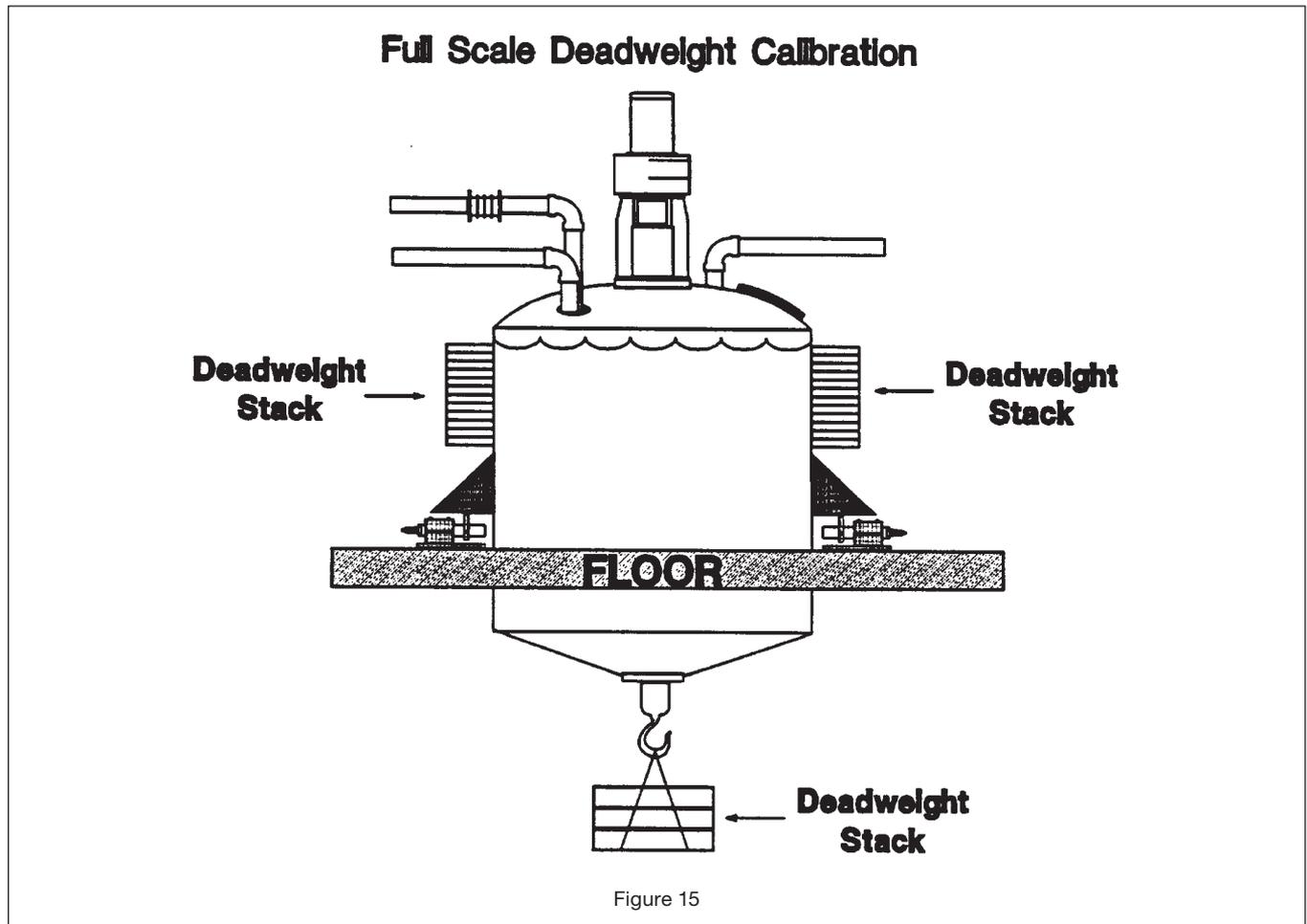
Figure 15

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Case Histories

Case History #1 – mV/V Calibration of Inventory Silos

Application: The application involves the calibration of very large, relatively freestanding inventory silos containing self-leveling plastic pellets.

Considerations: Due to the large capacities involved and the nature of the material being processed, it was not possible to use deadweights or a material substitution/build-up calibration. However, since there is minimal connected piping, there is little concern about mechanical interaction problems and an electronic calibration method can be used.

Method Used: The customer chose to use an mV/V simulation method to perform an electronic calibration. Alternatively, an mV source could be been used, but the calibration uncertainty is greater. A pushbutton, or PROM type calibration method would have also been possible if the technology had been available when the equipment was manufactured. Unfortunately, it wasn't.

