Introduction

Conventional industrial weighing instruments predominantly use strain gage load cells to generate analog electrical signals which are converted to usable information by dedicated instruments.

The main areas of concern, apart from cost and accurate weighing centre around:

- System calibration
- High dead load to live load ratio
- Force shunts such as pipe work
- Diagnostics and fault finding
- Replacement of components
- Long cable runs

There is no doubt that improvements in the design and sophistication of electronics are helping to address most of these subjects.

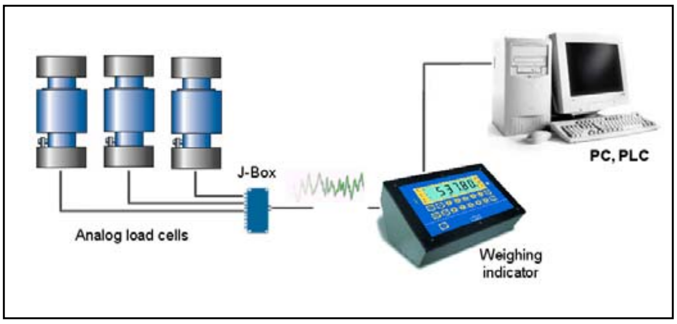
One of the early misconceptions associated with digital load cells was that low cost electronics could be used to transform a low quality load cell into a high precision device. Nothing could be further from the truth. Firstly, in order to achieve adequate internal resolution for a variety of applications, each load cell needs a minimum of a 16 or 17 bit analogue to digital converter (ADC). Secondly, electronics can only be used for highly repeatable results which mandates a basic load cell with a high level of stability and repeatability under a variety of working conditions.

In general, the complexity of digital strain gage load cells varies from a minimum configuration, where an ADC is used to convert fully compensated load cell data to a digital format for re-transmission via a standard interface, to an advanced configuration where extensive software algorithms and additional hardware are used to optimise non-linearity, hysteresis, creep or temperature effects.

System configurations

Conventional configuration

Analog load cells systems



Most conventional weighing systems typically use three or more load cells connected in parallel via a junction box. Each load cell provides an output in the range of 1 to 3 mV/V. The combined output is the arithmetic mean value of the individual load cell outputs.

The measuring device or indicator uses an amplifier, an analog to digital converter (ADC), a microprocessor and software to produce a calibrated reading (in weight units) on the display. More advanced instruments also provide the means to communicate with external devices such as printers, computers…

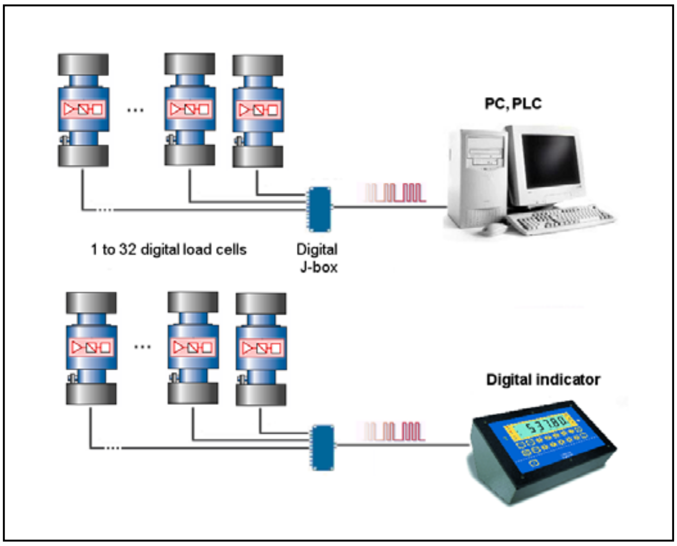
Analog load cells

It is common for analog load cells to be "rationalised", i.e. to have a minimal tolerance on output signal. However, when connected in parallel, each load cell will be loaded with the output impedance of the other load cells in the system. As a result, in order to ensure consistent readings regardless of load placements, the system requires the adjustment of individual load cell outputs. Such adjustments are time-consuming, particularly for high capacity systems or where test load application is difficult (silos, hoppers, etc).

