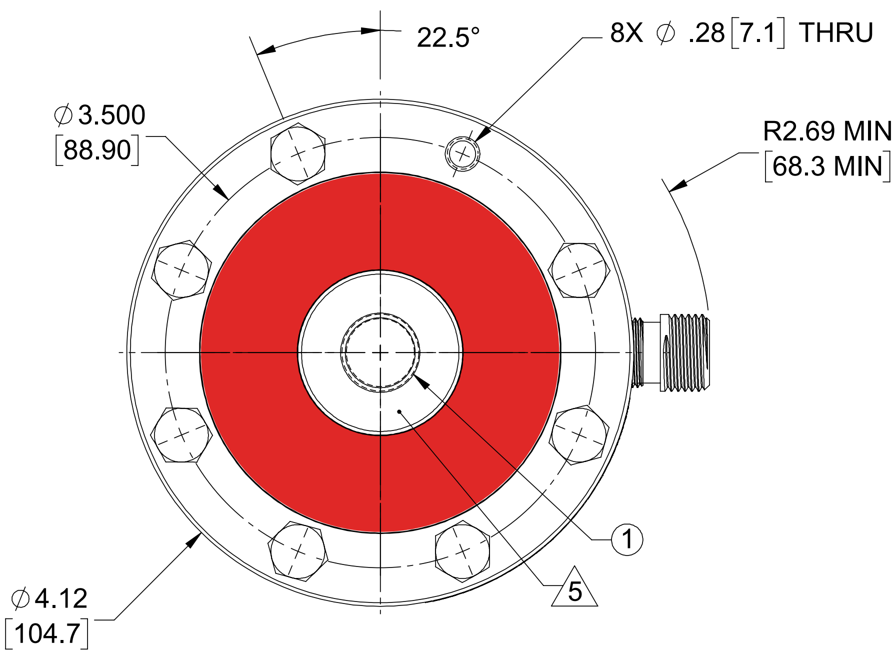
Interface

FORCE MEASUREMENT SOLUTIONS®

LOAD CELLS 101 GUIDE

THE LOAD CELL PRIMER



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Interface Load Cell Basics Primer

The Interface Load Cell Basics Primer is your roadmap to understanding these essential tools instrumental to force measurement. Interface load cell engineers take you from the rudimentary proving ring to modern marvels of strain gage technology in this introductory primer. Along the way, we'll delve into essential test and measurement topics that include:

- Key concepts and terminology influencing sensor designs include creep, deflection, temperature sensitivity, and extraneous force interference.
- The revolutionary impact of strain gages paved the way for sophisticated measurements from minute forces used in surgical instrumentation to millions of pounds of force used today to launch rockets.
- Review of diverse flexure configurations like bending and shear beams, each with unique strengths and applications.
- An examination of input/output characteristics, errors, and calibration, critical success factors that ensure accurate force measurement.
- Applications of how load cells empower diverse fields, from weighing systems and scales to industrial automation and robotics.

Whether you're an engineer seeking a deeper understanding of load cell technologies, new to the field of test and measurement, or fascinated by the invisible forces shaping our world, this primer has something for you.

Prepare to unlock the secrets of force measurement and appreciate how load cells have a place in nearly every industry. Ready to begin your exploration? Let's begin with our Interface Load Cell Basics Primary, introducing our more comprehensive Load Cell Field Guide.

If you have questions or need help, always reach out to Interface. We are on this journey of learning and exploring measurement possibilities together.

Your Interface Team

THE LOAD CELL PRIMER

THE LOAD CELL PRIMER

THE "ELASTIC FORCE TRANSDUCER"

People have known for centuries that heavy objects deflect spring supports more than light ones do. Take, for example, a fly fisherman as he casts his line and catches a fish. The fishing pole is a flexible tapered beam, supported at one end by the fisherman's grip and deflected at the far end by the force of the line leading to the fish. If the fish is fighting vigorously, the pole is pulled down quite a bit. If the fish stops fighting, the pole's deflection is less. As the man pulls the fish out of the water, a heavy fish deflects the pole more than a light one does.

Figure 1. Bending beam deflection

This knowledge of the deflection effect in the example of the springy rod is not confined to the human race. As we watch movies of monkeys in the trees, we realize that they too have some understanding of this principle.

The phenomenon that is demonstrated in *Figure 1* relates to the deflection of a bending beam under load. We could also determine the relationship between the deflection of a coil spring and the force that causes it. For example, when the fisherman hangs his catch on a fish scale, a heavy fish pulls the scale's hook down farther than a light one does. Inside that fish scale is nothing more complicated than a coil spring, a pointer to mark the position of the end of the spring, and a ruler-like scale to indicate the deflection and thus the weight of the fish.

We can demonstrate a more exact quantitative relationship by running an experiment. We can calibrate a coil spring of our own choice by clamping the top end of it to a cross bar, connecting a pointer at the lower end of the spring, and mounting a ruler to indicate the deflection as we place weights in a pan hanging from the lower end of the spring.

On our particular scale, we note that the resolution of the ruler is 1/20TH of an inch, because the marks are 1/10TH of an inch apart. This is because we can distinguish between two readings of about half the distance between the marks.

With no weight in the pan, take a reading of the pointer on the ruler. Next, apply a one-pound weight and note that this particular spring is deflected one mark on the ruler from the original reading. Add another weight, and the deflection is one mark more. As we add more weights, we record all the readings. The table is a record of the weight versus deflection data that we recorded.

WEIGHT	MARK
0	0.5
1	1.5
2	2.5
3	3.5
4	4.5

If we plot these data on a graph, as shown in *Figure 2*, we find that we can connect all of the points with a single straight line. An algebra or geometry teacher would tell us that the equation of this line is:

$$D = D_0 + \frac{W}{k}$$

Where:
D = Deflection of the spring
D_0 = Initial deflection of the spring
W = Weight on pan
k = Stiffness constant of the spring

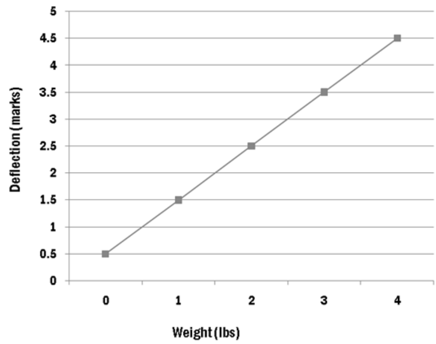

Figure 2. Deflection versus applied weight

The idea that the transfer function of the spring scale is exactly a straight line occurs to us only because the measurements did not have enough resolution. Our straight line graph is only a rough approximation of the spring's true characteristics.

