FORCE MEASUREMENT

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The aim is to provide a short historical background on force measurement and description of the analogue and digital strain gauge load cell sensors used for the measurement of force (mass). A comparison of certain aspects between analogue and digital load cells is also described.

Inside This Article

History

The existence of life itself has been attributed over the ages to an underlying "force." Life is manifested by change and movement it involves actions and interactions of a variety of forces. Therefore, no measurement is more fundamental to human activity than the measurement of force in its many manifestations, including weight, pressure, acceleration, torque, work, and energy.

While the ancient civilizations of 8,000 to 6,000 B.C., in the river valleys of Southwest Asia, Mesopotamia or Egypt and others in China, India, and South America, all used lever and roller systems to amplify the muscle power of men, the first attempts to formalize a theoretical understanding of force were in ancient Greece.

The role of the force of gravity was first fully understood by Sir Isaac Newton (1642-1727). His law of universal gravitation explained both the fall of bodies on Earth and the motion of heavenly bodies. He proved that gravitational attraction exists between any two material objects. He also noted that this force is directly proportional to the product of the masses of the objects and inversely proportional to the square of the distance between them. On the Earth's surface, the measure of the force of gravity on a given body is its weight. The strength of the Earth's gravitational field (g) varies from 9.832 m/sec2 at sea level at the poles to 9.78 m/sec2 at sea level at the Equator.

Carlo Rubbia (1934-) and Simon van der Meer (1925-) further advanced our understanding of force by discovering the subatomic W and Z particles which convey the "weak force" of atomic decay. Stephen Hawking (1952-) advanced our understanding even further with his theory of strings. Strings can be thought of as tiny vibrating loops from which both matter and energy derive. His theory holds the promise of unifying Einstein's theory of relativity, which explains gravity and the forces acting in the macro world, with quantum theory, which describes the forces acting on the atomic and subatomic levels

One of the basic limitations of all measurement science, or metrology, is that all measurements are relative. Therefore, all sensors contain a reference point against which the quantity to be measured must be compared. The steelyard was one of mankind's first relative sensors, invented to measure the weight of an object (Figure 1-1). It is a beam supported from hooks (A or B), while the object to be weighed is attached to the shorter arm of the lever and a counterpoise is moved along the longer arm until balance is established. The precision of such weight scales depends on the precision of the reference weight (the counterpoise) and the accuracy with which it is positioned.

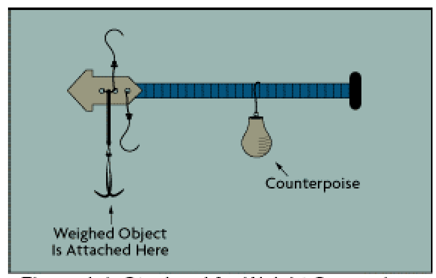


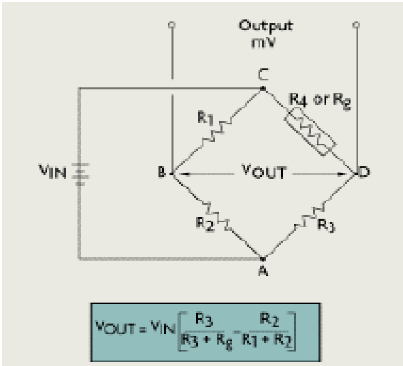
Figure 1-1: Steelyard for Weight Comparison

Another important consideration in force-related measurements is the elimination of all force components which are unrelated to the measurement. For example, if the goal is to measure the weight of the contents of a tank or reactor, it is essential to install the vessel in such a way that the tank will behave as a free body in the vertical but will be rigidly held and protected from horizontal or rotary movement. This is much more easily said than done.

Analogue Load Cells

A load cell is an electro-mechanical device (transducer) that is used to convert a force into an electrical signal. This conversion is indirect and happens in two stages.

Through a mechanical arrangement, the force being sensed deforms a strain gauge. The strain gauge converts the deformation (strain) to electrical signals. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration.