Output signals of multiple load cell systems are based upon the average output of each load cell. Therefore, it is possible for load cell failures to go un-noticed, compromising system integrity and risking product wastage. Once realised, the failure and its cause can often be difficult to identify and requires the use of test loads and additional measuring equipment such as volt- and ohmmeters.

Digital load cells configuration

Digital load cells system



A typical digital system consists of a number of digital load cells connected to a PC or measuring device (indicator).

The most important difference between analog and digital load cell systems is the fact that although connected together, each digital load cell operates as a truly stand alone device. This feature offers large benefits in terms of system set up, corner correction, calibration, diagnostics and overall control.

Digital load cells operate on a "Master/Slave" program control. They are connected via a RS485 interface on a specific protocol.

Within the system, each individual load cell can be identified by its own working address. Address "0" is used as an address which causes all load cells to respond while the serial number may be used to offer a specific address.

There are two primary modes of operation:

- the Master supervises all transmissions by communicating with each of the Slaves (digital load cells) in turn.
- the Master sends out a data request which causes the Slaves to respond in an address sequential order.

The first mode offers an advantage in terms of flexibility, while the second mode offers an advantage in terms of communication speed.

Digital load cells

Digital load cells have internal electronics that convert the analog signal into a digital one.

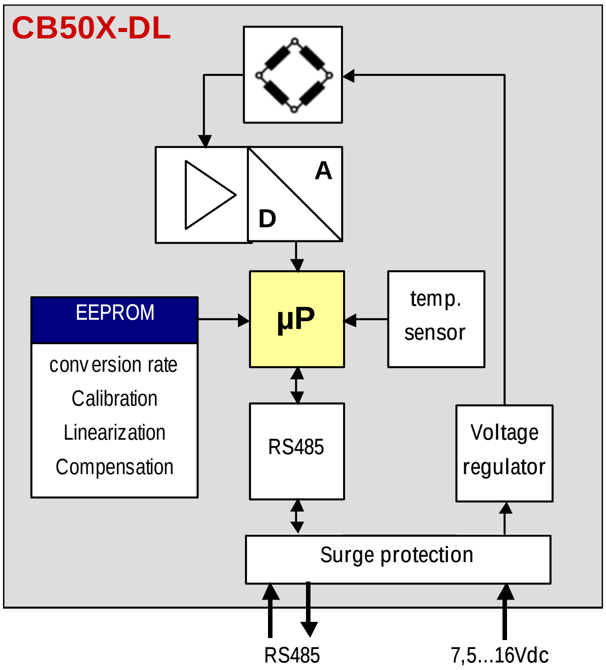
The SCAIME Digital Load cell CB50X-DL is a column compression for capacities from 15 to 50t. This load cell are already in use as conventional load cells and have proven to provide highly repeatable readings under a wide range of adverse loading conditions.

The CB50X-DL has an internal power regulator which converts a supply of 7,5 to 16 Vdc into a continuous square wave bridge excitation voltage. The uncompensated output of the bridge is fed to the input of an integrated circuit that includes an amplifier and a highly advanced **24-bit** Sigma-Delta analog to digital converter with digital filtering. A temperature sensor is used to measure the actual element temperature of the load cell for means of compensation.

The ADC, temperature sensor and digital output interface are controlled by a micro processor, and an integrated circuit has been added to prevent the load cell from being damaged by a variety of surges, such as heavy electrical switching and lightning.

The performance of any load cell depends primarily on the element design and measuring principle which determines parameters like creep, recovery (OIML R60), linearity and hysteresis. For a specific load cell design, these parameters can be further improved by using special gages which are matched to the specific behaviour of the element.

The CB50X-DL offers the possibility to compensate load cells for the above parameters on an individual basis. The result is a load cell with uncompromised performance and stability. In addition to this, it provides a strong digital output signal which is not affected by noise or additional temperature effects.



Environmental protection

Industrial load cells are designed to sense force or weight under a wide range of adverse conditions; they are not only the most essential part of an electronic weighing system, but also the most vulnerable. Typical disturbing factors are, overload, vibration, moisture, corrosion and electrical surges.

Overload

The strength of any conventional load cell is compromised by the requirement to provide 2mV/V output signal.

Digital load cells benefit from the fact that the strain gauge bridge is located in the very close proximity of the instrumentation amplifier. For this reason, the bridge output signal is inherently less affected by noise or temperature effects and lower values are acceptable. In turn, the strain in the element can be less and the load cell provides better overload capabilities.

