SMART LOAD CELL SYSTEMS

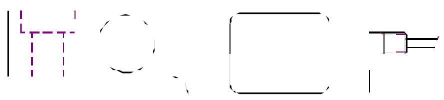
Conventional industrial weighing instruments predominantly use strain gage load cells to generate analog electrical signals which are converted to usable information by dedicated instruments.
Such low level signals can easily be affected by electro-magnetic interference (RF transmissions, heavy power switching, etc) and cable resistance changes caused by temperature fluctuations. System accuracy and integrity is therefore optimised by minimising the distance between load cell and measuring device.
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.

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

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

There is no doubt that improvements in the design and sophistication of electronics are helping to address most of these subjects. However, limits are reached where advances in technology have focussed on the load cell itself and complementary electronics.

Since the late 1970s load cell manufacturers have investigated the possibilities offered by combining modern electronics with the basic load measuring element.
The use of modern electronics has also accelerated the development of alternative, so called, “active” measuring principles such as the vibrating wire, electro-magnetic compensation, etc. Load cells which are based on this technology are used successfully in single cell, high accuracy applications (>10000d).
The most common type of transducer used in industrial weighing today is the strain gage load cell. Load cells based on this type of technology utilise a Wheatstone bridge of four, or a multiple of four, strain gages which are bonded to a sensing or measuring element.
Perhaps one of the main advantages of this technology is the fact that, within certain parameters and depending on the design which has been used (shear, bending, compression, etc.), the sensing element may have many different sizes and shapes. This feature offers the user flexibility as well as a potential commercial advantage.
The manufacture of load cells requires a considerable amount of "hand building" together with significant testing and compensation to achieve acceptable performance. Such compensation can at best be only a first order correction (straight line fit) and the idea of using electronics to carry out more sophisticated correction routines is very attractive.
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 convertor (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 or "smart" configuration where extensive software algorithms and additional hardware are used to optimise non-linearity, hysteresis, creep, temperature effects, etc.
Electronic modules may be stored in the load cell, the load cell cable or in a smart junction box and critical load cell characteristics are stored in EEproms which are fitted within the module.
Fig.1: The Revere Transducers Smart Beam Cell.



1 SYSTEM CONFIGURATIONS

1.1 CONVENTIONAL 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 convertor (ADC), a micro-processor 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, etc.

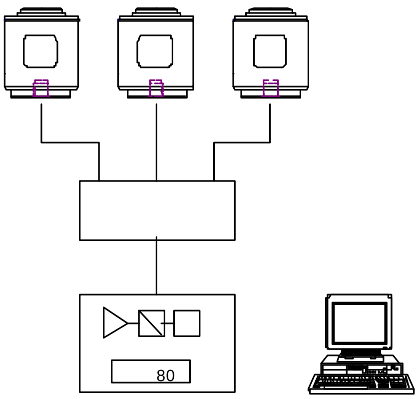


Fig.2: Typical conventional weighing system

1.2 DIGITAL LOAD CELL SYSTEMS

A typical digital system consists of a number of digital load cells connected to a PC, PLC or dedicated measuring device (indicator).
Within the system, each individual load cell can be identified by its own specific working address. A working address can be programmed by the user via one or more addresses allocated by the manufacturer. Usually address "0" (zero) is used as an address which causes all load cells to respond while the load cell's serial number may be used to offer a specific address.
Digital load cells operate on a "Master/Slave" program control, which designates one device (usually the computer or indicator) on the network as Master. There are two primary modes of operation: the Master supervises all transmissions by communicating with each of the Slaves (digital load cells) in turn, or the Master sends out a data request which causes the Slaves to respond in an address sequential order. The first mode of operation offers an advantage in terms of flexibility and error handling, while the second mode of operation offers an advantage in terms of communication speed.
Most digital load cells are connected via a standard RS485 or RS422 interface. Both interface types have similar characteristics and provide a multi-drop environment. The communication with each connected device is based on a protocol designed by the load cell manufacturer.

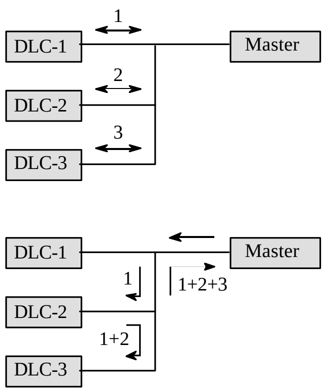


Fig.3 Primary modes of operation

Perhaps 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 (via the instrument), calibration, diagnostics and overall control.
In order to offer this feature each load cell must have its own set of electronics which may be located in the load cell junction box, the load cell cable or in the system junction box.

