Document : AN EXPLANATION OF TRADITIONAL AND C2® CALIBRATION/VALIDATION METHODS & USE

Last Revised : Q2 2017

Authors : Rodger Jeffery (Principal Author); Hardy Engineering Team; Hardy Tech Support Team

Abstract

Manufacturers often use a Quality Management System (e.g. ISO 9001) to ensure their process measurement devices, including industrial tank, floor, platform and bench scales, are properly maintained (i.e. calibrated and validated). These systems require Standard Operating Procedures (SOPs) for maintenance that is documented, controlled and calibration results logged.

This document discusses two methods of complying with these requirements. A "TRADTIONAL" method that requires calibration weights to be loaded onto the scale in the manufacturing environment every time a calibration is required and Hardy's "C2®" method that does not require test weights to be loaded for a successful calibration.

Requirements of ISO 9001

A comprehensive extract from the ISO 9001 guidelines regarding the Control & Monitoring of measurement equipment is attached (Appendix 1). Summarizing these guidelines, a device is required to be calibrated or verified, or both, at specified intervals, or prior to use, **against measurement standards traceable to international or national measurement standards**; where no such standards exist, the basis used for calibration or verification shall be recorded.

Note: The most important phrase above is bolded, and it will be addressed again later in this document.

The Elements of an Industrial Scale

To understand the logic and benefit behind each method we first look at the 3 basic elements of a scale.

- Load Cell/s (Fig. 2 on page 2) the load sensing devices … typically 3 or 4 are used for a tank or platform scale
- Junction Box (Fig. 7 on page 2) also called Summing Card
- Instrument (Weight Controller, Weight Processor or PLC Plug-In Weight Module)

Each load cell usually has 4 strain gauges (see Fig. 3 on page 2) attached to a specially constructed metal billet (see Fig. 2 on page 2) and arranged in a "Wheatstone bridge" formation (see Fig. 1 below & Fig. 4 on page 2). The inputs A and C of the Wheatstone are excited by a voltage (typically 5 to 15 V) and as a load is applied to the load cell the strain gauges deform, their resistance changes and the output voltage of the bridge Vg (usually measured in millivolts) changes in proportion to applied load.

*A **Wheatstone bridge** is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component.*

The Junction Box sums the millivolt signals from the individual load cells and passes this small voltage change to the Instrument, which can typically measure and resolve incremental changes as fine as 0.15 microvolts.

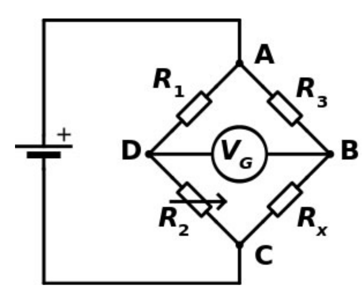


Fig. 1 Wheatstone Bridge

The diagrams below are provided for illustration, discussion and to highlight the differences between traditional load cells and junction boxes and Hardy C2 load cells and junction boxes.