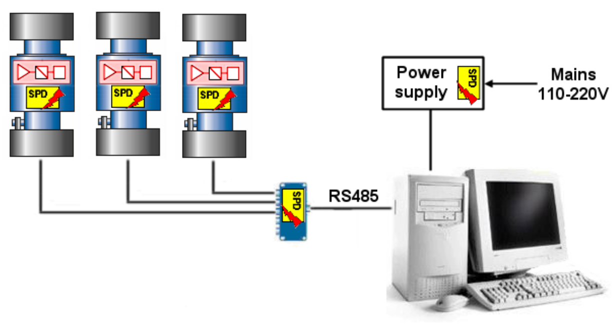
Surge protection

Lightning, or electrical surges is one of the reasons for digital load cell malfunction. Conventional load cells are able to withstand surges up to 500 volts between circuit and housing. Digital load cells are able to withstand similar levels surges, however data stored in the EEPROM may be compromised at voltage levels well below 200 volts.

The possibility of damage because of lightning strikes increases when the individual components of a system are located at a long distance from each other. Hence, load cells require a dedicated surge protection device in the junction box and a second stage protection within the load cell itself.

Surge protection devices (SPD) are designed to control line-line and line-earth voltages to levels acceptable to the equipment. An SPD incorporates combinations of gas-filled discharge tubes for high current diversion and zener diodes for secure voltage clamping with minimal leakage. The principal of an SPD system is based on diverting large currents to a local ground. By doing so, the whole system will rise and fall at the same electrical potential.

It is obvious that a high level of protection can only be established if the complete system is protected. This means that the input side of the measuring device or computer, as well as the mains and any other data link needs the installation of specific SPDs.



CB50X-DL system with a first stage protection in the load cells and a second stage in the junction box (for levels up to 20KV/20KA). A 110/220Vac SPD protects the mains of the load cell power supply computer.

RS485 Interface

RS485 employs a differential method of transmission which in turn means that signals are relatively unaffected by changes in ground potential. Each bus cable has to be a wire pair, preferably twisted and screened to keep induced noise to a minimum. If screened cables are used, it is recommended that the screens are connected to earth at a single point of one device.

The CB50-DL RS485 interface works only In half duplex. In this mode of operation, the same wire pair is used for sequential transmission.

RS485 specifications	
Mode of operation	**Differential**
Number of drivers	**32**
Number of receivers	**32**
Max. cable length	**1200m / 3600ft**
Max. data rate	**10MBd**

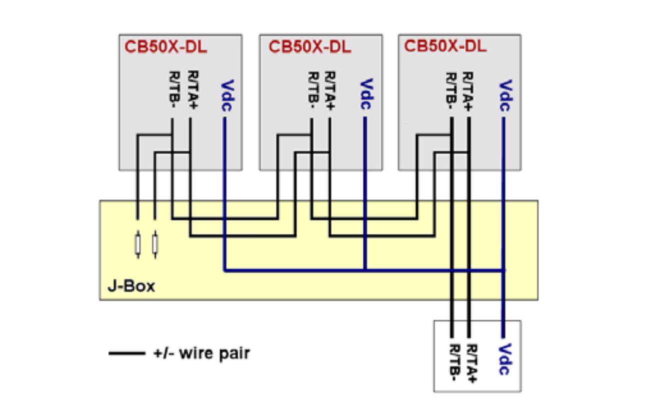
Connections

In a multi-drop environment, the cable should be "looped through" each device. For optimum operation of the RS485 bus, multi-drop or point-to-point communication, it is recommended that termination is applied to the receiver end of the data lines.

The simplest form of termination is line-to-line with typically a 120Ω resistor across the differential input.

In a multi-drop system, the termination resistor is only required at the device receiver located at the far end of the cable. In half duplex operation, then both ends of the bus cable are equipped with receivers (transceivers) so termination is necessary at both ends.