Load cells of one or two strain gauges are also available. The electrical signal output is typically in the order of a few millivolts and requires amplification by an instrumentation amplifier before it can be used. The output of the transducer is plugged into an algorithm to calculate the force applied to the transducer.

Although strain gauge load cells are the most common, there are other types of load cells as well. In industrial applications, hydraulic (or hydrostatic) is probably the second most common, and these are utilized to eliminate some problems with strain gauge load cell devices. As an example, a hydraulic load cell is immune to transient voltages (lightning) so might be a more effective device in outdoor environments.

Other types include piezo-electric load cells (useful for dynamic measurements of force), and vibrating wire load cells, which are useful in geo-mechanical applications due to low amounts of drift.

Bending beam type

Bending beam type

S-type

Tension low profile type

Compression type

Photographs of the most widely used analogue strain gauge load cells.

Digital Load Cells

Most load cells which are sold as “digital load cells” are strain gauge based analogue load cells with built-in electronics to convert the analogue output into a digital output signal. A digital load cell, therefore, comprises a measurement system illustrated in Figure 2.1.

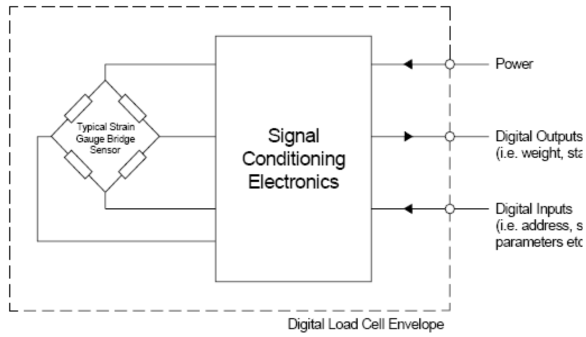


Figure 2.1 A Schematic representation of a digital load cell.

The load cells are presumed to be of the strain gauge type and the signal conditioning electronics is assumed to be contained within the envelope of the transducer housing. The signal conditioning electronics may have a minimum configuration such as an Analogue to Digital Converter to convert the analogue signal into a digital format for retransmission.

It may incorporate additional electronic devices to store various load cell performance characteristics and optimise these by the use of software algorithms. Load cells that utilise some of the features of the digital load cell but whose electronics are separately housed or are not dedicated to a single transducer are not considered here.

Typical compression type digital load cells with signal conditioning circuits

Analogue vs Digital

Factors that may influence the choice between a digital and analogue load cell for a particular weighing application.

Calibration

Load Cell Calibration

Much emphasis is placed by manufacturers on claims that digital load cells are pre-calibrated at source and that this fact makes for simple commissioning and service interchange.

The definition of calibration used in metrology may be paraphrased as follows:

"Calibration is a set of operations, which establish under specified conditions the relationship between the value of load applied and the corresponding value of the measured load cell output."

Establishing and documenting this relationship in the laboratory at the end of the manufacturing process is common practise for both digital and analogue load cells.

The fact that the output data from a digital load cell is in numeric form and can be linked to data identifying the individual device makes recording and data retrieval simpler for the manufacturer. There can also be benefits for the user in the ease of handling this data for purposes such as quality control or as a diagnostic tool.

When the load cell is used as a component in an industrial process weighing system there are several influence factors that can affect the relationship between the force exerted by the material being weighed and the force been applied to the load cell. These are well-documented and include installation issues such as load cell alignment and piping forces.

For this reason, theoretical data on the original manufacturer's calibration of a digital or analogue load cell is acceptable only in applications where verification of performance is not critical or is not practical.

Rationalisation

It is an accepted practice to adjust an analogue load cell's output expressed in mV (output signal)/V (excitation voltage) and its output resistance to nominal values within a tolerance band. This is important for applications where these load cells are installed in a multiple load cell application and their outputs are connected in parallel in a junction box. This is a time consuming and costly operation especially in the case of high capacity load cells.