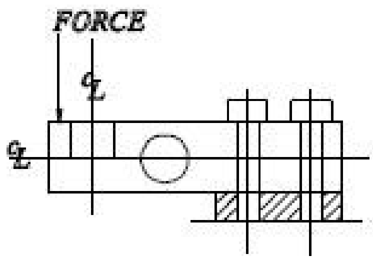


Fig. 2 Load Cell

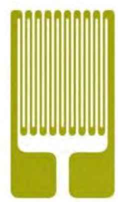


Fig. 3 Strain Gauge

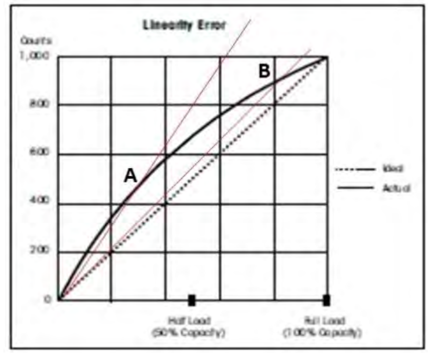


Fig. 4 Linearity Errors

Fig. 5 Traditional 4 Wire Load Cells

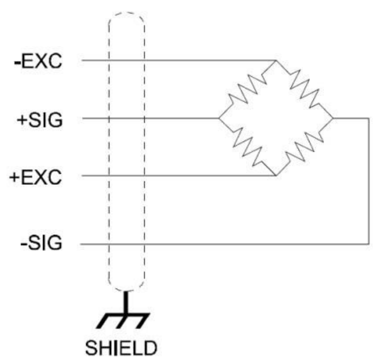


Fig. 6 Hardy 6 Wire C2 Load Cell

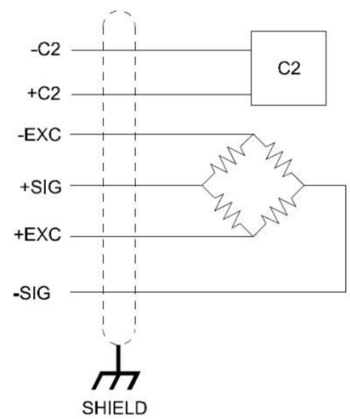


Fig. 7 Traditional Summing Card with Trim Pots

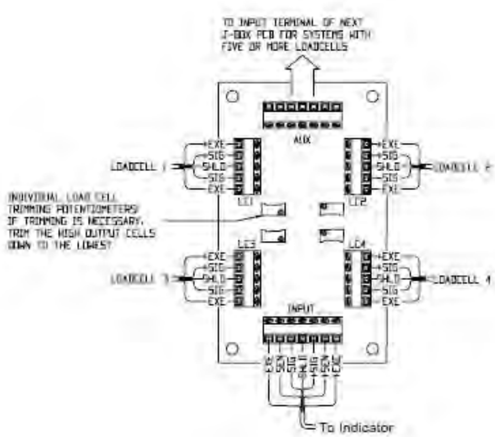
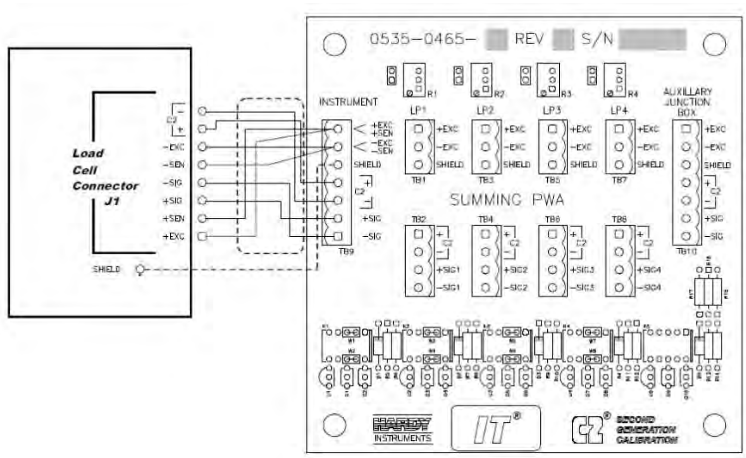


Fig. 8 Hardy Summing Card with C2 and IT (Integrated Technician)



a) An Overview of the TRADITIONAL Calibration Method:

The traditional method used to calibrate and validate industrial scales can be very time consuming, costly, disruptive to production and/or place employees and the manufacturing supply chain at some risk. Usually the higher the capacity of the scale, the greater the impact to one or more of the situations listed. Traditional scales use load cell and junction box wiring configurations as shown above (Fig. 5 & Fig. 7 on page 2).

The TRADITIONAL method requires the following steps:

1. Installing, connecting and configuring the scale: load cells; junction box; and instrument.
2. Trimming the load cell millivolt outputs using the Traditional Junction Box trim pots (Fig. 7 on page 2)
3. Using the Instrument, capture ZERO i.e. the summed millivolt signal with tank or platform scale "empty".
4. Using the instrument, capture the SPAN i.e. the summed millivolt signal with test weights loaded equal to or greater than 80% of the max scale capacity, preferably 100%.
    a. In many higher capacity scales, for example above 1000 lbs this may not be feasible because:
        i. There are not enough "available" certified test weights on site.
        ii. There is not enough "space" to load all the test weights onto the vessel or platform.
        iii. The vessel's construction may not be "able to sustain" the load of test weight(s) externally.
        iv. The test weights may create a "safety issue" sitting in a raised location in the work area.
    b. In such situations some companies may be forced or elect to include and/or repeat extra steps in the calibration process. These steps are called "electronic calibration" & "weight substitution". These steps can significantly extend the calibration effort and time. The first extra step involves using a load cell simulator to inject a calculated (approximated) millivolt signal between Steps 1 & 2 to enable a rough "electronic" ZERO & SPAN capture. The second extra step involves loading a manageable "known" amount of certified test weight onto the scale say 500 lbs, then recording the reading of the instrument. The reading would not read the actual weight but an approximate weight of say 509 lbs. None the less, the person doing the calibration now knows that a 509 lbs reading on the indicator is actually 500 lbs. The test weight can now be removed and "substituted" with water or product till 509 lbs is again read on the scale. This tedious process is then repeated again and again until the "substitute" weight on the scale exceeds 80% of scale capacity and the SPAN weight is then captured. It should be pointed out that this is a widely used calibration method.
    c. Some companies may be forced or elect to compromise the calibration and complete calibrations with a SPAN load less than the 80% of capacity, thereby deviating from the guidelines laid out for "best weighing practices". The reason this is a compromise is shown in Fig. 4 (on page 2). Using calibration weight A extrapolates further and further away from the actual span at 100%. Using weight B on the other hand is far closer to the actual span point. The diagram has been exaggerated to show the potential error.

The following are the positives and negatives of using the TRADITIONAL method:

Positives

1. If Steps 1, 2 & 3 and b (if necessary) are completed comprehensively, then an accurate calibration is achieved.
2. The calibration is traceable to certified test weights and meets the requirements of ISO 9001.

Negatives

1. The process usually takes a long time (hours). The larger the scale the longer it takes (hours and hours). This can drive production (OEE) down and cost up.
2. The method masks (hides) any external forces that act on the scale by calibrating them in at ZERO and SPAN. If these forces increase or decrease at other points on the scales operating range, or are nonlinear, then errors will be introduced.
3. The process can create unsafe conditions for operators and the person doing the calibration
4. The certified test weights which are usually brought in from outside by a 3rd party can contaminate the manufacturing area if that have not been thoroughly steam cleaned since being used on another site with contaminants.

b) An Overview of Hardy's C2 Calibration Method:

This calibration method seeks to deliver all the positives of the TRADITIONAL method and minimize the negatives. The C2 "on-site weightless calibration" method approaches the problem on the premise that the only reason test weights have to be loaded onto the scales with TRADITIONAL methods is to calibrate the load cells at the customers facility. This is because the manufacturer of the load cells elected not to load each load cell to 100% with "certified test weights" at their own manufacturing facilities. By not doing this step the opportunity is missed to capture the characteristics (mV/V/ohm) of each load cell and compensate for its output characteristics. Hardy includes this step, so that every load cell we manufacture is identical (electrically matched). Hardy records and embeds that data in a chip in the load cell for use in our customers manufacturing facility. The instrument is calibrated to relate a sensor signal to a weight value.

Once the sensor is calibrated, the whole scale can be calibrated without any test weights and only a small test weight of 5% to 10% (depending on the scale size) is loaded for "validation" on the customers site. This is not a unique technique. This method of pre-calibrating the sensor is also used, for example, in smart pressure sensors.

In Hardy's case our MANUFACTURING process involves the following extra steps so we can minimize the number of steps you need to perform on your plant floor to calibrate and/or validate your scales.

1. We and our suppliers follow the requirement of the ISO 9001 guidelines for the calibration and maintenance of measurement instrumentation and have created and follow our own Standard Operating Procedures (see Appendix 1 & 2).
2. We load our load cells to 100% with certified & traceable test weights, accurate to 1 part in 10,000 (see Appendix 3 for an example of calibration certificates).
3. We measure the output of our load cells with a certified & traceable high precision microvolt meter, accurate to 1 part in 100,000 (see Appendix 4 for an example of a calibration certificate).
4. We use this data to match the load cells and store the final calibration on a chip that is inserted in the back of the load cell that is later read by our instrument.
5. The calibration data is also stored in the cloud for retrieval, on demand anywhere, anytime.
6. An example of the level of best case accuracy and resolution that can be achieved with this method is shown using a scale with 4 x Hardy C2 110 lb compression load cells and a HI 6600 in this document (see Appendix 5).
7. C2 load cell and junction box wiring configurations are shown above (Fig. 6 & Fig. 8 on page 2).