1.2.1 Digital junction box

Conventional load cells may be connected to electronics which are located within a junction box. Typically, the output from each load cell can be individually sampled and converted to digital format. If one ADC is used then the load cells in a system must be scanned sequentially. If one ADC per load cell is used then it is possible to sample the load cells simultaneously. The junction box is then connected to a host controller via a standard interface.
Basic load cell information (such as serial number, capacity, rated output, zero balance, etc.) can be entered into the host controller via a key pad.

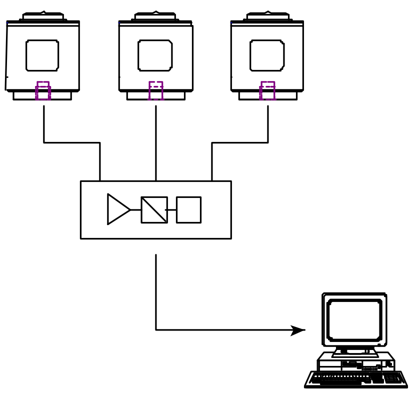


Fig.4: Digital junction box.

A digital junction box offers the main advantages of a digital system and, in addition, flexibility to the system designer, as it facilitates the connection of any standard conventional load cell. The disadvantages of the system are that a considerable amount of information needs to be entered into the main controller, the load cell signal is still affected by interference and temperature effects on the cable and that no cost reduction for the load cell is achieved. In addition to this, the system will be more vulnerable as the electronics are located in the field (subjected to adverse environmental conditions) while relatively easy access for load cell connection is required.

1.2.2 Digital cable box

Instead of building electronics into the junction box, they may also reside in a small box which is built into the cable near the load cell. Critical load cell characteristics, generated during the manufacturing process will be stored in EEPROMs which are fitted within the module. In general, its ingress protection will be considerably better than that of a digital junction box as field access is not required. However, the electronics may be easily damaged during installation and operation of the system.

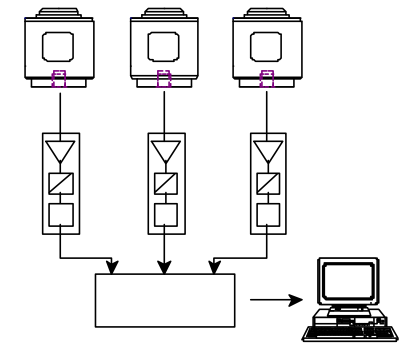


Fig.5: Electronics built in the load cell cable

1.2.3 Digital load cells

Digital load cells have internal electronics that convert the analog signal into a digital one. The cell has an internal power regulator which provides a stabilised voltage to the strain gage bridge. The uncompensated output of the Wheatstone bridge needs further compensation to provide a temperature independent and calibrated output signal. Compensation might be done by means of software algorithms, by the use of analog components, or by a combination of both.

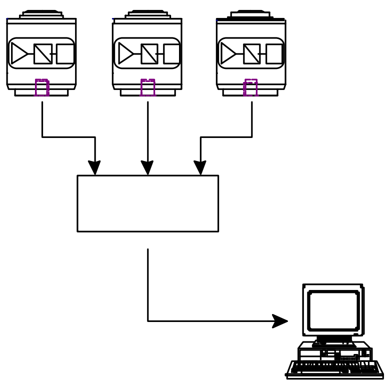
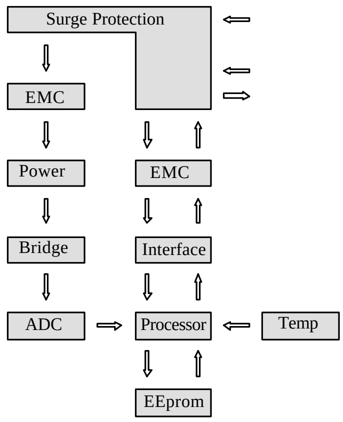


Fig.6: Digital load cell system

The Revere Transducers Smart Load Cell (SLC) is based on two sensing element configurations; a shear beam measuring principle for capacities from 500 to 10000kg and a multiple column compression measuring principle for capacities from 10 to 100t. Both configurations 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 Smart Load Cell (SLC) has an internal power regulator which converts a supply of 12 to 17 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 instrumentation amplifier, a demodulator and a highly advanced 20-bit Sigma-Delta analog to digital convertor 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, while the incumbent software has routines for additional filtering, compensation algorithms and communication.
The input and output lines are filtered to reduce noise to values acceptable for the European EMC directive and the EN45.501 standard. In addition to this a second integrated circuit has been added to prevent the load cell from being damaged by a variety of surges, such as heavy electrical switching, lightning, etc. Both load cell types are hermetically sealed to provide optimum protection against moisture ingress.