We have now demonstrated the two basic components of a load cell: a springy element (usually called a flexure), which supports the load to be measured, and a deflection-measuring element, which indicates the deflection of the flexure resulting from the application of loads.

ADDING SOPHISTICATION

We can improve the resolution of the measurements by replacing the ruler with a micrometer having a fine-thread screw so that we can resolve thousandths or even ten-thousandths of an inch. Now, as we re-run the experiment, we can easily observe—by simple

WEIGHT	MARK
0	0.500
1	1.509
2	2.516
3	3.511
4	4.495

visual inspection of the data—that it will not perfectly conform to a straight line.

When we look closely at the deviation of the data from our hoped-for straight line, we can see that the differences are so small that they are less than the thickness of the graph line. Such a graph would not be useful, since it would not portray any useful information except a gross representation of the zero intercept and slope of the spring's characteristics. Therefore, in order to present the data in a meaningful form, it is necessary to modify our classical idea about the graphing of data. We will need to magnify the scaling of the graph in such a way that the deviations from a straight line are easier to see.

Rather than graphing "Weight" versus "Deflection," we can plot "Weight" versus "Deviation from a Straight Line." Then, it becomes necessary to choose which straight line to use as a reference. One common choice is the "End Points Straight Line," which is the line passing through the point at zero load and the point at maximum load.

As you can see in *Figure 3*, the horizontal axis represents the straight line that we have chosen to use as a reference. Notice, however, that we have given up the scaling information about the spring. We can't calculate the "pounds per inch" constant of the spring from the graphed information. Therefore, for the graph to be most useful, we should print the scaling constant somewhere on the graph.

Also, if we choose "Deviation" for the vertical axis, it is not too useful, since we can't relate the numbers to the performance of the spring without dividing all of the numbers by the full scale output range of the test. We can help the user of the graph by performing that division ahead of time, converting the units on the vertical axis to "Percent of Full Scale." In our example, we would divide all of the deviation numbers by 4.495 (that is: 4.995 – 0.500), the range of the test outputs from no load to full load.

By using "Percent of Full Scale," we can easily compare the performance of many springs in a way that allows us to select the ones that have the characteristics we want. Later on, we will see that springs have many more parameters than just the simple spring constant, which was presented earlier in the deflection equation for springs.

You will notice that our new graph in *Figure 3* gives us a much clearer picture of the true characteristics of the spring over the range of interest.

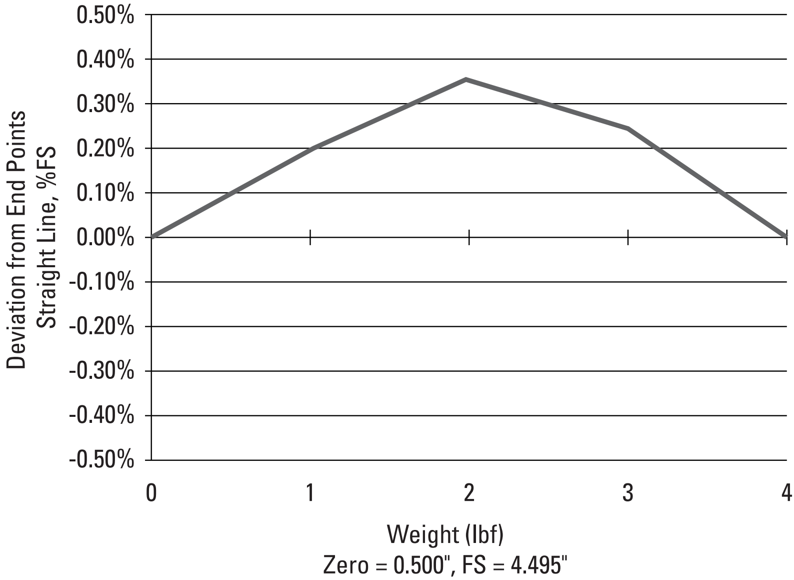

Figure 3. Deviation from straight line versus applied weight.

A RUDIMENTARY LOAD CELL: THE PROVING RING

Decades ago, the Proving Ring was conceived as a device to be used for the calibration of force measuring dial gauges. It consisted of a steel ring with a micrometer mounted so as to measure the vertical deflection when loads were applied through the threaded blocks at the top and bottom.

For many years proving rings were considered the standard of excellence for force calibration. However, they suffer from the following adverse characteristics:

Figure 4. Proving ring

CREEP

When a force is applied to a solid material within its elastic limit, the resulting deflection will increase very subtly with time if the force is held constantly. This is true whether the force is in tension or compression. This phenomenon is called creep, and by definition, is not permanent but is recoverable. The signal from a load cell exhibits this creep, and therefore it should be understood in all load cell applications. Both loaded creep and creep recovery are exponential with time, as illustrated in *Figure 5*.

Referring to *Figure 5*, a force is applied in time 0 to (*A*), and the deflection goes from point 0 to point (*K*). Then in a stable loading condition, the deflection increases up to point (*M*) during time (*A*) to (*B*). This is positive creep. It is also possible that it could have been negative creep, in which case the curve from (*K*) to (*M*) would have gone negative rather than positive. When the force is released at time (*B*), the deflection quickly goes to point (*J*), then creep recovery occurs and the deflection goes back toward 0 with about the same curve shape as the loaded creep inverted.

