Load cells that measure up in ‘real-world’ conditions

Robert Sarnelli

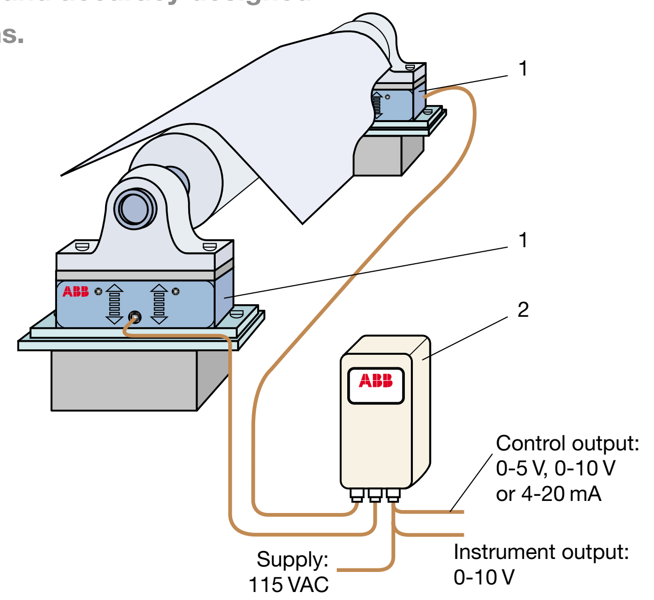
In papermaking, as in other industries, speed is of the essence. A five meters wide paper machine, for example, may produce a web of tissue at the rate of one kilometer a minute. Imagine, then, the cost to the papermaker of this web suddenly tearing. And the ensuing chaos as the tissue spills out onto the factory floor, creating a scene known in the business, aptly enough, as a ‘hay-out’.

Given this scenario, it is easy to see why dependable and consistent web tension measurement is critical in industries producing plastic film, textiles, and commercial print materials. Unfortunately, though, the load cells used to sense web tension are often not up to the harsh conditions that exist in the industrial world.

Over the past few years, ABB has introduced high-tech load cells which represent a major advance in the field. Based on the company’s exclusive Pressductor® transducer technology, they offer levels of robustness and accuracy designed to withstand real-world industrial conditions.

Operators of continuous web processing machines know that web tension measurements have to be dependable if product quality and machine efficiency are to be maximized. But like many other components, web tension measurement load cells work perfectly under *laboratory* conditions yet run into trouble in the real world, under ‘normal’ *operating* conditions.

Many environmental factors and one-time events can compromise the reliability and consistency of load cell systems used to measure web tension. The problems can show up as drifting or unstable outputs, with consequent impact on machine performance and the production quality. In fact, mistrust of load cell data is frequently cited by



1 A typical web tension system with measurement roll, load cells (1) and control unit (2). Output signals are sent to displays and tension regulating devices. Pillow block load cells are mounted between bearings holding the measurement roll and the machine pedestals.

customers as their biggest problem in the tension measurement area.

Anatomy of a tension measurement system

A web tension measurement system typically comprises two load cells mounted at the ends of a (usually non-driven) roll on the web processing machinery and connected by signaling cable to a control unit 1. This roll is referred to as the *measurement* roll. The 'electronics', which may be installed on the machine itself or remotely, amplify and enhance the output from individual load cells – sometimes combining the signals.

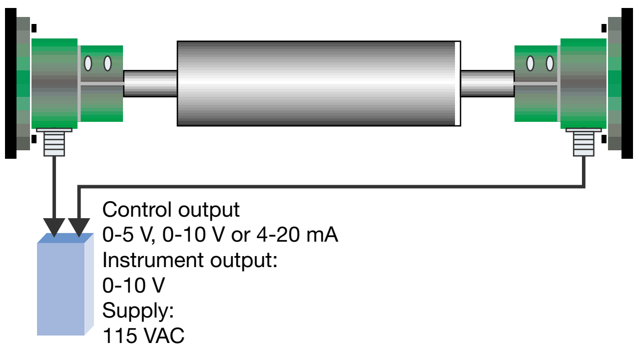
There are two basic load cell arrangements in use on the web processing machinery: So-called *pillow block* load cells are mounted between the pillow block bearings holding the roll shafts and the machine pedestals; *shaft-coupled* load cells are fitted directly onto each of the shafts of the measurement roll and attached to the machine walls 2.