Digital load cells have their signal outputs matched utilising the software programmed into their conditioning electronics and the term rationalisation does not apply to them. The resultant cost savings in manufacturing may be passed on to the user as a benefit.

Load Distribution

In many weighing systems utilising more than one load cell to support the load receiving element the distribution of load between the individual load cells can vary considerably. In such applications the relative contribution of each load cell to the total output is clearly important.

When using analogue load cells, which are not matched sufficiently well during, manufacture there is sometimes a need to introduce and adjust by testing - compensating circuitry usually located in the load cell junction box. This procedure can be time consuming, technically difficult and costly.
The rationalisation procedures are less costly for the manufacturer, than with conventional analogue load cells and this cost saving helps to offset other component costs.

This is a particular cost and time advantage to the user in two specific cases:

- High performance platform weighing systems (such as those complying with statutory requirements for use in trade) - where in almost every installation analogue load cells require some adjustment during the commissioning phase of the application.

- High performance vessel weighing systems, where the loading is asymmetric and where testing to establish the system output under such conditions is impractical.

Performance

Non-Linearity

Digital load cells have the capability to allow the signals from the strain gauges to be linearised before being presented as the final output. This is an advantage to the manufacturer in that the performance of the basic transducer design can assume a lesser importance**.** An analogue load cell, which might meet a given specification for non-linearity, can be tuned to meet a better specification as a digital device.

Hysteresis

The strain gauge load cell exhibits an output the value of which depends on whether the applied load is increasing or decreasing. Linearisation using digital processing capability of the decreasing load characteristic as well as the increasing characteristic would be complex.

Creep

The output of a load cell following a change in applied load has a small time dependant element called creep. It is conceivable that this effect could be digitally modelled and this model can be used to provide compensation

Temperature Compensation

The wheatstone bridge configuration of the strain gauges in a load cell provides substantial automatic temperature compensation for the resistance changes that occur in individual gauges. However the final output of a strain gauge load cell is temperature dependent due to changes in the elasticity of the measuring element and other factors. An analogue load cell utilises additional components within the transducer to compensate for these variations.

A digital load cell uses the relationship between temperature and output established during manufacture to compensate the output signals. The power of digital processing can be used to perform this compensation and the algorithms used can be complex and comprehensive.

Resolution and Repeatability

The discrimination of a load cell is the smallest change of load that can be detected and may be a very small interval. The repeatability of a load cell is a measure of the agreement between the resulting outputs of several repeated load applications

The environment will limit the practical level of repeatability that can be demonstrated to about 1 part in 10 000. This level of resolution is available from both analogue and digital systems.

Reliability

There is no evidence to suggest a difference in reliability between digital and analogue load cells and it is considered that any differences are likely to be insignificant.

Diagnostics

Analogue load cells have no integral diagnostic capability.

Digital load cells lend themselves to extensive diagnostics structure to verify the integrity of the individual load cell. Although these load cells often work in conjunction with each other and may be connected together by their power supply and/or communication outputs they are stand-alone units and can be individually addressed. This feature may be utilised to monitor the following;

- ADC performance
- Excitation voltage applied to the strain gauge bridge circuit
- Power supply to the load cell
- Built in E^2PROM containing the set-up parameters
- Temperature sensor

Service and Maintenance

There are a number of factors that may be listed having consequences on the long-term ownership of a system incorporating digital load cells:

- ease of service replacement
- digital storage and retrieval of calibration data in a computer
- facilities for initial set-up
- facilities for diagnostics.

Service replacement

The impact of the failure of one digital load cell in a multi load cell application will depend on the system software. Replacement of a failed digital load cell can be implemented fairly speedily with the same type of load cell provided that the system software has the facility to store its past performance in that location.

An analogue load cell will often be provided with a manufacturer's calibration certificate that may enable the user to compute and input the replacement performance parameters into the final signal processor.

In the case of a legal-for-trade weighing system, the system will require re-verification in accordance with the requirements of the applicable National Standard.

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