The Hardy C2 method requires the following minimal 3 steps:

1. Installing, connecting and configuring the scale: load cells, junction box, and instrument.

2. Using the Instrument, capture ZERO (the summed millivolt signal with tank or platform scale "empty").
3. The calibration is complete. Next, we "validate" the calibration with a small "local" certified test weight. For good practice, we typically use 5 to 10% of scale capacity. Customers often use less than this range (1 to 2 % of capacity) successfully.
   a. We recommend this be done close to ZERO.
   b. Later, when the scale reading reaches a higher point (80% of capacity) validate with the small test weight again to verify the scale is weighing at the entire range of capacity.

Positives

1. The Hardy C2 calibration is completed without local test weights in less than 30 secs.
2. The calibration is traceable to certified test weights and instruments meeting requirements for Quality Management (e.g. ISO 9001).
3. This method helps to sustain or drive production (OEE) up and cost down.
4. This method unmasks (exposes) any external forces that act on the scale when we complete the "validation" step.
5. The validation process ensures fewer test weights and safer conditions for operators and the person doing the calibration.
6. Contamination can be contained by purchasing a small number of "validating" test weights for each manufacturing area (then steam cleaning is not required each time they are used).

An example of a typical ISO procedure for a "startup/routine" calibrations is provided below as an example.

ISO 9000 certification does not establish a national standard procedure to be followed, but requires that a procedure that is written, followed, and documented. The following is an example of an ISO 9000 procedure:

1. Perform C2® or Hard Calibration using procedure in the Operation and Installation Manual. This need only be performed once and then only after major modifications and repairs.
2. Verify the system is properly calibrated and has no mechanical binding by placing a calibrated test weight, typically 10% or less of expected loading, near the center of the system. Mark this position for future verifications. Ensure the weight reading increases by the correct amount. Remove the test weight. Ensure the weight reading returns to the previous reading. +/- 0.1% is acceptable for maintenance verification (+/-0.1% is of the full rated capacity of the scale system, not the test weight applied. For example, a 1,000 lb capacity scale would use a verification test weight of +/- 1lb).
3. Step #2 may be performed at any weight within the systems live load capacity. Considerations for the test weight value should include operator ability, environment, physical ability to add or subtract weight safely, and weight handling procedures. Mechanical devices may need to be installed to assist weight installation and removal.
4. Repeat step #2 every X number of weeks, as directed by your Quality Assurance department. Document results on appropriate data sheets.

NOTE: Cyclic tests for correct weight readings should be repeatable to + / - 0.1% of total system load cell capacity on systems with no mechanical interference. Original installation Certification testing should be within +/-0.02% of the full rate capacity. For example, a 1,000 lb capacity scale would require +/- 0.2lb.

Hardy Knowledge Base Answer ID 74 | Published 11/20/2001 05:05 PM | Updated 06/09/2014 05:28 PM

Appendix 1. – Requirement extracted from the ISO 9001 Guidelines for the Control & Monitoring of measurement equipment.

7.6 Control of monitoring and measuring equipment

The organization shall determine the monitoring and measurement to be undertaken and the monitoring and measuring equipment needed to provide evidence of conformity of product to determined requirements.

The organization shall establish processes to ensure that monitoring and measurement can be carried out and are carried out in a manner that is consistent with the monitoring and measurement requirements.

Where necessary to ensure valid results, measuring equipment shall

a) be calibrated or verified, or both, at specified intervals, or prior to use, against measurement standards traceable to international or national measurement standards; where no such standards exist, the basis used for calibration or verification shall be recorded (see 4.2.4);

b) be adjusted or re-adjusted as necessary;

c) have identification in order to determine its calibration status;

d) be safeguarded from adjustments that would invalidate the measurement result;

e) be protected from damage and deterioration during handling, maintenance and storage.