The *transducer* inside a load cell is the sensing element that converts the mechanical forces into electrical signals. The load cell housing, besides supporting and protecting the transducer, directs the forces in the web into the transducer element.

Calculating the most appropriate *measurement range* of a load cell, ie its nominal load rating, is usually the most important, and often the most daunting, task when specifying load cells for an application. To ensure dependable output, this range must take into account factors such as the processed material, tension level, web speed and web width, as well as the angles at which the web wraps around the measurement roll.

Impact of operating conditions

Having to frequently maintain or replace the load cells in web processing plants can be a major nuisance, and may even



2 Shaft-mounted load cells are mounted on the inside machine walls and coupled to the shaft of the measurement roll.

Glossary

Accuracy class: Also measurement accuracy. A combination of certain load cell performance errors expressed as a percentage of the nominal load.

Control unit: Converts load cell output into signal output for control devices and displays.

Deflection: Physical movement in load cell caused by mechanical force loading.

Drift: Change in output value at constant web tension.

Electromagnetic interference (EMI): Electrical interference with measurement system from sources such as power cabling and variable frequency drives.

Load cell: Mechanical housing containing one or several transducers.

Mechanical stop: Prevents a movement-based transducer from deflecting beyond a certain point as an overload force is applied.

Nominal load: Also rated capacity. Maximum load for which load cell is designed to measure at full accuracy.

Operating range: Also application range. The ratio of the highest to the lowest load levels between which the load cell system will perform.

Overload: Load level resulting in a permanent change in load cell characteristics.

Radio-frequency interference (RFI): Interference in measurement system stemming from sources of radio frequencies, such as walkie-talkies and cell phones.

Recalibration: Resetting zero-point and gain settings.

Repeatability: The ability of the measurement system to produce identical output from repeated exposures to identical tensions.

Re-zeroing: Adjusting zero-point setting in order to bring system output to zero when no web tension is applied.

Seals: Membranes of rubber or plastic compounds used to prevent contaminants from reaching the interior of the load cell housing.

Shock loads: Abrupt, transient loads.

Transducer: Force-sensing element within a load cell that converts mechanical forces into electrical signals.

Wrap: The portion of the circumference of a roll that is covered by the web material. Generally stated in degrees.

Zero-point drift: Also zero-drift. Change in output at zero tension.

throw into question the very practicability of web tension measurement. But what is the cause of this 'reliability gap'? While, in theory, load cells should be able to survive the performance challenges they are likely to face, the sheer number of potential hazards usually results in a certain level of unreliability or attrition (see *Table*).

Because load cells are continually in operation, continually in contact with the force exerted by the web, and continually affected by environmental conditions, even low probabilities of failure can accumulate and result in failure and unreliability.

Factors affecting the performance of load cells
Events
Overloads
Shock loads
Application, installation and use
Bearing type
Mounting arrangement
Over- and undersizing
Amount of wrap
Wrap angles
Handling
Operating conditions
Chemicals
EMI and RFI
Fumes carrying corrosive agents and/or deposits
Moisture
Particulates
Ambient temperature
Temperature gradient
Contribution to vibration
Effect of vibration on measurements

Overloads and shock loads

When such loads act on the measurement roll they can instantly throw the load cell out of calibration or even destroy it. The roll momenta dissipated during an emergency stop can produce very high overloads, as can web material that wraps around a roll after a break or personnel inadvertently stepping on a measurement roll.