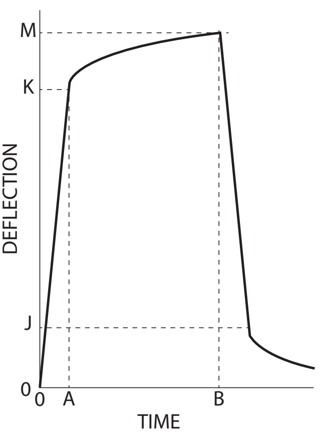

Figure 5. Creep

Creep continues as long as a force is applied, but the rate of creep decreases significantly with time. It is typically measured and specified for a 20 minute interval. To illustrate the concept, the creep in the first 20 minutes is about equal to the creep in the succeeding 24 hours.

DEFLECTION MEASUREMENT

When forces are applied to the proving ring, it departs from its circular shape and becomes slightly egg-shaped. The determination of the deflection of a proving ring depends on the subtraction of two large numbers, namely, the inside diameter of the proving ring and the length of the micrometer measurement assembly. Since the difference is so small, any slight error in measuring either dimension leads to a large percentage error in the number of interest, the deflection.

Any mechanical deflection measurement system introduces errors that are difficult to control and/or overcome. The most obvious problem is resolution, which is limited by the fineness of the micrometer threads and the spacing of the indicator marks. Nonrepeatability of duplicate measurements taken in the same direction depends mainly on how much force is applied to the micrometer's screw threads, while hysteresis of measurements taken at the same point from opposite directions is dependent on the preload, friction, and thread looseness.

TEMPERATURE EFFECTS

Variation in the temperature of either the steel ring or the micrometer assembly will cause expansion or contraction, which will result in a change in the deflection reading. A first-order correction would be to make all of the parts out of the same material so that their relative temperature effects are equal, effectively causing them to cancel one another. Unfortunately, this presumes that all of the parts track one another in temperature, which is not true in practice. A light shining on one side of the ring or a warm breeze from a furnace vent will cause differential warming, and a proving ring is very susceptible to temperature gradients in the proving ring mechanism. Also, the spring constant changes with temperature, thus changing the calibration.

RESPONSE TO EXTRANEOUS FORCES

The construction of a proving ring does not lend itself to the cancellation of extraneous forces, such as side loads, torque loads, and moment loads. Any load other than a pure force through the sensitive axis of the ring can result in an extraneous output.

CONCLUSION

The proving ring requires trained personnel for proper operation because of the possibility of errors introduced by creep, as well as the potential for errors due to temperature and extraneous loads.

IMPROVEMENTS ON THE PROVING RING IDEA

By now, it is obvious that the deflection measurement element would need to be changed dramatically to achieve a practical load cell with the desired characteristics. The element needs to be smaller and it needs to be in close thermal contact with the flexure so that their temperatures will track closely. It needs to have high resolution. It should be rugged and simple to operate.

INTRODUCING THE STRAIN GAGE

It is a well-known fact that the resistance of a length of wire will increase if we stretch it. *Figure 6* shows an exaggerated view of a wire segment of length (L_1) and diameter (D_1). When it is stretched, it assumes length (L_2), and the diameter becomes (D_2) (smaller) to maintain the same volume in the piece. Of course, the smaller diameter of the wire means that its resistance per unit length will be higher.

If we could somehow bond a piece of fine wire onto a flexure, we could perhaps make use of this change in resistance to measure the change in length of some dimension in a load cell flexure when a force is applied.

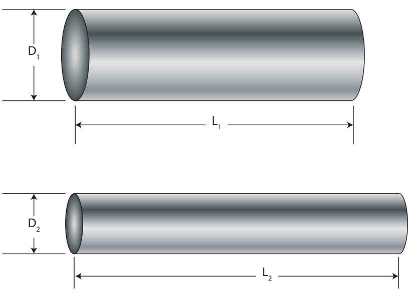

Figure 6. Wire elongation under stress.

A practical design for such a deflection-sensitive resistance device is shown in *Figure 7*, with magnification of 10x the actual size. The vertical grid lines are the resistance wires, and are aligned with the maximum strain lines in the flexure.

The thicker ends connecting the grid lines at each end are designed to connect the grid lines without introducing resistance, which would be sensitive at 90 degrees to the desired sensitive direction. Finally, the large pads are provided for attaching the wires that carry the resistance signal to the external measuring equipment.

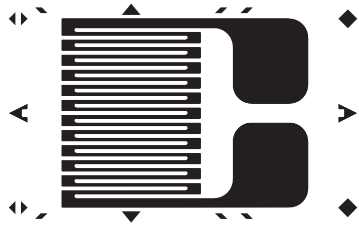

Figure 7. Simple strain gage.

The grid-line pattern is created optically on a thin Mylar substrate that can then be bonded to the flexure at any location and with the proper orientation to respond to the forces that are applied to the load cell. This strain gage is the heart of the modern load cell, and it has the characteristics that we first outlined as necessary, specifically as follows:

THERMAL TRACKING

Since it is bonded to the flexure with a thin line of an epoxy, the strain gage tracks the flexure temperature, responding very quickly to any changes.

TEMPERATURE COMPENSATION

An added advantage is the fact that the alloy of the gage can be formulated to provide compensation for the change in modulus of elasticity (spring constant) of the flexure with temperature. Thus, the calibration constant of the load cell is more consistent over the compensated temperature range (the range of temperatures over which the compensation holds true).

CREEP COMPENSATION

It is also possible to match the creep of the strain gage to the creep of the flexure material, thus at least partially canceling out the creep effect. Interface® is able to produce load cells with a creep specification of ±0.025% of load in 20 minutes, a factor of 10 better than the uncompensated flexure material. On special order, creep performance of ±0.010% of load can be achieved.

An interesting facet of creep compensation is that, in any production lot, the compensated creep of each load cell can be positive, negative, or even zero. This happens because the gage creep can be slightly smaller than, slightly larger than, or exactly equal to the flexure creep, within the specification limits.

FREQUENCY RESPONSE

Since the strain gage's mass is virtually zero, the frequency response of a load cell system is limited only by the response of the flexure itself, the weight of the customer's attached fixtures, and the bandwidth of the external amplifier.