In addition, the organization shall assess and record the validity of the previous measuring results when the equipment is found not to conform to requirements. The organization shall take appropriate action on the equipment and any product affected.

Records of the results of calibration and verification shall be maintained (see 4.2.4).

Appendix 2. – Example Standard Operating Procedures (SOP) extracted from Hardy's own Published ISO 9001 SOP.

7.6 Control of monitoring and measuring equipment

- Hardy uses Anmar Metrology Inc & Flintec to perform equipment calibration services on equipment that is used to base product acceptance throughout the facility.
- This facility is ISO 9001.2008 certified and is compliant to ISO/IEC 17025:2005, ANSI/NCSL Z540.3-2006.

To achieve compliance, the monitor and measurement calibration certificate must bear the following:

- An unambiguous identification of the item calibrated;
- Evidence that the measurements are traceable to international or national measurement standards;
- The method of calibration;
- A statement of compliance with any relevant specification;
- The calibration results;
- The uncertainty of measurement, where necessary;
- The environmental conditions, where relevant;
- The date of calibration;
- The signature of the person under whose authority the certificate was issued;
- The name and address of the issuing organization and the date of issue of the certificate;
- A unique identification of the calibration certificate.

Appendix 3: Certificate of Calibration for 3 Sets of Certified Test Weights used to calibrate Hardy's C2® load cells (pulled from permanent archives kept on file indefinitely).

CALIBRATION REPORT

Division of Metrology
Sri Lanka Standards Institution
No. 17, Victoria Place, Elvitigala Mawatha
Colombo 08, Sri Lanka

ISO/IEC 17025
CL 002-01

Client :
P.O. Box 24, Spur Road 2,
Phase 1, KEPZ, Katunayake.

Unit Under Test (UUT) : **Set of Weights**
Make : HAFNER
Nominal Value(s) : 1 kg , 2 x 2 kg , 5 kg , 10 kg , 2 x 20 kg , 2 x 50 kg
Markings : ---

Date of calibration : 2015-11-18
Method of calibration : Substitution weighing method, DM/M/TM/02 (Rev.5) based on OIML R 111-1:2004

Ambiant conditions (Average)
Temperature : (25.5 ± 3.0) °C
Relative Humidity : (45 ± 5) %
Air Pressure : (1008 ± 5) hPa

Equipment Used

	Model	Manufacturer	Capacity	Resolution
Mass Comparator	AT 1005	Mettler	1100 g	0.00001 g
Electronic Balance	PM 2000	Mettler	2100 g	0.001 g
Mass Comparator	ID 7	Mettler	50 kg	0.000005 g
Electronic Balance	XP 64001 L	Mettler	64 kg	0.1 g

Measurement Traceability : The Measurements are traceable to Swiss Calibration Service(SCS)of Switzerland via following standard(s)

Standard Weight set No.	11117321	B217882177	B217882178	B331621627	15871	15872
Due Date of working standard	2019-03-04	2022-02-27	2022-03-26	2023-06-10	2016-10-17	2016-10-20

This report is issued by Metrology Division of Sri Lanka Standards Institution and shall not be reproduced other than in full, except with the prior written approval from the Director of Metrology Division of SLSI. It applies only to the specific equipment given at the time of calibration

Technical Manager
Mass Laboratory

Director
Director
Division of Metrology
Sri Lanka Standards Institution

Report Number **DM/3111/2015**
Date of Issue 2015-12-16
Page 01 of 02

Tel(Direct)/Fax : (0)94 (0)112674819
E-mail : dm@slsi.lk
Tel(General) : (0)94 (0)112671567-72
Web : www.slsi.lk

Appendix 4. - Certificate of Calibration for High Precision Voltage Meter used to calibrate Hardy's Instruments (pulled from permanent archives kept on file indefinitely).

