**Introduction**

Kistler-Morse (KM) introduced bolt-on weight measuring systems three decades ago. These devices featured Walter Kistler’s invention, the Microcell. Over the years, many improvements were made to the Microcell and additional products including high stress strain sensors, load cells, and the two-axis L-Cell evolved from the original design.

KM weight measurement transducers fall into two categories:

- **Bolt-on** – Sensors are attached to the existing vessel supports (metal columns, beams, or silo skirts). Bolt-on transducers are ideal for retrofit applications, as they can be installed without taking the vessel out of service. However, they are not as accurate as direct support load cells due to limited control over material and method of construction of the support structure.

- **Direct support** – Transducers are built into a structural element, which is installed as part of the vessel’s structural support system. KM produces both tension and compression direct support load cells. Direct support transducers provide the highest accuracy, but require the vessel to be taken out of service for installation.

While KM bolt-on and direct support products differ in shape, capacity, and application, most KM products share the common platform of silicon semiconductor strain gages incorporated into half of a Wheatstone bridge circuit.

**Definition of Terms**

Before proceeding, a few definitions are needed to insure a proper understanding of the information.

**Stress** – Any action on a body that results in deformation. Usually measured in pounds per square inch or Pascal’s.

**Thermal stress** – Two dimensional strain caused by thermal heating (expansion) or cooling (contraction).

**Strain** – Deformation of a body or structure as a result of an applied force.

**Bending strain** (moment strain) – The relationship between the force and the amount of bending that results from it.

**Torsional strain** – Strain produced by twisting.

**Shearing strain** – The angular distortion of an object under stress.

**Compression** – Stress by forces pushing together.

**Tension** – Stress by forces causing extension (pulling).

**Strain gage** – A device that converts mechanical deflection to an electrical signal.

**Poisson’s ratio** – The ratio of transverse strain to longitudinal strain – the ratio for carbon steel is 0.3.

**Shear** – The component of a horizontal beam that is being measured.

**Live load** – The design capacity of a vessel.

**Working load** – Normal operating capacity of a vessel.

**Dead load** – The empty weight of a vessel.
**Weight Measurement Technology**

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**Introduction**

**Millivolt** – 0.0001 volts: the unit of measure of output from sensors.

**PSI** – Pounds per square inch: Unit of measurement of stress used in the application of strain gage sensors.

**Wheatstone bridge** – An electrical circuit used to detect small resistance changes in strain gages.

**Signal lines** – The lines that return the signal from the load cell to the signal conditioner. In half bridge systems, there is only one signal line.

**Sense lines** – In full bridge systems, these lines sense the excitation voltage at the load cell and return it to the power supply. The power supply then attempts to regulate the voltage to maintain a stable and accurate excitation voltage level at the load cell.

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**Theory**

**KM Strain Gages**

KM uses silicon semiconductor strain gages as the strain sensing elements. The gages are solid-state resistors made from a single-crystal silicon boule, a linear elastic material. The boule resembles a cylindrical rod, and the rod is 'sliced and diced' to form rectangular gage bars. The raw gages are acid-etched to the required resistance and aluminum wires are welded to the gages. These wires connect the gages to the circuit.

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**Wheatstone Bridge**

The Wheatstone bridge is an electrical resistance bridge circuit used to measure differential resistance. KM’s implementation of the Wheatstone bridge consists of two silicon strain gages forming one-half of the bridge circuit at the transducer, and two precision-matched resistors forming the other half of the bridge at the signal processor. This design resolves and measures small resistance changes that occur when the strain gages respond to a load. The two gages that make up the sensor half of the Wheatstone bridge are glass-fused to the transducer frame bending beam, providing a very stable and rugged bond.

Imagine a piece of foam rubber with a weight on it. The weight compresses the foam in the longitudinal direction, and at the same time causes the foam to expand a small amount in the transverse direction. This same type of behavior occurs in all materials, including steel. A vessel support structure will experience these types of changes and they are in direct proportion to the material weight changes in the vessel.