Fig.7: Block diagram of SLC



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 SLC 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.

2 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 placed out in the field, also the most vulnerable. Typical disturbing factors are, overload, vibration, moisture, corrosion and electrical surges.

2.1 OVERLOAD

The strength of any conventional load cell is compromised by the requirement to provide an acceptable output signal. The most commonly used type of strain gauge is made of constantan and requires a certain strain in the element to provide a rationalised bridge output of 2 or 3 mV/V.
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.
The above mentioned principle may also be used to manufacture a type of load cell where the rated capacity can be selected by means of software. This feature offers distinctive advantages for service companies in terms of stock and logistics.

2.2 VIBRATION

Component weight plays an important role in the resistance against vibration. As such, and to reduce the overall size of the digital printed circuit board, all components should be of SMD type. In addition to this, SM components require the use of fully automatic "pick and place" machines, which guarantee the integrity of the solder connections. The printed circuit board should be fully encapsulated to enhance its resistivity against vibration and to provide additional protection against (condensing) moisture.

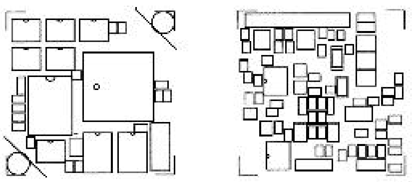


Fig. 8: The SLC multi-layer printed circuit board with dimensions of approx. 44x44mm (1.8 by 1.8 inch)

2.3 SURGE PROTECTION

Lightning, or electrical surges in general have been identified as one of the main possible reasons for digital load cell malfunction. Conventional load cells are able to withstand surges up to 500 volts between circuit and housing. Tests have shown that digital load cells are able to withstand surges of at least similar levels, however critical 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 considerable distance from each other. Hence, low and medium capacity load cells could be adequately protected with a dedicated surge protection device in the junction box, while high capacity load cells require a second stage protection within the load cell itself.
Surge protection devices provide so called internal protection. They 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. For AC applications, varistors are often used because of their higher power absorption capability. Most SPDs are connected in series, similar to shunt diode barriers for intrinsically safe systems. 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.

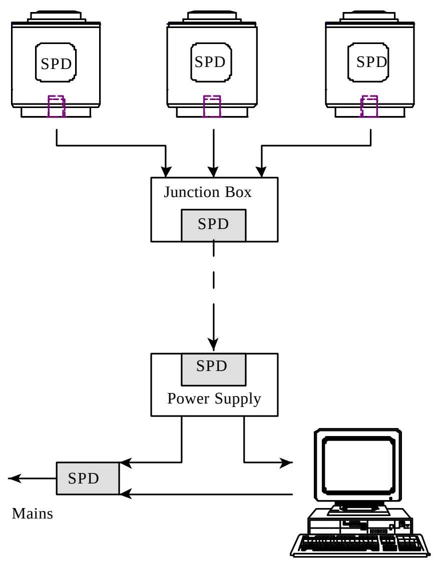


Fig. 9: A fully protected SLC-CSP system with a dedicated first stage protection in the load cells (for levels up to 4KV and 2KA) and a second stage protection in the junction box and power supply (for levels up to 20KV and 10KA). A standard 110/220 Vac SPD protects the mains of the load cell power supply and the computer.

2.4 MOISTURE AND CORROSION

Digital load cells need similar protection against moisture and corrosion as conventional load cells. The critical cable entry needs particular attention and requires a cable gland in conjunction with a water-block or glass-to-metal barrier to prevent moisture from penetrating the cell through the centre of the cable itself.
Because of its resistance against corrosion and its suitability for varies industries, in particular food and chemical, stainless steel load cells are preferred. They can also be weld-sealed and the use of potting material which deteriorates in time can be avoided.