NON-REPEATABILITY

The strain gage is intrinsically repeatable because it is bonded to the flexure and the whole assembly becomes a monolithic structure. The major contributor to non-repeatability of a load cell system is the mechanical connections of the external fixtures.

RESOLUTION

The major advantage of the strain gage as the deflection measuring element is the fact that it has infinite resolution. That means that no matter how small the deflection, it can be measured as a change in the resistance of the strain gage, limited only by the characteristics of the electronics that have been used to make the measurement. In fact, tests have been run in which the load cell output appeared to be erratic simply because the system resolution was too high; someone walked by the lab bench and the force of the moving air caused the reading to shift! Of course, the appropriate resolution should always be used. Too much resolution can sometimes be worse than not enough, especially when the applied loads are erratic themselves, as in many hydraulic systems.

FLEXURE CONFIGURATIONS: BENDING BEAMS

The field of force measurement has the same types of constraints as any other discipline: weight, size, cost, accuracy, useful life, rated capacity, extraneous forces, test profile, error specs, temperature, altitude, pressure, corrosive chemicals, etc. Flexures are configured in many shapes and sizes to match the diversity of applications out in the world.

BENDING BEAM CELL

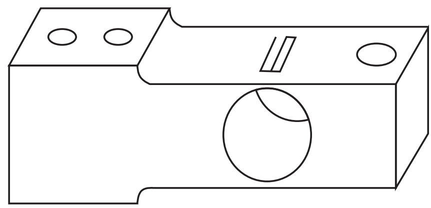

Figure 8. Bending Beam Flexure

The cell is bolted to a support through the two mounting holes. When we remove the covers, we can see the large hole bored through the beam. This forms thin sections at the top and bottom surface, which concentrate the forces into the area where the gages are mounted on the top and bottom faces of the beam. The gages may be mounted on the outside surface, as shown, or inside the large hole.

The compression load is applied at the end opposite from the two mounting holes, usually onto a load button that the user inserts in the loading hole. Interface® MB Series load cells are available in capacities from 5 to 250 lbf. SSB series cells have a splash-proof sealing cover and come in sizes from 50 to 1000 lbf.

DOUBLE BENDING BEAM CELL

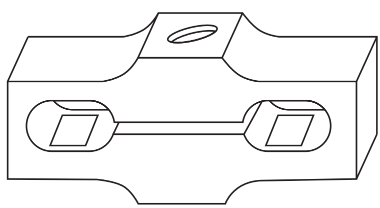

Figure 9. SML Double Bending Beam

A very useful variation on the bending beam design is achieved by forming two bending beams into one cell. This allows the loading fixtures to be attached at the threaded holes on the center line, between the beams, which makes the sensitive axis pass through the cell on a single line of action. In general, this configuration is much more user-friendly because of its short vertical dimension and compact design.

The Interface® SML Series load cells are available in capacities from 5 to 1000 lbf. The 5 and 10 lbf cells can also be ordered with tension/compression overload protection, which makes them very useful for applications in which they could by damaged by an overload.

S-BEAM CELLS

The Interface® SM (Super-Mini) Series load cells are a low-cost, yet accurate, cell with a straight-through loading design (*Figure 10*). At slightly higher cost, the SSM (Sealed Super-Mini) Series is a rugged S-Cell with splash-proof covers. Either series gives exceptional results in applications that can be designed so as to operate the cells in tension.

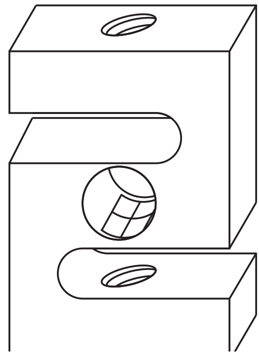

Figure 10. Typical S-Beam

Although the forces on the gaged area appear the same as in a bending beam cell, the theory of operation is slightly different because the two ends of the "S" bend back over center, and the forces are applied down through the center of the gaged area. However, considering it as a modified bending beam cell may assist the reader in visualizing how the cell works.

Some caution should be exercised when using these cells in compression to ensure that the loading does not introduce side loads into the cell. As we shall see later, the LowProfile® Series is better-suited to applications that may apply side loads or moment loads into the cell.

SMT OVERLOAD PROTECTED S-CELL

The incorporation of overload protection is a major innovation in S-Cell design. By removing the large gaps at the top and bottom, and replacing them with small clearance gaps and locking fingers, the whole cell can be made to "go solid" in either mode (tension or

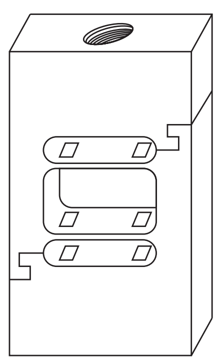

Figure 11. SMT Overload-Protected Flexure

compression) before the deflection of the gaged area exceeds the allowed overload specification. Those gaps and fingers can be seen in *Figure 11*, which shows the flexure with the covers removed. The double-stepped shape of the gaps is necessary to ensure that overload protection operates in both modes.

The SMT Series is ideally suited for applications that may generate forces as high as eight times the rating of the load cell. The two loading holes are vertically aligned, which makes the cell easy to design into machines that apply reciprocating or linear motion, either from a rotating crank or from a pneumatic or hydraulic cylinder.

The covers provide physical protection for the flexure, but the cell is not sealed. Users should therefore be cautioned not to use it in dusty applications that might build up collections of dust in the overload gaps. Should a buildup occur, the overload protection would come into effect before the load reaches the rated capacity, thus causing a non-linear output.

The SMT Series is especially suited for use in laboratories or medical facilities where large loads could be applied accidentally by untrained or non-technical personnel.

LBM AND LBS LOAD BUTTON CELLS

Figure 12. LBM Load Button

Many applications require the measurement of forces in a very confined space. Where high precision is required, the Interface® LowProfile® cell is the obvious choice. However, where space is at a premium, the smaller LBM or LBS can fulfill the need for force measurements at a very respectable precision level that is sufficient for most applications.

Figure 13. LBS Miniature Load Button

These miniature compression cells range in capacities from 10 lbf to 50,000 lbf. Diameters range from 1 inch to 3 inches, with heights from 0.39 inch to 1.5 inches. The shaped load button has a spherical radius to help confine misaligned loads to the primary axis of the cell.