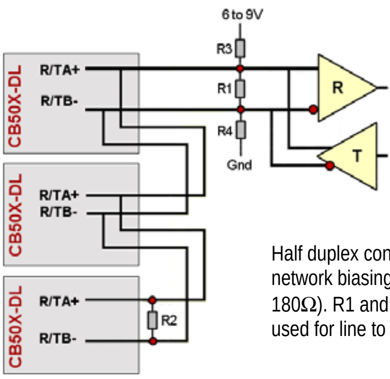
RS485 transmitter circuits are specified as being capable of driving a minimum load resistance of 60Ω, so no more than two terminator resistors should be connected to any one bus.



Network biasing resistors

In some instances, particularly in half duplex RS485 multi-drop operation, noise may be detected at the receiver. In the multi-drop configuration, there can be brief periods when no transmitter is enabled, and the network is therefore allowed to flow. The programmer can overcome this situation by ensuring that the communications protocol flushes the input buffer until the beginning of the message flag is found.

If a problem is encountered and software solutions are not feasible, two extra resistors can be added externally to the transceiver at one end of the bus, so that the network is biased to about 1 volt when all transmitters are disabled.



Half duplex connection with network biasing resistors (R3, R4: 180Ω). R1 and R2 (120Ω) are used for line to line termination.

Software set-up

Initialisation

The first step in most digital load cell systems would be to designate a working address to each unit. This working address will be used later to efficiently communicate with all cells in the system. For the CB50X-DL, address designation is done via its unique serial number, or when just one load cell is connected, via general address "0".

The second step would be to test the functionality of the unit and to exchange data which will be used during operation and calibration.

The CB50X-DL provides a rationalised output of 200,000 counts (ASCII format) at full load. The load cell capacity is stored and can be transferred to the instrument during initialisation.

Balancing and calibration

In order to provide readings which correspond to the actual load input of the system, scale calibration is used to correct the combined load cell output for offset and gain. Most analog weighing systems typically use three or more cells connected in parallel via a junction box. To overcome different outputs from the individual load cells, resistors are added to the junction box to "balance" or corner adjust the system.

A multi-drop, digital load cell system offers discrete information regarding the weight on every cell. This feature facilitates corner correction via the instrument and, assuming the load cell output is rationalised, the possibility to calibrate the system without the use of dead weights.

A digital system based on four CB50X-DL load cells may use the following formulae to calculate the weight on every cell and the combined system output:

$$U_{ci} = (x_i - U_{0i}) * F_{ci} * F_s$$

$$U_{ct} = \sum_{1\text{-}4} U_{ci}$$

Where:
- U_{ci} Calibrated output of CB50X-DL "i"
- x_i Output in counts from CB50X-DL "i"
- U_{0i} Offset for CB50X-DL "i"
- F_{ci} Corner factor for CB50X-DL "i'
- F_s Span factor (the same factor is applicable for all load cells)
- U_{ct} Calibrated output of all CB50X-DL in the system

Before corner correction and calibration starts, all parameters can be given a default value:

$$U_{0i} = 0$$

$$F_{ci} = 1$$

$$F_s = E_{max} / 200{,}000$$

Where:
- E_{max} represents the load cell's rated capacity
- **200,000** represents the rationalised output of every CB50X-DL

The default parameters are used to provide important data during the calibration procedure. The system can be calibrated "automatically" by just performing a dead load or offset calibration. After offset calibration, the default values for U_{0i} are replaced by the actual values.

With the CB50X-DL, it is possible to store in EEPROM and manage the new parameters U_{0i}, F_{ci} and F_s, allowing the CB50X-DL to deliver directly the calibrated output U_{ci}. In that case, the digital indicator (or PC) have only to add the CB50X-DL calibrated outputs to obtain the calibrated output of the all system.

Example

The output of the individual load cells, in a hypothetical system with dead load (tare) and an unknown weight is:

The capacity of each load cell is **30,000kg.**

N° CB50X-DL	Dead load	Unknow weight
1	14501	78095
2	14825	79072
3	15090	79425
4	14323	78678

1 **The pre-calibrated dead load (in kg) on every load cell is:**

- U_{c1} = (14501-0)*1*(30,000/200,000) = 2175
- U_{c2} = (14825-0)*1*(30,000/200,000) = 2224
- U_{c3} = (15090-0)*1*(30,000/200,000) = 2264
- U_{c4} = (14323-0)*1*(30,000/200,000) = 2148

The dead load (in kg) on system is:

- $U_{ct} = U_{c1} + U_{c2} + U_{c3} + U_{c4} = 8811$

2 **The unknown weight (in kg) on every load cell is:**

- U_{c1} = (78095-14501)*1*(30,000/200,000) = 9539
- U_{c2} = (79072-14825)*1*(30,000/200,000) = 9637
- U_{c3} = (79425-15090)*1*(30,000/200,000) = 9650
- U_{c4} = (78678-14323)*1*(30,000/200,000) = 9653

The unknown weight (in kg) on system is:

- $U_{ct} = U_{c1} + U_{c2} + U_{c3} + U_{c4} = 38425$

A weighing system is normally calibrated with the use of test weights. However, for some systems the application of test weights may be not possible.

The digital Load Cell allows the use of an extremely simple procedure to accurately calibrate a system without the use of test weights. It also provides critical information regarding the weight distribution over each cell in the system. Systems with good mechanical integrity can be automatically calibrated to within ±0.05%.

High accuracy systems, or systems with mechanical shunts require the use of test weights to verify actual performance.

Physical corner correction

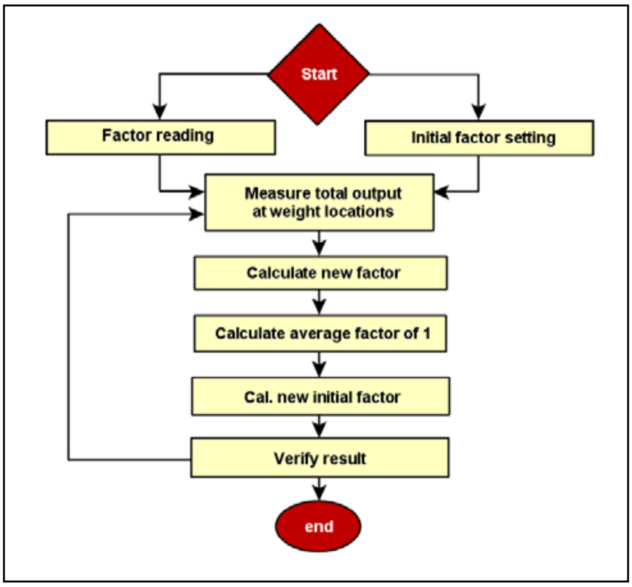
In practical applications it is impossible to measure the output of individual load cells for the purpose of corner correction, as all load cells receive an undefined proportion of the test weight placed on the scale. Therefore, digital corner correction, similar to analog correction, is based on measuring the total scale output when a load is placed at each corner.

The procedure can be carried out for a new scale, where the initial corner factors "F_{ci}" are set to "1".

A test weight should be placed on each corner in turn, and after stabilisation of the weight, the total offset corrected output should be calculated. New factors can be calculated by dividing the total output at the first test weight location by the total output at each test weight location.

These new factors will influence the overall system calibration and therefore they need to be recalculated by dividing them by the arithmetic mean value of all factors.

The corner correction procedure will be completed when the initial factors are upgraded by multiplying them with the newly determined factors.



Example

In a same hypothetical system: For a new application the corner factors are set to "1": **Factor(1) = Factor(2) = Factor(3) = Factor(4) = 1**

1

At each corner test the total output is measured:

- Total output(1) = 10007
- Total output(2) = 10020
- Total output(3) = 10001
- Total output(4) = 10012

2

Calculation of new factors:

- Factor(1) = 10007 / 10007 = 1.0000
- Factor(2) = 10007 / 10020 = 0.9987
- Factor(3) = 10007 / 10001 = 1.0006
- Factor(4) = 10007 / 10012 = 0.9995
- Total = 3.9988
- Mean value = 3.9988 / 4 = 0.9997

3

Recalculation of factors to an arithmetic mean value of "1":

- Factor(1) = 1.0000 / 0.9997 = 1.0003
- Factor(2) = 0.9987 / 0.9997 = 0.9990
- Factor(3) = 1.0006 / 0.9997 = 1.0009
- Factor(4) = 0.9995 / 0.9997 = 0.9998
- Total = 4.0000