3 THE 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.
The bus cable is effectively a transmission line, and appropriate techniques should be used for installation of the cables. If screened cables are used, it is recommended that the screens are connected to earth at a single point of one device. The voltage between the earth connection of the various devices must not cause the common mode voltage rating of any device on the bus to be exceeded. The table below summarises the principal RS485 and RS232 parameters:

EIA Standard	RS232	RS485
Mode of operation	Single ended	Differential
Number of drivers and receivers	1 Driver 1 Receiver	32 Drivers 32 Receivers
Max. cable length	15m / 50ft	1200m / 3600ft
Max. data rate	20kBd	10MBd
Max. common mode	N/A	+12, -7V
Driver voltage	± 5 → ± 15V	± 1.5V min.
Driver load	3 → 7kΩ	60Ω min.
Driver output short circuit limit	500mA to Vcc or Gnd	150mA to Gnd 250mA to Vcc
Receiver sensitivity	± 3V	± 200mV
Receiver input resistance	3 → 7kΩ	12kΩ
Receiver hysteresis	1.15V	50mV

RS485 offers two primary modes of operation: In full duplex operation, the serial RS485 signals are transmitted on a wire pair Tx+ and Tx-, and the incoming signals are received on a second wire pair Rx+ and Rx-. In half duplex operation, the same wire pair is used for transmission and reception. Full duplex facilitates simultaneous transmission and reception over the two independent wire pairs, while half duplex only allows sequential transmission or reception over a single wire pair.

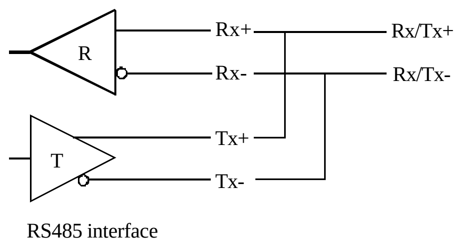
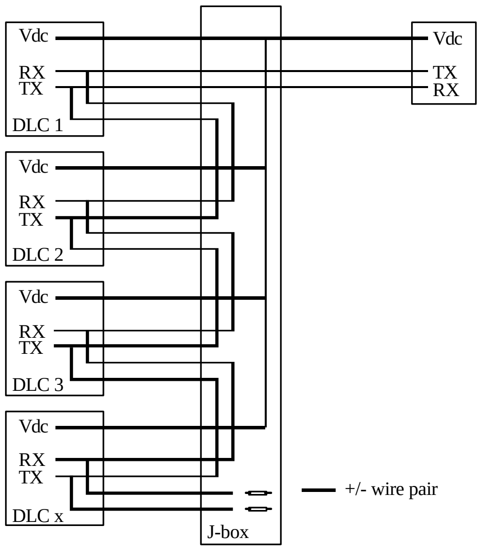


Fig.10: Full and half duplex configuration.

3.1 CONNECTIONS AND BUS TERMINATION

In a multi-drop environment, the cable should be "looped through" each device, or if a spur is necessary, its length should be kept to a minimum.



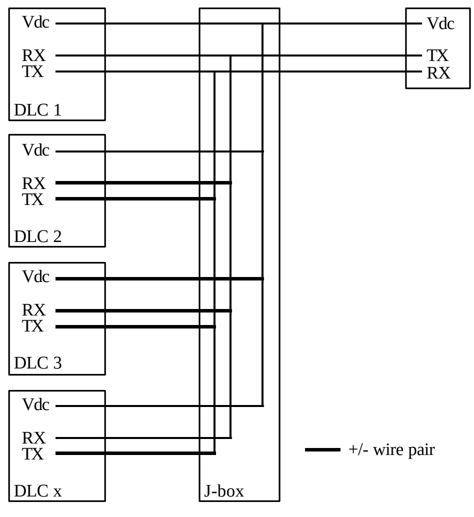


Fig.11: Multi-drop “Looped through” connection.

Fig.12: Multi-drop “spur” connection.

For optimum operation of the RS485 bus in full or half duplex, 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 120S 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. If this is in half duplex operation, then both ends of the bus cable are equipped with receivers (transceivers) so termination is necessary at both ends (the computer or indicator and the digital load cell at the far end of the cable).
RS485 transmitter circuits are specified as being capable of driving a minimum load resistance of 60S, so no more than two terminator resistors should be connected to any one bus!
Digital load cells with cable lengths of 5m/15ft and a full duplex mode of operation should have a shielded five times twisted pair cable, whereby the communication lines are "looped through" the device. Low and medium capacity load cells, with cable lengths below 5m/15ft could be connected in a spur or star connection. The number of wires can be reduced to six (three times twisted pair).