SPI SINGLE POINT IMPACT CELL

Although the SPI resembles competing weigh pan cells, it was specifically designed to have greater than normal deflection at full scale in order to provide for the addition of stops to protect the cell against compression overloads. This was necessary because the usual deflection of 0.001 inch to 0.006 inch of most load cells is much too small to allow for the accurate adjustment of an external stop to protect the load cell.

SPI cells with capacities of 3 lbf, 7.5 lbf, and 15 lbf contain their own internal compression overload stop, which is adjusted at the factory to protect the cell up to four times the rated capacity. These cells have an additional bar under the lower surface, to provide a mount for the internal compression stop screw. Capacities of 25 lbf, 50 lbf, 75 lbf, and 150 lbf can be protected by placing hard stops under the corners of a weigh pan to catch the pan before excessive deflection damages the SPI cell.

Figure 14 shows the internal layout that is typical of the larger capacities of the SPI. The cell mounts to the scale frame on the step at the lower left corner, while the scale pan is mounted on the upper right corner with its load centroid over the primary axis at the center of the cell.

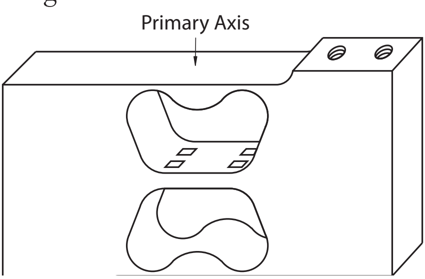

Figure 14. Typical SPI Flexure Layout

The center bar, containing the gages, is a bending beam. It is supported by the outer frame containing four thin flexure points, two on the top and two on the bottom, to provide mechanical strength for side loads and moment loads. This construction provides the superior moment canceling capability of the SPI, which ensures a consistent weight indication anywhere within the weigh pan size limits.

The SPI is also very popular with universities and test labs for its precision and ruggedness. It is also very convenient for lab use. Fixtures and load pans can be mounted easily on the two tapped holes on the top corner.

1500 LOWPROFILE® ROTATED BENDING BEAM

The Interface® Model 1500 combines the moment canceling advantages of the LowProfile® design, with the lower capacity desired by many customers who have precision testing applications.

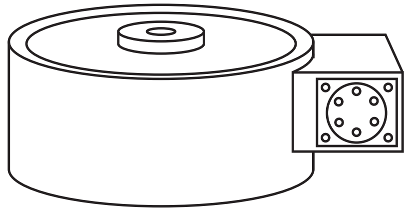

Figure 15. Model 1500 Outline

Although the external appearance of the 1500 is quite similar to that of the 1000 Series cells, the internal construction is quite different. *Figure 16* shows the cross section of one of the two crossed beams, and the similarity to the SML double-ended beam is obvious. Moreover, the additional crossed beam, at 90 degrees to the beam shown in section, ensures moment stability in all directions around the primary axis.

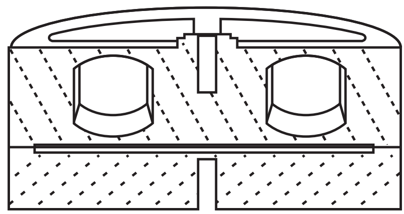

Figure 16. Model 1500 Flexure (Cross Section View)

The Model 1500 is available in capacities from 25 to 300 lbf to complement the Model 1200, whose lowest capacity is 300 lbf. In addition, the diameter of the Model 1500 is only 2.75 inches, and the connector orientation allows better clearance for the mating connector to clear nearby objects.

Note that the base is integral with the cell, which aligns the whole cell for straight-through applications. The balanced design around the primary axis ensures maximum cancellation of moment forces. The cell is sealed to protect it from the environment in typical production situations.

FLEXURE CONFIGURATIONS: SHEAR BEAMS

SSB SHEAR BEAM CELL

From the outside, a shear beam cell might look identical to a bending beam cell, but the theory of operation is entirely different. When the covers are removed we can see that the large hole, instead of passing all the way through the cell, is actually bored part of the way through from either side, leaving a thin, vertical web in the center of the cell. You can see the gage mounted on that web in *Figure 17*.

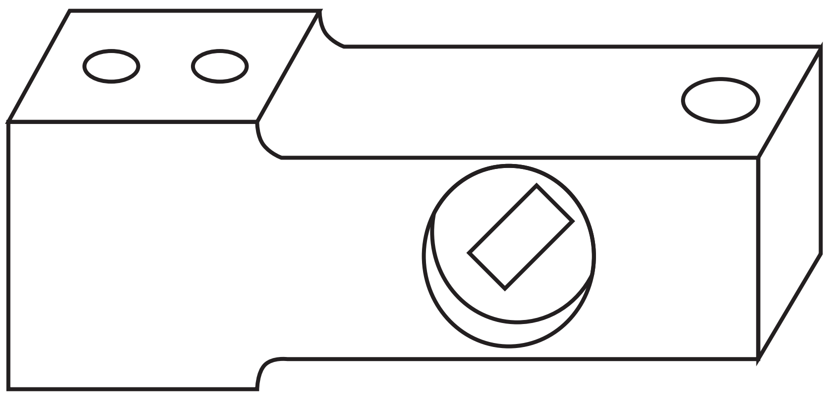

Figure 17. Sheer Beam Flexure

Notice that the gage is pictured as oriented at 45 degrees to the vertical; this is to remind the reader that the application of a force on the end of the beam causes the web to be stressed in shear, which has a maximum effect at 45 degrees.

The shear beam design is typically used to make larger capacity beam cells because they can be made to be more compact than a bending beam cell of the same capacity. Mounting of either cell is similar; because there is considerable moment loading on the mounting end of the beam, the larger capacities require Grade 8 mounting bolts to provide enough tensile strength to withstand the forces under full load.