EMI and RFI

The signal cabling between the load cell and the electronics functions, in effect, as a large antenna, picking up interference from a variety of sources. Power cabling and drive systems are the traditional culprits, but the situation is further aggravated by the proliferation of cell phones and other wireless devices used in the plant.

Signal cabling, with its high terminating resistances and impedance, is highly susceptible to induced currents and voltages. Minimizing these effects in the load cell design and construction increases resilience to interference. In addition, smart cable routing and proper shielding of power and signal cables types are essential.

Contamination

Moisture and fluids, fumes that carry depository or corrosive agents, and particulates, can compromise the functionality of load cells, cabling and electronics alike. Furthermore, these contaminants are often present under 'normal' conditions.

As the transducer produces a low-voltage analog signal it is particularly harmed by moisture-induced leakage paths.

Corrosion often affects mechanical functionality – obviously an issue with transducers exploiting movement. In addition, the functioning of the mechanical stops often used to prevent overload can be disrupted. The stops engage too soon, which reduces the measurement range of the load cell in addition to diminishing sensitivity and/or accuracy.

Impact of machine design and operation

Measurement performance is also affected by factors related to the specification and application of a tension measurement system and by the operation of the web processing machine.

Vibration

As an integral part of the mechanical structure, the load cells are both the subject of and contributors to natural machine vibration. This vibration may complicate machine startups and bring a resonance frequency down into the operating speed range of the machine. High-speed operations, such as rewinding and web printing, are especially susceptible.

Temperature variations

Thermal expansion and contraction of the measurement roll causes axial forces to act on the load cell which need to be alleviated in order to ensure accurate measurement. However, uneven temperature distribution within the load cell structure is usually of greater consequence. Roll bearings and newly greased bearings tend to run warm, leading to temperature gradients in the load cell. These produce internal stresses that can result in measurement drift. Load cells usually employ some type of temperature compensation to lessen the impact of temperature gradients.

Capacity sizing

There is an inclination to 'play it safe' by oversizing the load cell for a certain nominal load on the assumption that 'bigger is better'. But measurement accuracy class, repeatability, and other load cell properties are specified for a nominal load rating, and load cells perform best when they use all or most of their capacity. When operating at lower tension values, interference (eg, temperature, and RFI and EMI pickup) comprises a larger part of the total force sensed. The signal-to-noise ratio decreases, yielding more unreliable measurements.

Load cell mounting and alignment

Inadequate mounting stiffness – notably bracketing that is structurally too weak – is not uncommon in the industry. It is easy to underestimate the tendency of the roll structure to flex when subjected to the tension in the web.

Roll misalignment, improper bearing selection, and failure to take into account temperature-related expansion and contraction when designing the equipment line, also contribute to the creation of 'irrelevant' forces that can falsify measurement values.

Transducer technologies

While load cells are offered in different designs by a multitude of manufacturers, they tend to be based on just a very few basic transducer operating principles. Two of these depend on physical movement in the load cell and in the transducer to generate an electrical measurement signal that is proportional to the applied mechanical load. By far the most common technology is that used by the strain gage transducers, while the linear variable differential transformer (LVDT) runs a distant second.

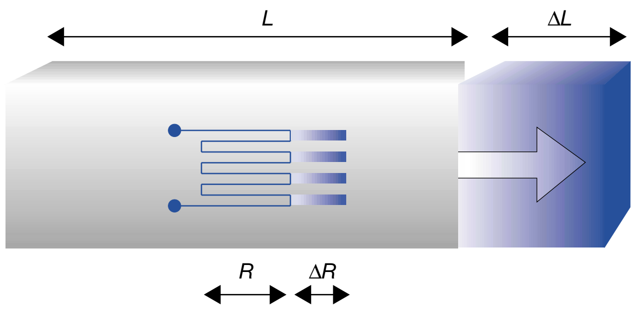
A third technology draws on the internal magnetic properties of certain steels to produce a signal, without the requirement of physical movement in the transducer. This technology is the basis of one of ABB's central and high-tech developments in the area of force measurement, marketed under the name Pressductor®. In 1998, ABB launched a new series of highly dependable and resilient load cell products based on the Pressductor® operating principle and with a mechanical design strategy intended to further enhance measurement quality.