3.2 NETWORK BIASSING 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 biassed to about 1 volt when all transmitters are disabled. This arrangement is shown in figure 13:

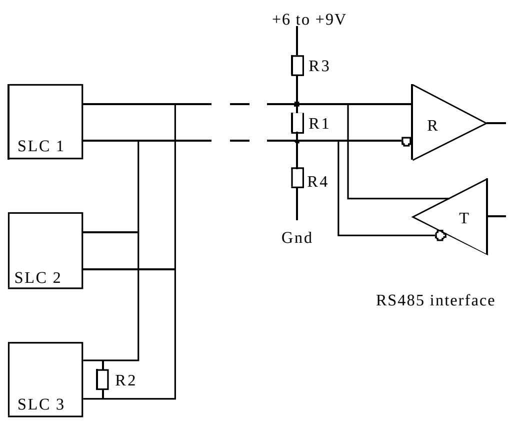


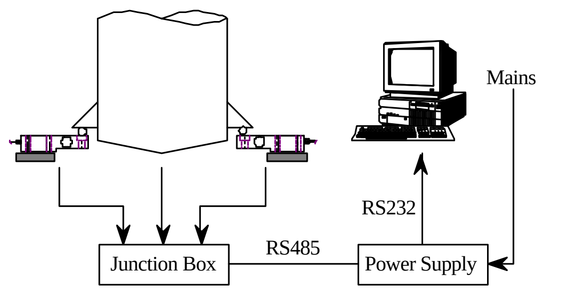
Fig.13: Half duplex connection with network biasing resistors (R3 and R4: 180S). R1 and R2 (120S) are used for line-to-line termination.

4 SMART LOAD CELL SYSTEMS

A range of Smart Load Cell accessories is available which allow various systems to be built meeting the users requirements. Five examples of typical system layouts are shown below.

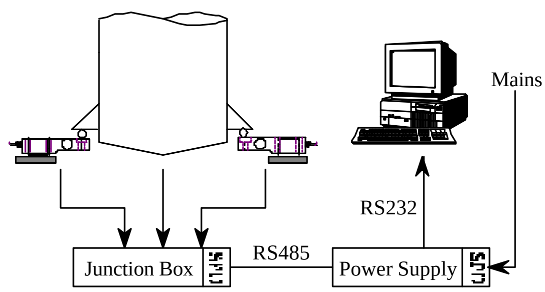
4.1 SLC SYSTEM 1

The SLC provides an output via an RS485 interface. Multiple load cells are connected in parallel or in a “looped through” configuration. Both configurations are available in the Revere Transducers junction box for 4 SLCs. An eight load cell junction box is available to offer parallel connection for 5 to 8 SLCs. A dedicated power supply is available to provide a reliable excitation voltage to the cells. The power supply also features an RS485 to RS232 convertor for a direct connection to standard PCs or SLCS.
The system offers auto-calibration (without the use of test weights), electronic corner correction via the PC or PLC and extensive diagnostics.



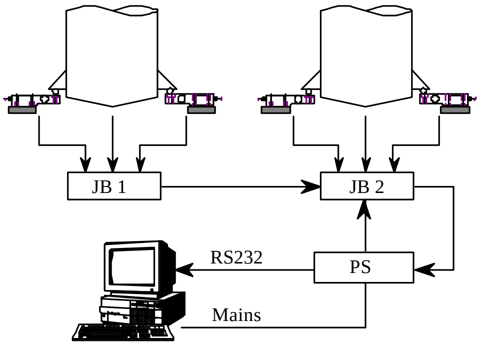
4.2 SLC SYSTEM 2

Dedicated surge protection devices are available to protect the load cells and host computer against the harmful effects of surges and over voltages. The surge protection devices can be mounted in the junction box and power supply; they don’t require separate enclosures.



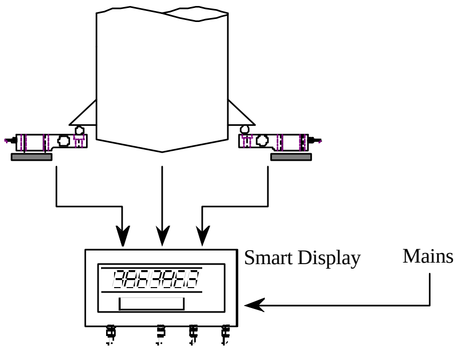
4.3 SLC SYSTEM 3

Within a Smart Load Cell system, each cell can be approached individually via a user defined address. Multiple systems may therefore be connected to one control unit, simplifying wiring and reducing overall costs. The control unit (PLC or PC) may control up to 32 Smart Load Cells.