INSTRUMENTS CALIBRATION DATA SHEET

INSTRUMENT DETAILS

DESCRIPTION :Weights # WL BRM-01 (05)

LOCATION : WELDE

TEST CONDITIONS

TEMPERATURE : 25 °C

HUMIDITY : 60 rH

RESULTS OF CALIBRATION

SE#	ASSET #	CAPACITY (kg/~~lb~~.)	Maximum permissible errors +/- (kg/~~lb~~.)	Capacity Direct conversion to ~~lb~~./kg	Reading with Instrument error of the Mass comparator			Cal. Date	Due. Date	Cal. Done BY
					Standard weight /Target weight (~~lb~~./kg)	Reading Measured (~~lb~~./kg)	Reading Adjusted (~~lb~~./kg)			
A	WKT0006	170.39752	0.00500	-	170.37957	-	170.37995	2014-Oct-18	2017-Oct-18	Wickrama
B		170.39752	0.00500	-	170.37957	-	170.37995	2014-Oct-18	2017-Oct-18	
C		170.39752	0.00500	-	170.37957	-	170.37995	2014-Oct-18	2017-Oct-18	
D		511.19156	0.02500	-	511.13871	-	511.13930	2014-Oct-18	2017-Oct-18	
E		1022.38512	0.05000	-	1022.27743	-	1022.27855	2014-Oct-18	2017-Oct-18	

Remarks: Weights calibrated after paint , Adjusted values within specefication

REFERANCE STANDARD

CALIBRATION STANDARD : Class F1&F2 Standard weights

SERIAL NO. : N/A

CAL. DONE DATE : 2010-Sep-23

CAL.DUE DATE : 2015-Sep-23

APPROAVAL

2014-10-23

DATE

FQA-0002-029 Rev 2

INSTRUMENTS CALIBRATION DATA SHEET

INSTRUMENT DETAILS

DESCRIPTION :Weights WLMR5K-01

LOCATION : WELDE

TEST CONDITIONS

TEMPERATURE : 24.8 °C

HUMIDITY : 58.5 rH

RESULTS OF CALIBRATION

SE#	ASSET #	CAPACITY (kg/lb)	Maximum permissible errors +/- (kg/lb)	Capacity Direct conversion to lb./kg	Reading with Instrument error of the Mass comparator			Cal. Date	Due. Date	Cal. Done BY
					Standard weight /Target weight (lb./kg)	Reading Measured (lb./kg)	Reading Adjusted (lb./kg)			
A	WKT00015	51.11926	0.00250	-	51.11517	-	51.11540	2014-Aug-21	2017-Aug-21	Wickrama
B		51.11926	0.00250	-	51.11517	-	51.11535	2014-Aug-21	2017-Aug-21	Wickrama
C		102.22583	0.00500	-	102.22583	-	102.22610	2014-Aug-21	2017-Aug-21	Wickrama
D		306.67975	0.01000	-	306.67975	-	306.67995	2014-Aug-21	2017-Aug-21	Wickrama

Remarks: weight calibrated After paint.

REFERANCE STANDARD

CALIBRATION STANDARD : Standard weight (kg)

SERIAL NO. : N/A

CAL. DONE DATE : 2010-sep-23

CAL.DUE DATE : 2015-sep-23

APPROAVAL

DATE 2014-08-22

QA-0002-029 Rev 2

Appendix 4. – Certificate of Calibration for High Precision Voltage Meter Used to Calibrate Hardy's Instruments (pulled from permanent archives kept on file indefinitely).

INSTRUMENT CALIBRATION DATA SHEET

Instrument Details

Calibration ID	0275222017		
Description	Weihing Indicators(API)	Model Number	LDU
Category	Weighing Indicators	Location	WELDED
Asset Number	0275	Cal.Frequency	3
Serial Number	00074134	Notif.Frequency	7

Ambient Conditions

Temparature (°C)	24.5	Humidity (%rH)	59

Range/Steps	Requirement	Measured Value				Specification		Pass/Fail	Adjusted Value	Pass/Fail
		Value 1	Value 2	Value 3	Average	Lower Limit	Upper Limit			
mV/V	Zero	0.00000				-0.00050	0.00050	PASS		
	0.00000	0.00000				-0.00002	0.00002	PASS		
	0.60000	0.60000				0.59996	0.60004	PASS		
	1.00000	1.00002				0.99995	1.00005	PASS		
	2.00000	2.00003				1.99990	2.00010	PASS		

Appendix 5. Example of the level of best case accuracy and resolution that can be achieved with this method is shown using a scale with 4 Hardy 110 lb compression load cells and an HI 6600 Instrument.