When a transducer is bolted to a vessel support (bolt-on) or is part of a direct support (load cell), it translates the support strain changes into bending of the...
transducer beam on which the silicon strain gages are attached. This causes the strain gages to flex in tension or compression on opposite sides of the bending beam. The gages’ resistances change as the sum of this flexing and create a signal change proportional to the resistance change. This signal change is used to monitor the change in material weight in the vessel.

**Factors that Affect Performance**

An independent, isolated vessel with no connection to any other vessel or adjacent structure provides the most accurate results for a weight measurement system. Examples of this type of application are floor scales and truck scales. Connections to other vessels or structures affect accuracy because the transducers interpret strain changes caused by the connecting structures as being caused by changes in the material weight.

Some typical causes of error related to connecting structures and, where applicable, methods for reducing the errors follow:

- **Catwalk** between vessel and another adjacent structure - Reduce errors by allowing float between connections with a slip-joint coupling and double-nutting.

- **Hidden load bearing members**, such as discharge chutes, supported by floor - Reduce errors by breaking the hard connection with a flexible coupling.

- **Vessel goes through roof** of a surrounding structure - Reduce errors by installing a flexible seal between the vessel and the roof.

- **Tripper conveyors or deck plating** welded to structure as flooring or roofing - Eliminate errors by cutting the connection to the vessel and supporting from another structure.

- **Rigid piping connection** between vessel and another adjacent structure - Reduce errors by softening the connection with a flexible coupling or lengthening the free pipe run (increasing the length from the nearest pipe support to the connection to the vessel). The cross sectional area of the pipe, the pipe spring rate, and its unsupported length determine the influence that the piping will have. Assuming a Schedule 40 Pipe, a good rule of thumb is to have 3-5 feet of unsupported horizontal run for each inch of cross sectional area of the pipe. Elbows and couplings should be included in this measurement. Vertical piping is considered to have no spring rate. Therefore, for any weight system to be accurate, vertical piping must be offset with horizontal run flexible coupling.
A well-built structure provides the most accurate results for a weight measurement system. Some typical causes of error related to the structure and where applicable, methods for reducing the errors follow:

- **Poor Foundation** - A level concrete or steel foundation is essential to good system performance. If required, grout or add shims to ensure an even distribution of load on the support points.
- **Flexible Structure** - The vessel and support structure must have adequate rigidity to prevent excessive deformations, which affect strain levels read by the transducers.
- **Uneven Loading** - A vessel’s weight is not evenly distributed to all legs if the structure is not level or the material center of gravity is off-center. This can cause errors if all the legs are not instrumented. To eliminate this error, KM instruments every leg, averaging the load carried by each leg to obtain an accurate weight measurement.

**Side Loading** - In addition to vertical loading from the structure and material weight, vessels are subject to side loads from wind, equipment vibration, etc. Side loads cause additional tension/compression forces and strains in the legs. Overall, these add up to zero; i.e., they cancel out. However, if all legs are not instrumented, the system incorrectly interprets strain caused by side loads as caused by weight change. To eliminate this error, KM recommends instrumenting every leg with weight transducers, thereby canceling the side loading effects.

The following additional factors affect the weight measurement system performance:

- **Shock loads can damage transducers** - In areas where fork lifts, trucks, etc. are used, install protective barriers or stops to prevent vehicles from hitting the vessel supports.
- **Excessive electrical noise or heat** - Avoid locations with excessive electrical noise or heat when determining the application feasibility, selecting the type of weight transducer, bolt-on or direct support, and routing interconnecting cables. The signal cables between the transducers and electronics should not be run in the same conduit with high voltage control and power wiring.

Strain gages measure compression, tension, thermal, bending and torsion forces at the same time. The gage cannot differentiate pure compression or tension forces. The design of the load cell or bolt on transducer takes into consideration these total forces and attempts to minimize their effect but, because bolt on devices are attached to the support structure, they will measure all of these types of forces. This must be taken into consideration when quoting accuracy.