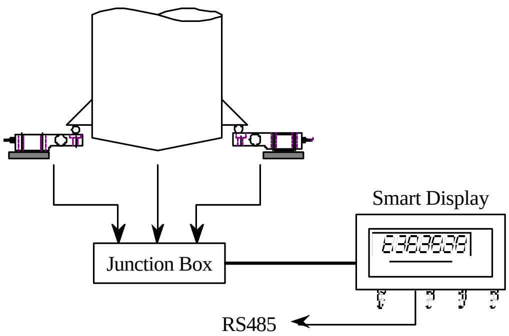
4.4 SLC SYSTEM 4

A dedicated “Smart” Display is available to interface directly with the Smart Load Cells. Connections can be made in the Display or via a junction box, depending on the conditions of use. The Smart Load cell Display, or SLD, features advanced weighing functions (electronic corner correction, calibration auto-calibration, auto- and manual tare, batching, counting, etc) and offers several I/O functions. The unit is Weights and Measures approved to 10,000 divisions, has a stainless steel housing and is suitable for a power supply of 220Vac, 110Vac or 24Vdc.



4.5 SLC SYSTEM 5

The Smart Load cell Display may be connected as a stand alone device or in a multi-drop system. Each unit can be programmed to have its own address and is able to interface with standardised bus systems (Profibus or Modbus).



4.6 COMPUTER VERSUS INDICATOR

The Smart Load Cell, as with many other digital cells or digital configurations, provides an output via a standard data interface. Although this feature allows direct communication to a PC or PLC, careful considerations should be made before a dedicated measuring instrument is taken out of the system. These considerations are:

■ Reliability
A high quality weighing instrument provides a reliability which is much better than that of a standard PC. This is certainly applicable for the power supply which provides better protection against transients and short time power reductions. A weighing instrument is an industrial device, a standard computer is not!

■ Weights and Measures requirements
Weights and Measures regulations require that critical calibration data can not be altered by the operator or system owner. Protection is usually established by a hardware seal (stickers, etc.) or by a software code. The general acceptance for a code on standard PC software is still relatively low. Acceptance varies from country to country.

■ Continued operation
The use of a dedicated weighing instrument allows continued operation at PC or network failure.

■ Local display for calibration and diagnostics
For process weighing applications, where there is a considerable distance between the system and the control room, an instrument which is mounted in the close proximity of the system will be essential for efficient calibration. The unit can also be used for process monitoring and diagnostics.

■ Protocol / standardised bus systems
Most digital load cells operate on a fairly low level of communication or relatively simple protocol. High communication levels such as the standardised Profibus and Modbus are not only much more complex in terms of software, they also require faster processors and more memory.
From a cost, as well as a technical point of view, the preferred solution is to have a relatively simple protocol between load cells and instrument, while a standardised more complex protocol is used between the instrument and its environment.

■ Operator interface
A weighing instrument provides an operator interface which is specially designed for the functions which are offered. Its operation (usually not its configuration or set up) is more dedicated and robust than a computer keyboard.

5 "SMART" SYSTEM SET-UP

5.1 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 SLC, 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. Systems which are based on a digital junction box as described in 1.2.1 will require the entry of parameters such as load cell capacity and rated output. Load cells which have built-in electronics, usually have this information stored in the EEPROM.

The SLC provides a rationalised output of 240,000 counts (ASCII format) at full load. The load cell capacity is stored and can be transferred to the instrument during initialisation. A number of tests confirm the functionality of all critical components in the unit (strain gage bridge, power supply, ADC and EEPROM).

5.2 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 which is based on four SLC type load cells may use the following formulae to calculate the weight on every cell and the combined system output:

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

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

where:

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

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

$U_{0i} = 0$
$F_{ci} = 1$
$F_s = E_{max} / 240,000$

where E_{max} represents the load cell's rated capacity (240,000 represents the rationalised output of every SLC).

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.