1	**HARDY PROCESS SOLUTIONS SCALE CALCULATOR:- INPUTS**		
2	**STEP 1: Enter your VESSEL or PLATFORM parameters here:**		
3	lb		What is the Unit of Weight? (enter lb, oz, kg, g, etc.)
4	300	lb	What is the Live Weight? (enter the max weight of material you want the scale to be able to measure)
5	20	lb	What is the Dead Weight? (enter the weight of the empty vessel or platform, include all supported fixtures such as pumps, valves etc.)
6	4	#	How many load bearing points are there? (enter the # of vessel legs, hanging rods/chains or platform support points)
7	**STEP 2: Enter the selected LOAD CELL specifications here:**		
8	SBB06		Which Load Cell model have you selected?
9	110	lb	What is the Rated Capacity of Load Cell?
10	2	mV/V	What is the Rated mV/V value of the Load Cell?
11	0.018	%	What is the Rated Combined Error (takes Non-Linearity, Creep and Hysteresis into account) of the Load Cell? If this spec is not available use the Non-Lineratity spec.
12	**STEP 3: Enter the selected WEIGHING INSTRUMENT/MODULE specifications here:**		
13	6600		Which weighing instrument or module have you selected?
14	5	V	What is the Load Cell excitation voltage?
15	20000	#	What is the RECOMMENDED # of displayed increments for STABLE weight readings?
16	100000	#	What is the MAX possible # of displayed increments for weight measurements?
17	0.15	uV	What is the MINIMUM possible scale microVolt build?
18	110	Hz	What is the Update Rate?

19	**HARDY PROCESS SOLUTIONS SCALE CALCULATOR:- OUTPUTS**								
20	**A)Your SCALE requirements are:**								
21	320	lb	This is the MINIMUM Scale Capacity required						
22	107	lb	This is the MINIMUM Load Cell Capacity required for each Load Cell						
23	4	#	This is the number of Load Cells required						
24	**B)We calculate the SCALE capacity & theorectical performance capabilities using the selecetd load cell and instrument/module as follows:**								
25	440	lb	Scale Capacity: this is the max capacity of the scale based on the load cells selected (dead load + live load + safety margin)						
26	0.04	lb	Scale Accuracy: is better than or equal to +- this number (assuming the scale is fully isolated using flexible couplings and no binding is present)						
27	0.02	lb	Scale Resolution: this is the RECOMMENDED resolution for STABLE weight readings						
28	0.00	lb	Scale Resolution: this SMALLEST possible display resolution for weight measurements(round up/down), expect some fluctuation in the last digit/s of the displayed weigh value						
29	**C)The calculated Scale Build & Weight Update Rate information is:**								
30	68%	%	Is the **ACTUAL percentage of the Load Cell capacity untilized** by this scale build (NOTE: the higher this is the better, as a rule of thumb **>50% is acceptable**)						
31			*Fig 1: The table below illustrates the calculated mV output signal from the load cell system under 4 different load conditions.*						
32			NO load	0.00	mV	0	lb		
33			DEAD load	0.45	mV	20	lb		
34			DEAD + LIVE load	7.27	mV	320	lb		
35			FULL scale capacity	10.00	mV	440	lb		
36	0.50	uV	Is the **ACTUAL scale build in microVolts per increment** at the recommended resolution setting shown above						
37			(NOTE: as a rule of thumb, this number highlighted in RED to the left must be higher than the "minimum" microVolt scale build on line17 above)						
38	9.09	mSecs	Is the **ACTUAL period at which the weight readings will be updated** on the display and at all communications ports						
39			*Fig 2: The table below illustrates the theorectical weight increments we can expect at different material flow rates at the stated instrument/module update rate, for FEED CONTROL purposes.*						
40			At a material feed rate(flow) of	3	lb	per sec	0.027	lb	per update
41			At a material feed rate(flow) of	6	lb	per sec	0.055	lb	per update
42			At a material feed rate(flow) of	9	lb	per sec	0.082	lb	per update
43			At a material feed rate(flow) of	30	lb	per sec	0.273	lb	per update