LOWPROFILE® SHEAR BEAM CELL

This structure was a dramatic advance in the design of precision load cells, first introduced to the precision measurements community by Interface® in 1969. It offered higher output, better fatigue life, better resistance to extraneous loads, a shorter load path, greater stiffness, and the possibility of compression overload protection integral to the cell.

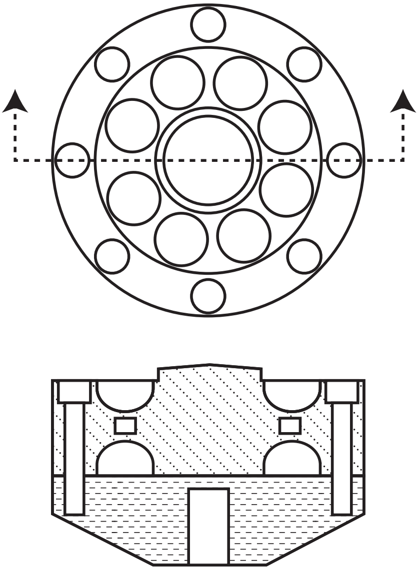

Figure 18. Model 1111 Cutaway views

The top view in *Figure 18*, with the sealing diaphragms removed, shows how the eight holes are bored down through the flexure to leave eight shear webs, formed by the material left between the holes after the boring operation.

Referring to the section through the flexure in *Figure 18*, the reader can visualize how the radial shear webs, along with the center hub and the outside rims on both sides, resemble two shear beam cells end-to-end. The LowProfile® cell thus exhibits the stability of a double-ended shear beam, augmented by the fact that the circular design is the equivalent of four double-ended cells, thus providing stability in eight directions about the center point.

The two gages shown in *Figure 18* are aligned straight across, rather than at 45 degrees because the gages themselves have their grid lines set at 45 degrees. (*See Figure 19*)

Figure 19. Shear Gage

Figure 18 also shows the base, bolted to the flexure around its outside rim. The base is a flat surface, guaranteed to provide optimum support for the flexure. Use of the base, or a support surface with its equivalent flatness and stability, is required to ensure the exceptional performance of the LowProfile® Series. Note that the threaded hole in the base is on center, and a plug is permanently installed to seal dirt and moisture out of the space between the bottom hub of the flexure and the flat surface of the base.

The LowProfile® Series comes in both compression models and universal models. The standard configuration for compression cells is shown in *Figure 20*. The bolts for mounting the cell to the base are socket head cap screws, flush with the top surface, so that the load button protrudes above the top surface of the cell for clearance. The integral load button has a spherical surface, to minimize the effects of misaligned loading on the output. The seven-wire cable version is stocked, because users prefer the extra protection against moisture intrusion into the electrical system. Connector versions are available as a factory option, where the cells will be protected against the environment.

Figure 20. Model 1211BAY-1K-B

The standard configuration for universal cells is shown in *Figure 21*. Hex head machine bolts are used to mount the cell to the base, although socket head cap screws can be provided as a factory option. The electrical connections are brought out to a PC04E-10- 6P connector on stock cells, and several connector styles are also available on special order.

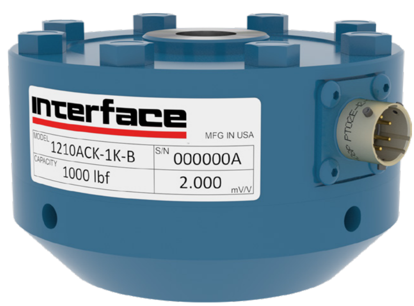

Figure 21. Model 1210ACK-1K-B

Compression overload protection is available as an option on both compression cells and universal cells. It provides protection up to 500% of rated capacity on cells up to 25,000 lbf rating, and up to 300% of rated capacity on larger cells. (See our catalog for restrictions on Fatigue Rated cells.) This protection is obtained by limiting the travel of the center hub as it is deflected under load toward the flat surface of the base. (See *Figure 18*.) By carefully grinding and lapping the mounting surface of the cell, the gap between the hub and the base is adjusted so that the hub hits the base at about 110% of rated capacity. Any further loading drives the flat hub surface against the base, with very little further deflection. Since this total deflection is of the order of 0.001″ to 0.004″, this critical adjustment can be done only at the factory, where the cell is mated to the base and tested as a completed assembly.

> *NOTE:*
> *This overload protection operates only in compression and is available on both compression and universal cells, except for fatigue rated cells (see below).*

The LowProfile® Family is available in three major application series: Precision, Ultra Precision, and Fatigue Rated. The smaller cells, from 250 lbf to 10,000 lbf capacity, are in a package 4.12″ in diameter and 1.38″ thick. Intermediate capacities are contained in packages of 4.75”, 6.06”, 7.50”, 8.00”, and 8.25” diameter, from 1.75” to 2.50” thick. The largest universal cell, at 200,000 lbf capacity, is 11” in diameter and 3.5” thick.

The basic construction of all the cells in the family is quite similar. The major differences within each series are in the number of shear beams and the number of gages in the legs of the bridge. The product differentiation between the types relates to the specific application that they are designed to support.

EXTRANEOUS LOAD SENSITIVITY

One process step that is standard in all LowProfile® Series cells is the adjustment of extraneous load sensitivity. Although the design itself cancels out the bulk of this sensitivity, Interface® goes one step further and adjusts each cell to minimize it even more.

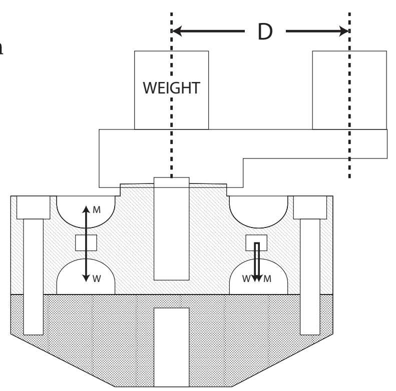

Figure 22. Moment Adjustment

Figure 22 shows a simplified view of a moment testing setup. Assuming a weightless arm mounted on a load cell’s hub, the load cell’s flexure will be stressed by the application of weight (*W*) on the centerline of the cell. The stress vectors are shown as (*W*) in the detail in *Figure 23*.