4

Calculation of new factors by multiplying the newly factors with the initials

- Factor(1) = 1 * 1.0003 = 1.0003
- Factor(2) = 1 * 0.9990 = 0.9990
- Factor(3) = 1 * 1.0009 = 1.0009
- Factor(4) = 1 * 0.9998 = 0.9998

5

Corner readings with these factors:

- Total output(1) = 10007 * 1.0003 = 10010
- Total output(2) = 10020 * 0.9990 = 10010
- Total output(3) = 10001 * 1.0009 = 10010
- Total output(4) = 10012 * 0.9998 = 10010

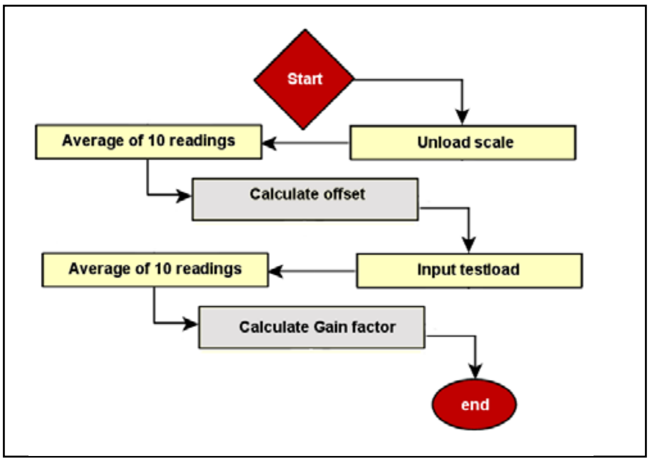
Physical calibration

In order to provide readings which correspond to the actual load input of the system, scale calibration is used to correct the combined corner corrected output of the load cells for offset and gain.

This procedure is based on two series of at least 10 measurements taken consecutively over a short period of time, one series while the scale is un-loaded and one series while the scale is loaded with a known weight. The consecutive measurements are used to calculate stable average readings (per load cell) which in turn are used to calculate an offset value and span/gain factor.

Note:

All factors and offset values are stored in the computer, rather than in the load cell. This allows easy load cell replacement (they all provide the same number of counts at a given load)

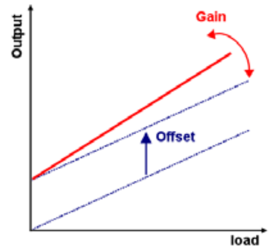


The formulae for calculating the offset values and the span factor are:

$$U_{0i} = x_i$$

$$F_S = L / \sum_{1\text{-}4}(x_i - U_{0i}) * F_{ci}$$

Where "**L**" represents the known weight.



Example

A system employing 4 CB50X-DL with rated capacity 30,000kg.

The corner factors and the average output of the individual load cells, with system dead load (tare) and a weight of 6000 kg, are:

N° CB50X-DL	Dead load	6000kg	Corner factor
1	5125	46707	1,0056
2	5170	47114	0,9969
3	5245	47800	0,9826
4	5078	46279	1,0149

After corner correction and calibration, the weight on every load cell and the combined system output (in kg) can be displayed by:

1

The offset values are:

- U_{01} = 5125
- U_{02} = 5170
- U_{03} = 5245
- U_{04} = 5078

2

The span factor is:

- U_1 = (46707 – 5125)*1,0056 = 41815
- U_2 = (47114 – 5170)*0,9969 = 41815
- U_3 = (47800 – 5245)*0,9826 = 41815
- U_4 = (46279 – 5078)*1,0149 = 41815
- $U_t = U_1 + U_2 + U_3 + U_4$ = 167260
- $F_S = L / U_t$ = 6000/167259 = 0,03587

3

Display output

- $U_{c1} = (X_1$ – 5125)*1,0056*0,003587
- $U_{c2} = (X_1$ – 5170)*0,9969*0,003587
- $U_{c3} = (X_1$ – 5245)*0,9826*0,003587
- $U_{c4} = (X_1$ – 5078)*1,0149*0,003587
- $U_{ct} = U_{c1} + U_{c2} + U_{c3} + U_{c4}$

Diagnostics

Conventional load cell systems provide an output which is based upon the arithmetic average of the individual load cell outputs. As a direct result, diagnostics on such a system are difficult and time consuming. In addition to this, load cell failure may go unnoticed, potentially compromising system integrity and batch quality.