Strain gage technology

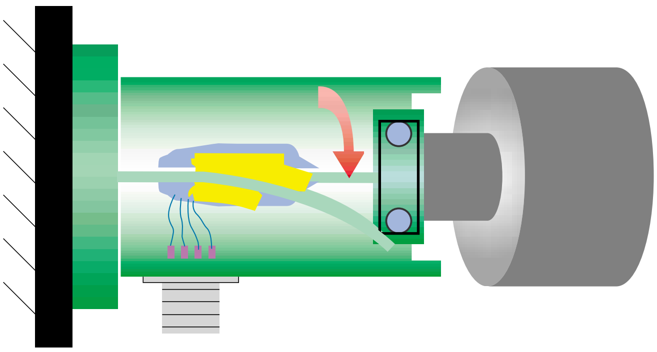
Consider a length of copper wire with a given cross-section and electrical resistance, to which a certain physical tension is applied so that the wire stretches somewhat. As the cross-section of the wire is reduced by the stretching, its electrical resistance increases. By measuring that change in resistance, an electrical signal can be produced which is proportional to the mechanical force applied to stretch the wire. This is the fundamental operating principle of a strain gage transducer.

The strain gage transducer element is essentially a pattern of very fine wires or metal foil 'fingers' arranged into an electrical grid pattern on a substrate. Two

3 Circuitry (ie, strain gage element) glued onto the load cell construction stretches or compresses as mechanical force is applied.



4 A signal is generated as the measurement beam of the strain gage load cell is bent by mechanical force.



or more of these stamp-sized measuring elements are bonded to opposing interior surfaces of the load cell construction at strategic locations 3.

The strain gage load cell is constructed in a way that allows opposing interior surfaces to stretch on one of the sides and compress on the other when the load cell is subjected to a mechanical force. The transducer elements, carefully positioned and bonded to the surfaces, closely follow these movements 4.

The two measurement elements are interconnected into a classical electrical circuit design known as a Wheatstone bridge. The electrical imbalance produced in the bridge by the changes in the resistance of the measurement elements gives rise to the load cell signal.

The extent of physical movement in strain gage load cell constructions used in converting and similar web processing applications is approximately 0.005 to 0.010 inches. The resistive elements are typically 350-ohm devices, producing changes in resistivity in the micro-ohm range. The output signal from the Wheatstone bridge is approximately 30 millivolts, which puts signal output power at approximately 2.5 microwatts.

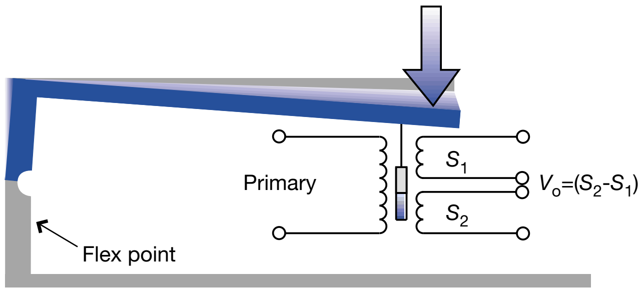
LVDT (Linear Variable Differential Transformer)

An LVDT sensor converts the deflection produced in a cantilevered bending beam when a mechanical force is applied to the load cell into an imbalance in two transformer coils to generate a measurement signal 5.

The bending beam moves a core positioned between a primary and two secondary transformer coils in the direction of the force. As the core moves, it changes the magnetic coupling between the primary and secondary. The load cell signal output is the difference between the voltages induced in the two secondaries. When the load cell is at rest, the core remains in a neutral position that produces equal coupling between the primary and secondary coils, yielding zero difference and therefore no load cell signal.