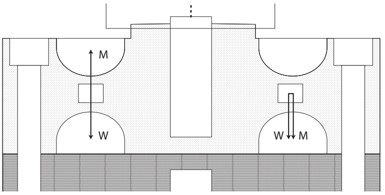

Figure 23. Weight and Moment Vectors

Notice that there is an equal (*W*) vector on both the right side and the left side of the flexure, because the force of the weight is on the centerline of the cell. The gages are wired into the bridge circuit so as to sum up all the force vectors acting in the same direction in the cells ' shear webs, so the weight vectors in this example are additive.

If we now move the weight to the end of the arm, (*D*) distance off the centerline, the cell sees the weight vectors and also a new set of vectors due to the moment (*M*), the twisting action that is caused by the weight's position at the end of the arm, tending to push down on the web on the right side and pull up on the web on the left side.

Remembering that the gages are connected so as to add the (*W*) vectors, we can see that the (*M*) vectors will cancel, thus not causing any output signal due to the moment. This statement will be true, of course, only if both webs are exactly the same dimension and if the two gages have exactly the same gage factor. In practice, everything has a tolerance, so the cancellation of moments probably won't be within specified limits when the cell is first assembled. In actual practice, the test station is designed so that the arm can be rotated to any position, and each pair of webs is tested and adjusted for optimum cancellation of moments.

THE LOWPROFILE® PRECISION SERIES

This series, with capacities from 300 lbf to 200,000 lbf forms the backbone of the force testing capability at companies all over the world. It features very competitive prices combined with specifications that satisfy the majority of force-testing applications. It offers 4 mV/V output in 5,000 lbf and greater capacities, resistance to extraneous loads, a short load path, very low compliance (high stiffness), and a very respectable static error band specification (±0.04% to 0.07% FS).

THE LOWPROFILE® ULTRA PRECISION SERIES

This series, with capacities from 300 lbf to 200,000 lbf, was developed to satisfy the most demanding requirements of sophisticated testing labs. It features a very moderate price adder over the Precision Series, combined with specifications that are better than the Precision Series cells in the critical parameters such as static error band (±0.02% to 0.06% FS), non-linearity, hysteresis, non-repeatability, and extraneous load sensitivity.

THE LOWPROFILE® FATIGUE RATED SERIES

This series, with capacities from 250 lbf to 100,000 lbf, is the industry standard in the world of aerospace fatigue testing. It features a guaranteed fatigue life of 100 million fully reversed load cycles. Although constructed in the same packages as the Precision Series, the Fatigue Rated Series has tighter specifications on resistance to extraneous loads and offers stiffer compliance, for example, 33,000,000 lb/inch in the 100,000 lbf capacity. Since fatigue testing generally involves applying bimodal forces to test samples through the load cell, compression-only cells are not available in this series. Also, because of the cells' very low deflections, overload protection is not available.

People generally have an idea about the meaning of the word "fatigue," as it relates to the failure of a truck spring, for example. They envision the part, after thousands of hours of operation under vibration and shock loads, finally just "giving up" and failing. However, the phrase "fatigue rated," as it applies to an Interface® load cell, has a much more distinct and well-defined meaning.

FATIGUE RATED LOAD CELLS

An Interface® Fatigue Rated load cell will still meet its performance specifications after being subjected to 100 million fully reversed load cycles. Also, its static overload rating is 300% in both modes—tension and compression.

The fatigue-rated design was developed to support the critical testing requirements in the aerospace engineering. Not only was it necessary to have a load cell which would survive while driving the life test of critical aircraft and missile parts, but it was also crucial that the load cell still meet the specifications during the whole test in order to avoid having to repeat expensive tests due to failure of a load cell.

Another advantage of the LowProfile® design was the ability to install two, sometimes three, or in some cases four electrically isolated bridges in one load cell package. Many customers used this feature to provide a backup recording of the whole test, from the (*B*) bridge, to verify the test in the event of a failure in the primary data chain from (*A*) bridge of the load cell. The (*B*) bridge is thus able to back up the test system for either a failure of Bridge (*A*) in the load cell itself or for the failure of any element in the data/recording channel for Bridge (*A*).

A more technically complete explanation of fatigue as it applies to load cell flexure design is published in the Interface® catalog and on the Interface® website.

COMPRESSION LOADING

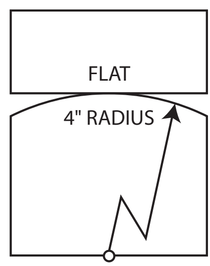

Figure 24. Load Button and Plate.

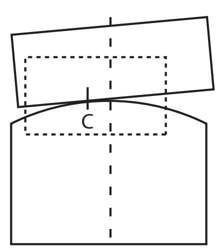

Figure 25. Five Degree Misalignment

The application of compression loads on a load cell requires an understanding of the distribution of forces between surfaces of various shapes and finishes.

The first, and most important, rule is this: Always avoid applying a compression load flat-to-flat from a plate to the top surface of a load cell hub. The reason for this is simple: it is impossible to maintain two surfaces parallel enough to guarantee that the force will end up being centered on the primary axis of the load cell. Any slight misalignment, even by a few microinches, could move the contact point off to one edge of the hub, thus inducing a large moment into the measurement.

One common way to load in compression mode is to use a load button. Most compression cells have an integral load button, and a load button can be installed in any universal cell to allow compression loading. Minor misalignments merely shift the contact point slightly off the centerline. *Figure 25* shows a major misalignment, and even the five degrees shown would shift the contact point only ⅜" off center on a load button having a 4" spherical radius, which is the type normally used on load cells up to 10,000 lbf capacity. For 50,000 lbf loading, a 6" radius is used, and for 200,000 lbf loading a 12" radius is used.

In addition to compensating for misalignment, the use of a load button of the correct spherical radius is absolutely necessary to confine the stresses at the contact point within the limits of the materials. Generally, load buttons and bearing plates are made from hardened tool steel, and the contacting surfaces are ground to a finish of 32μ inch RMS.