Digital load cells, although connected together, are in essence stand-alone devices which can be approached individually. Because of this feature, an extensive diagnostics structure can be programmed within the system. Diagnostics can be divided into internal (load cell) diagnostics, and external (system) diagnostics.

Internal diagnostics

An internal or load cell diagnostics structure offers the possibility to verify the integrity of individual load cell components. This structure is not only beneficial for the load cell manufacturer and user, but may also be required by Weights and Measures Authorities.

The CB50X-DL verifies the integrity and operation of the following components:

- Strain gage bridge circuit
- Power supply
- EEprom
- ADC
- Temperature sensor

External diagnostics

External or system diagnostics are mainly based on comparing individual load cell outputs to certain system parameters. For example, a vessel with a liquid content should have, within certain tolerances, an even weight distribution over the individual cells. Sudden deviations from the normal weight distribution may indicate a faulty load cell or a force shunt in the system.

An even more sophisticated system will use historic statistical data to predict, based on the output of all other load cells in the system, the output of a load cell. This system can be used to continue operation (although with less accuracy) when one of the load cells is damaged and needs to be replaced.
Other external diagnostics are:

- Check for rapid weight changes
- Check for correct reply on communication port
- Check for excessive ambient temperatures

Digital systems can also be monitored and maintained over a long distance by the use of computer modems or internet.

SCAIME

SUMMARY

Digital load cells offer distinct benefits for the user in terms of providing a strong output signal (cable lengths up to 1200m may be used), flexibility, system control (easy fault finding and diagnostics), ease of installation, corner correction by software, automatic calibration, load cell replacement (without the need to re-calibrate the system - depending on local W&M requirements),etc.

Digital load cells can also be compensated individually for parameters such as linearity. As such high accuracy versions are more feasible, and the costs in achieving these high levels can be minimised. The key features of a Digital Load Cell system can be summarised as follows:

Feature	Benefit
Digital Output	Strong output signal, unaffected by electrical noise or temperature fluctuations on the extension cable.
	Cable runs of up to 1200m
	The digital output signal may be processed directly by a PC or PLC
Stand alone device	Allows extensive diagnostics structure
	Ensures optimum system integrity by facilitating a constant verification of critical components
	Corner balancing can be done via the instrument. The correction of one load cell can be made independently from the others. Hence, no additional hardware is required while time is saved.
Rationalised output in counts	Low and medium accuracy systems can be automatically calibrated without the need for dead weights
	Load cell replacement without the need for re-calibration is possible
Standardised bus-system	Standard RS485/232 equipment can be used
	Multiple systems may be connected to one control system (usually PC or PLC), thus simplifying overall system design and reducing additional hardware
Simple and non proprietary protocol	Software can be developed by a third party
	Software can be developed by companies with in-house medium level programming skills

Digital Load Cells may be ideal for use in the following applications:

Weighbridges

Overall cost savings can be achieved by connecting the load cells directly to a computer or special display. The corner correction and calibration procedures can be completed in a shorter period of time, while load cell replacement can be done without the need to re-calibrate the system (depending on local W&M requirements). The system can be controlled and maintained by computer modem.

Systems which are difficult to calibrate

Most high capacity systems are difficult to calibrate as weights can't be applied easily. The digital Load Cell is in essence a fully calibrated weighing system by itself, and when correct load introduction methods are used calibration can be done automatically.

High accuracy systems

Systems often require high accuracy load cells to determine the weight of very expensive components. High accuracy (and high resolution - 200,000 counts) allow operation with smaller tolerances.

Systems with a high dead load to live load ratio

The digital Load Cell offers strong digital signals, even at very low utilisation rates. The amplifier and ADC are located close to the strain gage bridge which minimises interference. The CB50X-DL operates with 8 million counts internally and provides an extremely stable output of 200,000 counts.

Systems which require close monitoring

Conventional weighing systems may continue to operate even at individual load cell failure, thus compromising system integrity. The digital Load Cell offers an extensive diagnostics structure to avoid these situations.

Whatever advances are made in electronics, overall system accuracy will still depend heavily on the mechanical integrity of the system. Of equal importance, the user must select the correct load cell for his application in terms of design, performance and environmental compatibility.