The LVDT transformer provides a strong signal – typically an output voltage of 5 volts. The transducer requires

5 In LVDT sensor technology, web tension deflects a hinged plate of the load cell housing, causing a ferrite core to move between a set of electromagnetic coils to produce a measurement signal.



significant physical movement, however, in order to produce a measurement signal: approximately 0.030 inches at nominal load. The load cell design relies entirely on mechanical stops for overload protection 6. The transducer itself has no built-in overload protection.

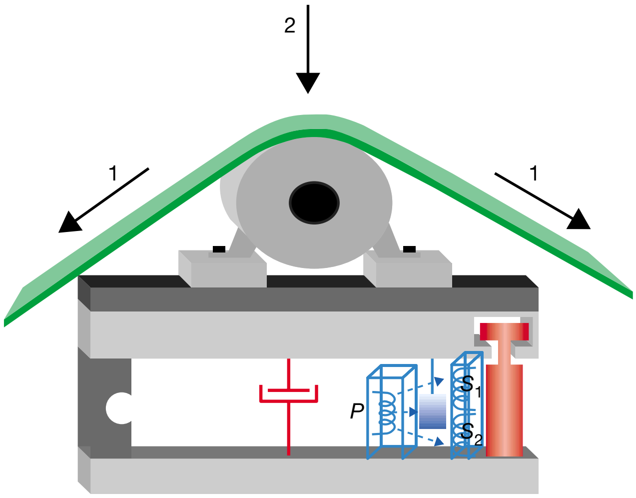
Magnetoelastic transducer technology

The magnetoelastic effect of some steels describes the metallurgical phenomenon by which a mechanical force alters magnetic permeability. This is the operating principle of the magnetoelastic transducer.

As with the LVDT technology, the net result of the magnetoelastic transducer operation is that changes in electromagnetic fields yield the measurement signals. But unlike the LVDT, the changes in the electromagnetic fields are caused not by physical movement within the load cell, but instead by the magnetoelastic nature of the steel used both in the transducer and the overall load cell construction 7.

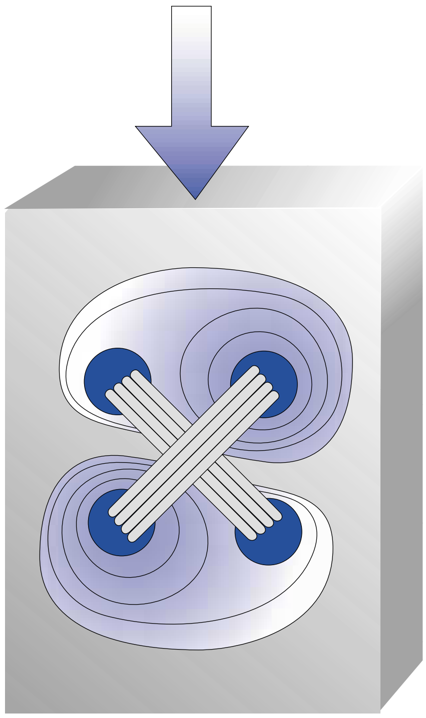
The magnetoelastic effect converts a portion of the energy of a mechanical force applied to the load cell into changes in the permeability of the steel. The steel's ability to support magnetic fields changes in both magnitude and direction. Just as resistivity and conductivity are terms used to describe the flow of electricity, permeability describes magnetic flow, or the ability to support a magnetic field.

It is on this principle that ABB based its new Pressductor® load cell products.