Example:

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

SLC #	Dead Load	Unknown Weight
1	14501	78095
2	14825	79072
3	15090	79425
4	14323	78678

The capacity of each load cell is 500 kg. The pre-calibrated dead load or tare of the construction (in kg) on every load cell and the system is:

$U_{c1} = (14501-0)*1*(500/240,000) = 30.21$
$U_{c2} = (14825-0)*1*(500/240,000) = 30.89$
$U_{c3} = (15090-0)*1*(500/240,000) = 31.44$
$U_{c4} = (14323-0)*1*(500/240,000) = 29.84$
$U_{ct} = U_{c1} + U_{c2} + U_{c3} + U_{c4} = 122.38$

The unknown weight (in kg) is:

$U_{c1} = (78095-14501)*1*(500/240,000) = 132.49$
$U_{c2} = (79072-14825)*1*(500/240,000) = 133.85$
$U_{c3} = (79425-15090)*1*(500/240,000) = 134.05$
$U_{c4} = (78678-14323)*1*(500/240,000) = 134.05$
$U_{ct} = U_{c1} + U_{c2} + U_{c3} + U_{c4} = 534.44$

A weighing system is normally calibrated with the use of test weights. However, for some systems (in particular high capacity process weighing systems) the application of test weights may be cumbersome or even not possible at all. The Smart 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%.

The commissioning and calibration of a weighing system is a vital step in ensuring optimum performance from that system. There are a number of recognised ways to effect such calibration, dependent on the design of the system and the precision required. In simple terms, systems calibration is a procedure to correlate instrument output with the actual load input of the system.
The corner correction and calibration procedure of a Smart Load Cell system is in essence similar to that followed for analog systems.

5.3 CORNER CORRECTION

In practical applications it is impossible to measure or to consider 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" or to upgrade the performance of an existing scale where the corner correction factors have already been determined.
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 as given in chapter 52. 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.

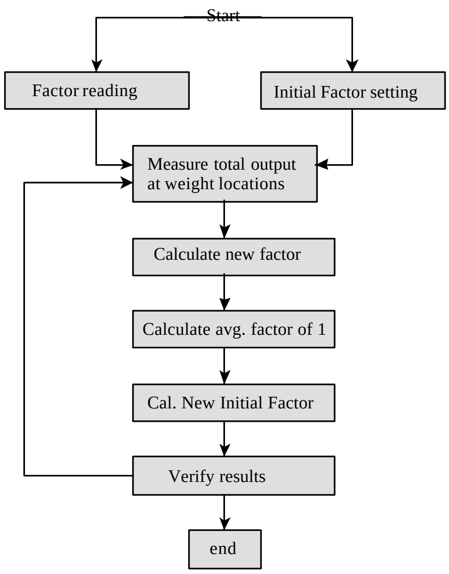


Fig.19: Flow chart of corner correction procedure.

For example: (in our hypothetical system)

- For a new application the corner factors are set to "1":

Factor(1) = 1
Factor(2) = 1
Factor(3) = 1
Factor(4) = 1

- At each test location the total output is measured:

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

- 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

- 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

- Calculation of new factors by multiplying the newly determent factors with the initial factors:

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

- 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

Notes:

- As with analog load cell scales, it may be necessary to perform a second run before optimum performance is achieved. This depends on parameters such as the initial corner error and the distance between the load cells (a shorter distance results in a higher proportion of the weight being distributed over the other cells in the system).

- During the corner correction procedure, the system output may be displayed by using a default span factor (load cell capacity divided by 240,000).

5.4 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.

For systems with good mechanical integrity, calibration can be carried out automatically, without the need for test weights. High accuracy systems, or systems with considerable force shunts (i.e. pipe connections, etc.) require the use of test weights to verify actual performance.

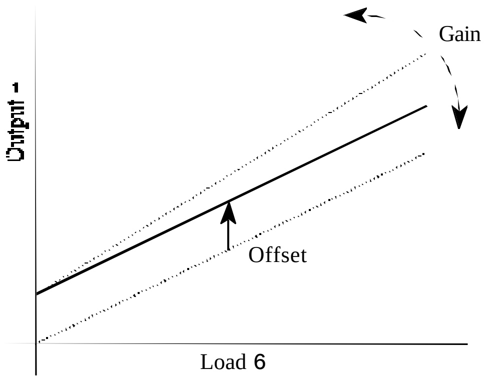


Fig.20: Offset and gain.

This procedure is based on two series of at least ten 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 gain factor.

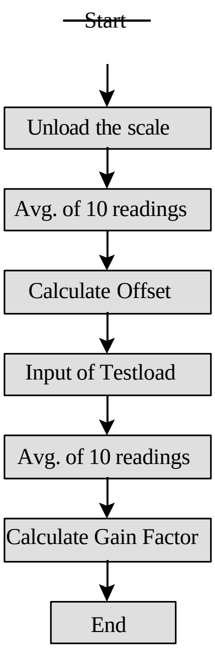


Fig.21: Scale calibration procedure

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

$$\mathbf{U_{0i} = x_i}$$

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

Where "L" represents the known weight.