Results: The BLH Nobel 625 calibrator has a specified accuracy of 0.02% of range. The load cell calibration data sheets indicated that the load cells were calibrated against a secondary standard with an uncertainty that doesn't exceed 0.05%. Interaction, or load shunting by connected pipes was determined to be negligible. The calibration accuracy is therefore conservatively stated as 0.1%.

Case History #2 – Combination Build-up and Deadweight Calibration of Reactor

Application: Pharmaceutical process vessel with several horizontal connected pipes equipped with Teflon-lined flex connections. The vessel volume and weigh system components are designed for process material with a specific gravity of 1.6. Demonstration of measurement accuracy of at least 0.1% is required for FDA validation of the process. Class F cast iron deadweights of up to 50% of vessel capacity were available and the vessel was equipped with a central hook to hang weights.

Considerations: Due to the numerous connected pipes and therefore possible load shunting problems, and the relatively severe accuracy requirement, an electronic calibration method would be inappropriate. If a build-up calibration method is used, the high specific gravity of the process material and the limited volume of the vessel require that a high density substitute material, actual process material, or combination of substitute material and a large quantity of deadweights be used.

Method: Actual process material and/or a high density substitute material were not available. Consequently, a combination build-up and deadweight calibration method was used. Essentially, a build-up test with water was used until the vessel was full, and then deadweights were applied to bring the weigh system up to full operating capacity. The system instrumentation was initially calibrated electronically using an mV/V calibrator, and then corrected at several span points if needed.

Results: The Class F cast iron deadweights have a specified accuracy (tolerance) of 0.01%. The displayed and transmitted weight data agreed within 0.05% of the applied deadweight at more than 10 points throughout the span. Consequently, it is conservative to conclude that the system accuracy meets the requirement of 0.1%.
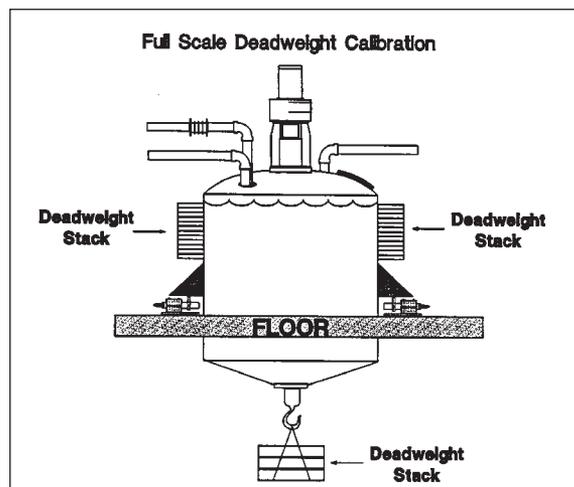
Document Number: 12223
Revision 10-Oct-2016
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An Overview of Calibration Methods and Procedures for Process and Inventory Weigh Systems

Case History #3 – Mass Flow Calibration of Mix Tank

Application: Pharmaceutical process vessel similar to that described in Case #2 but equipped with vertical pipes with flexes in addition to the horizontal flexed pipes. The requirement is demonstrated accuracy of better than 1.5% for FDA validation of the process. A specially calibrated mass flow meter with a certified accuracy of 0.4% was available.

Considerations: Due to the numerous connected pipes and therefore possible load shunting problems, and the relatively severe accuracy requirement, an electronic calibration method would be inappropriate. Since the accuracy requirement is not very severe, a mass flow calibration may be an economical alternative. However, if water is used, instead of a high density fluid, the full system capacity will not be attainable.

Method: A certified mass flow calibration method was used to calibrate the system to 66% of capacity. An initial electronic calibration using an mV/V calibrator had already established a full scale baseline calibration. Based upon the linear and repeatable results of the partial span calibration check, it was decided that mechanical interaction and/or load shunting was not a problem and that the benefit of using deadweights to load to full scale was not worth the cost of implementation.