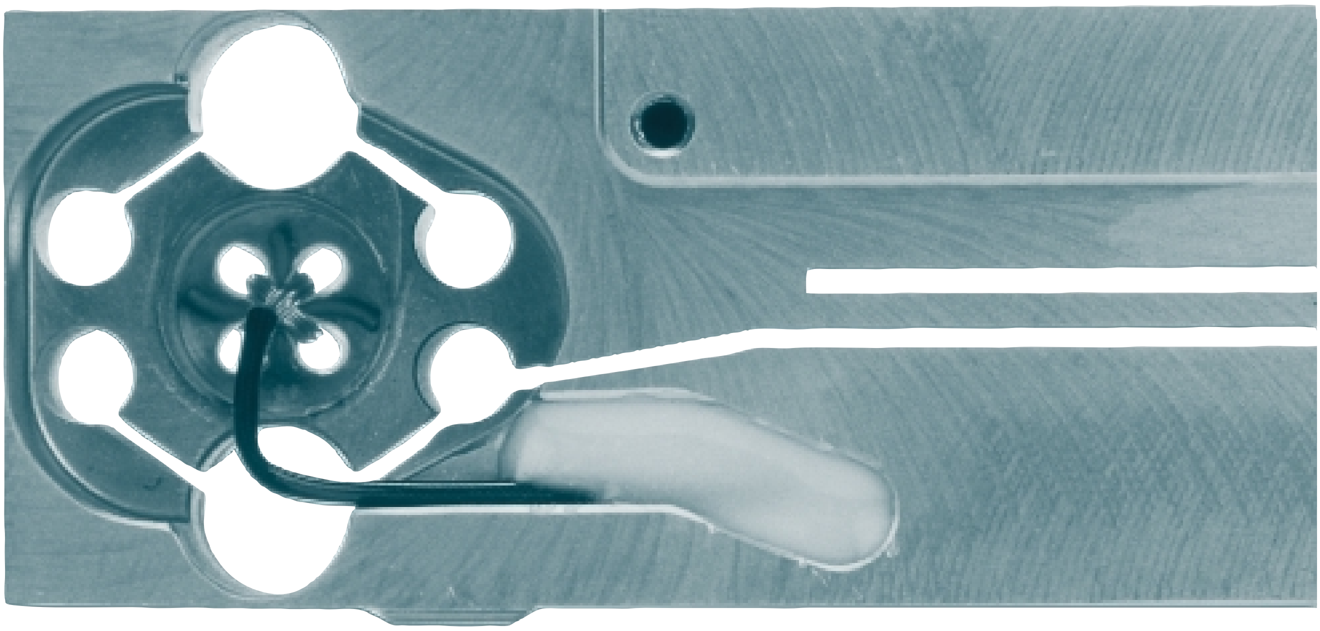
6 Load cell configuration. A plunger (center) dampens the physical movement in the LVDT load cell, and a mechanical stop (right) provides overload protection.

1 *Web tension* 2 *Web resultant force*



7 Magnetoelastic transducer technology at work. Force applied to a steel block changes the magnetic flux pattern inside it to yield the measurement signal.

8 Partial interior of magnetoelastic load cell. Constant current in the primary winding creates a magnetic field. The flux pattern changes when a force is applied to the load cell, producing a signal output in the perpendicular secondary winding.



Conceived for use at the tension levels typically found on machinery used for processing converted products, plastic film, and textiles, as well as commercial web printing, they additionally incorporate a mechanical design strategy intended to further enhance measurement quality by limiting the force reaching the transducer to the force in the measurement direction. Forces in all other directions that impede measurement accuracy are canceled out.

Fundamentally, the Pressductor® transducer consists of two perpendicular windings of copper wire running through four holes of a steel membrane – the measurement zone 8. A magnetic field is created in one of the windings by a constant excitation current. When the transducer is subjected to a mechanical force, the magnetoelastic property of the steel alters the magnetic field pattern so that a portion of the field couples with the secondary winding to induce an AC voltage proportional to the force.

At approximately 20,000 microwatts, the signal is exceptionally strong for a transducer designed for converting and similar applications. The operating principle also yields a substantial natural overload tolerance and stiff load cell construction – both highly desirable attributes. The physical stress level remains low in the metal of the transducer membrane even at full nominal load, leaving a natural margin for overloads of 300 to 500 percent of the cell capacity, depending on the type of load cell.