For example: (in our hypothetical system)

The corner factors and the average output of the individual load cells, with system dead load (tare) and a weight of 1000 kg, are:

SLC #	Dead Load	1000kg	F_{ci}
1	14250	234285	1.0003
2	14564	237216	0.9990
3	15297	238275	1.0009
4	14123	236034	0.9998

The offset values U_{0i} are:

$U_{01} = 14250$
$U_{01} = 14564$
$U_{01} = 15297$
$U_{01} = 14123$

The gain factor F_s is:

$U_1 = (234285-14250)*1.0003 = 220101$
$U_2 = (237216-14564)*0.9990 = 222429$
$U_3 = (238275-15297)*1.0009 = 223179$
$U_4 = (236034-14123)*0.9998 = 221867$
$U_t = U_1 + U_2 + U_3 + U_4 = 887576$

$F_s = L / U_t = 1000 / 887576 = 0.0011267$

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

$\mathbf{U_{c1} = (x_1\text{-}14250) * 1.0003 * 0.0011267}$
$\mathbf{U_{c2} = (x_2\text{-}14564) * 0.9990 * 0.0011267}$
$\mathbf{U_{c3} = (x_3\text{-}15297) * 1.0009 * 0.0011267}$
$\mathbf{U_{c4} = (x_4\text{-}14123) * 0.9998 * 0.0011267}$
$\mathbf{U_{ct} = U_{c1} + U_{c2} + U_{c3} + U_{c4}}$

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) and avoids local Weights and Measures conflicts (Additional password protection is required when system parameters are stored in the load cells).

6 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.

6.1 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 SLC load cell provides an extensive structure which verifies the integrity and operation of the following components:

- Strain gage bridge circuit
- Power supply - external/internal
- EEprom
- ADC
- Temperature sensor

6.2 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.
The same system can be used to determine the exact time of load cell malfunction which may help to understand the reason for damage. It also allows individual load cell overloads to be detected.
Other external diagnostics are:

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

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

7 SUMMARY

The industrial weighing industry predominantly uses analog strain gage load cells. The technology associated with these systems is well known. In addition, analog devices are more or less standardised, especially in terms of output, which allows easy interfacing between the various components in the system.
The first commercial load cells with on-board electronics were developed by companies that have the advantage of being both a load cell and scale manufacturer, thus "controlling" the complete environment in terms of load cells, electronics and mechanics. Advantages were gained in both manufacture and in-field service.
Digital load cells, or "digital load cell" configurations (e.g. the digital junction box) made by independent load cell manufacturers are becoming more available to the market. They offer distinct benefits (in varying degrees) 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. Smart load cells can also be compensated individually for parameters such as creep and 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 Smart 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
	Connector on load cell feasible ease of load cell replacement
	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 RS485/422/232 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, non-proprietary protocol. Drivers available	Software can be developed by a third party
	Software can be developed by companies with in-house medium level programming skills
Complementary hardware available	The “Smart” digital technology can be applied easily, without the need for customer designed hardware

Smart 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 (SLD). 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 Smart 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

Batching systems often require high accuracy load cells to determine the weight of very expensive micro-components (i.e. vitamins in animal food mixtures). High accuracy (and high resolution - 240,000 counts) allow operation with smaller tolerances, while batch quality can still be guaranteed.

- Systems with a high dead load to live load ratio

The Smart 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 SLC operates with 1 million counts internally and provides an extremely stable output of 240,000 counts.

- Systems which require close monitoring

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

Digital load cell technology is relatively new which inherently means that protocol standards have not yet been developed. In addition, specific devices such as junction boxes and power supplies are required. The Revere Transducers Smart Load Cell concept includes a complete range of dedicated complementary hardware and software such as junction boxes (for 4 and 8 load cell systems), power supply with RS485 to RS232 convertor, lightning protection devices and a Smart Load Cell Display.
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.

For more information, application notes and load cell instructions for use, please contact:

Revere Transducers Europe
Ramshoorn 7
P.O. Box 6909
4802 HX, Breda
The Netherlands
Tel.: (+31) 76 54 80 700
Fax.: (+31) 76 54 12 854

Revere Transducers Inc.
14192 Franklin Avenue
Tustin, CA 92780-7016
U.S.A.
Tel.: (+1) 714 731 1234
Fax.: (+1) 714 731 2019
Http://www.reveretransducers.com