Results: The weigh system span point checks were found to agree with the mass flow meter data within 1%. Combining this result with the 0.4% uncertainty of the flow meter calibration results in a combined accuracy of better than 1.5%.
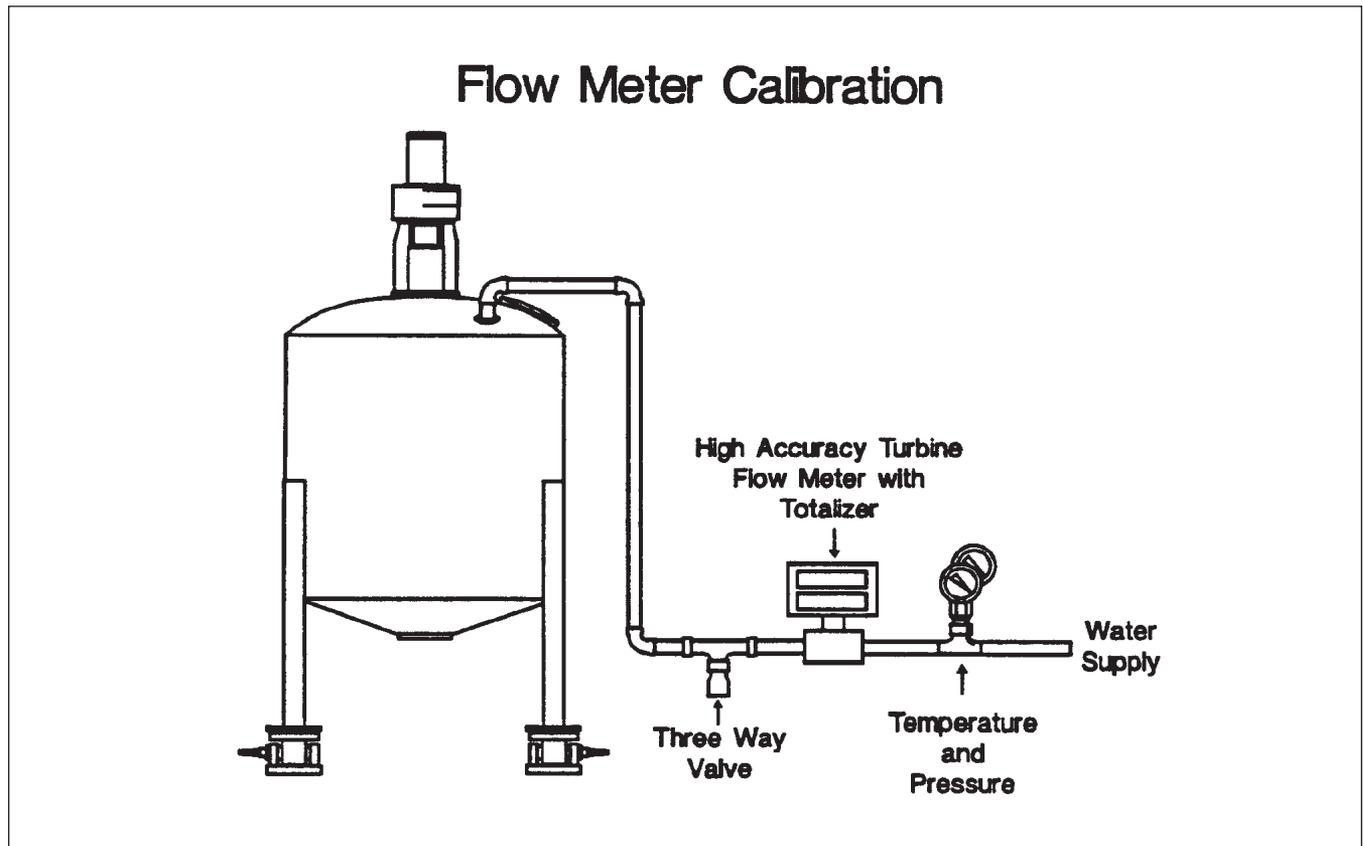
Flow Meter Calibration

Document Number: 12223
Revision 10-Oct-2016
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Summary Of Calibration Options

Relative Difficulty	Type	Accuracy	Model Structure?	Applicable Vessels		Equipment Required					
				Silo	Mixer/Blender	DVM	MV Source	mv/V Calibrator	Weights	Load Cell Cal. Data	Special Equip.
				ELECTRONIC METHODS							
1	Pushbutton/PROM (Digitally summed systems only)	0.05 to 0.5%	No	Yes	Marginal	No	No	No	No	Yes	No
2	MV Simulation	0.25 to 1.0%	No	Yes	Marginal	Yes	Yes	No	No	Yes	No
3	mv/V Simulation	0.10 to 1.0%	No	Yes	Marginal	No	No	Yes	No	Yes	No
				PHYSICAL METHODS							
4	Partial Deadwt	0.5 to 2.0%	Yes	Yes	Yes	No	No	No	Yes	No	No
5	Flow	0.25 to 1.0%	Yes	Yes	Yes	No	No	No	No	No	Yes
6	Applied Force	0.25 to 1.0%	Yes	Yes	Yes	No	No	No	No	No	Yes
7	Full Build-up	0.05 to 0.2%	Yes	Yes	Yes	No	No	No	Yes	No	No
8	Full Deadweight	0.02 to 0.1%	Yes	Yes	Yes	No	No	No	Yes	No	Yes