The deflection at the nominal load of magnetoelastic load cells for converting industry applications is approximately one-half of one-thousandth of an inch (0.0005 inch). Machined out of a solid block of stainless steel, their displacement under load is between 10 and 100 times less than that typically experienced with movement-based devices.

Impact of measurement technology on load cell design and performance

Strain gage load cells

Strain gage load cells are economical, widely available and technologically suitable for a broad selection of measurement ranges, physical shapes and performance characteristics. Suppliers often fabricate and provide complete tension measurement and tension control solutions. The transducer elements are independently manufactured by specialized suppliers.

Strain gage load cells are, however, often vulnerable to aspects of the machine operating environment and other factors:

- A comparatively weak signal – of the order of 2.5 microwatts – combined with the transducer's high electrical resistance produces a susceptibility to loss of signal quality due to electrical interference and force shunting.

Ground faults and the like also can cause problems; as the transducer's typical output resistance is approximately 350 ohms, a 10-kohm ground fault would produce a four percent reduction in signal levels.

- Sensitivity to environmental contaminants as described earlier.
- Limited overload tolerance. The movement-based transducer operates close to the plastic deformation point of the metal in the foil grid. The overload tolerance is limited to approximately 150 to 200 percent of the cell capacity.
- Contribution to machine vibration.

LVDT load cells

The output signal of LVDT load cells is strong, which increases their tolerance of electrical interference. The substantial physical movement in the load cell required for signal generation – upwards of 0.030 inch – greatly restricts stiffness levels, however. The consequent propensity to roll movement and the contribution it makes to machine vibration limit the load cell's usefulness wherever a high premium is placed on precise web handling, such as in commercial web offset printing.

The degree of physical movement also produces some sensitivity to the presence of particulates and fluids in the operating environment, so effective sealing is important. Whereas strain gage transducers use elastic sealants, the greater movement of LVDT cells requires the increased flexibility of 'rubber seals'. These, in turn, are susceptible to damage.

In short, LVDT devices are mechanically complex and require many mechanical adjustments and frequent maintenance if they are to operate properly.

Load cells based on the magnetoelastic technology

High-capacity load cells based on ABB's magnetoelastic Pressductor® transducer technology have been used for decades in the demanding production environments of the iron & steel and pulp & paper industries. Developments during the last several years in the areas of metallurgy, mechanical design, and production techniques, have in the meantime made it possible to design Pressductor® cells with much lower capacity ratings.

These load cells do not require physical movement in the transducer to produce a measurement signal. The smaller Pressductor® load cells are machined from solid blocks of corrosion-free stainless steel, giving strength and rigidity, and they do not need seals. Their permissible application range is extensive – approximately 30:1 – and the linear measuring range is twice the width of the nominal load. Mechanical stops are not used.

Since the measuring effect take place inside a steel core, environmental contamination does not influence the load cell's performance and reliability.

A strong AC signal – approximately 20,000 microwatts – contributes to signal integrity as well as tolerance of electrical interference. The low impedance of the electromagnetic windings that are integral to the magnetoelastic transducer – the few turns of copper wire produce less than 1 ohm – further reduces the cells' susceptibility to electromagnetic pickup and radio-frequency interference. Low impedance also limits the effect of ground faults; a 10 kohm fault would produce a signal error of less than 0.1 percent.

The magnetoelastic load cells are usually somewhat more costly than other types, principally due to high demands on the metallurgical and fabrication processes. Explosion proofing presents difficulties, mainly because of the load cells' significant excitation current.

The magnetoelastic transducer technology makes its most important contribution to load cell performance in the area of overall tolerance. It yields load cells that are forgiving of excessive loads, electrical and temperature interference, contaminants, and imperfections in specification and installation.

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