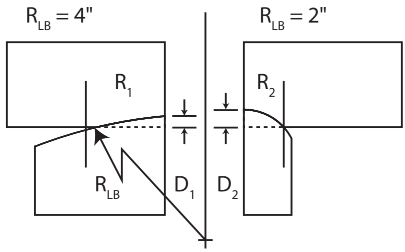

Figure 26. Indentation of Correct Load Button Spherical Radius vs. Smaller Radius

Use of too small of a radius will cause failure of the material at the contact point, and a rough finish will result in galling and wear of the loading surfaces. The half sections in *Figure 26* show (in exaggerated form) the indentation radius (R_1) on a flat plate caused by a load button having a 4-inch spherical radius and the corresponding indentation (D_1). The strains transmitted into the flat plate by a 10,000 lbf load are well within the specs for hardened steel. Compare that with the indentation radius (R_2) and the corresponding indentation (D_2). In this case, the strains could actually cause the steel to fracture.

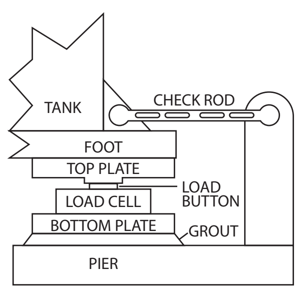

Figure 27. Typical Compression Foot and Check Rod installation.

Any one of the cells that have been described so far can be used in compression by mounting a load button in the cell and providing a smooth, hardened steel plate to apply the load to the cell. The disadvantage of this application is that although the load will be supported properly for weighing, it will not be constrained from moving horizontally. The usual solution for this problem is to provide check rods that are strategically placed to tie the load to the support framework. Of course, it is essential that these rods be exactly horizontal; otherwise, they will induce forces into the weighing system which don't reflect the true loading.

WeighCheck™ Weighing System

The complex mountings and check rods in a compression weigh system can be replaced in most cases with the simple, innovative self-storing and self-checking system that will be developed in *Figure 28* and depicted in *Figure 29*.

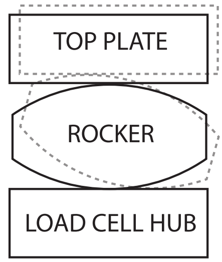

Figure 28. "Football" Self-Centering System.

Note that as the rocker rotates, the top plate rises. Thus, the weight of the load will tend to return the rocker to its original position. The spherical radius of the "football" can be very large, but it can be made much shorter than the equivalent round ball. The reader could imagine making a rocker by slicing a thick horizontal section out of a round ball and then gluing the remaining two pieces together.

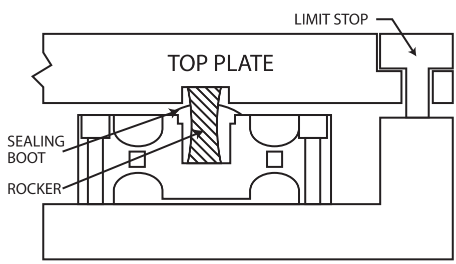

Figure 29. WeighCheck Weigh Mount.

In *Figure 29*, the rocker is modified even more drastically to remove all the unnecessary material. The only spherical surfaces that remain are at the top and bottom, so as to make contact with the top plate and the loading surface inside the load cell. The sealing boot is made of molded rubber to keep dirt and water away from the lower surface of the rocker. The boot is held down against the hub of the load cell by a lip on the rocker.

There are two limit stops, one at each end of the top plate, formed by oversize clearance holes in the top plate and shoulder bolts, which are screwed firmly into each end of the bottom plate. These limits operate both horizontally and vertically to contain the system in all directions.

The unique rocker provides a weigh mount with an extremely LowProfile®, only 4" tall in the low capacities (5,000 and 10,000 lbf) and 5" tall in the high capacities (25,000 and 50,000 lbf). It is available in a tool steel version or a stainless steel version.

ADVANTAGES OF THE LOWPROFILE® CELL

- The thermal path is massive and surrounds the whole cell. The thermal path between the outside surface and all the gages is very short. Temperature gradients are almost non-existent, and they settle out very quickly.
- Compensating resistors are mounted on the flexure, in close proximity to the gages.
- The diaphragms are used only as a sealing mechanism, not as a support, so they do not introduce appreciable errors into the cell.
- There are two opposing diaphragms, one on the top and one on the bottom of the cell. Their opposing forces due to pressure are equal and opposite, thus canceling out pressure effects.
- The cell is short and squat, thus making it much easier to integrate into many system designs.
- The design is intrinsically moment-canceling and is rotationally symmetrical. In addition, moment cancellation is enhanced by special testing and adjustment in the factory.
- Since the cross-sectional area of the flexure does not change appreciably with loading, the output is intrinsically more linear and is also symmetrical between tension and compression modes.
- The overall LowProfile® design is compact, with all the components bonded to the flexure structure, thus making it better able to withstand the 100 million cycle fatigue life.

THE COLUMN LOAD CELL

Column load cells are a great option for high force applications that require a very small foot print – 100K lbf capacity and above. They are popular in applications where it is not possible to install a high capacity LowProfile® load cell with a large diameter. They are available in a variety of configurations including compression-only, and any combination of internal or external threads on the top and bottom.

The cross-section view in *Figure 30* shows the components of the simple column cell. The "flexure" is the heavy column (*A*) running up the center of the cell, with massive blocks at the top and bottom and a thin, usually square, column in the center. This column plus the heavy outer shell and the diaphragms (*B*) are the basic support elements for the measurement flexure, the column (*A*) which runs from (S_1) to (S_2).

The column stress between (S_1) and (S_2) is about the same anywhere along its length, so the main gages (C_1 & C_2) are placed in the center, at (S_g). Compensation for the nonlinearity of the column design can be accomplished by using a semiconductor strain gage (*F*), or additional flexure design modifications.

Loads are applied by the customer's fixtures, which can be screwed into the threaded holes at the top and bottom ends of the column.

The "doghouse" on the side of the casing contains the bridge compensating resistors (*D*), which are wired (*E*) to the gages.

Due to its geometry, column load cells can be more sensitive to off center loading than a LowProfile® load cell, but they still perform well in the right applications.

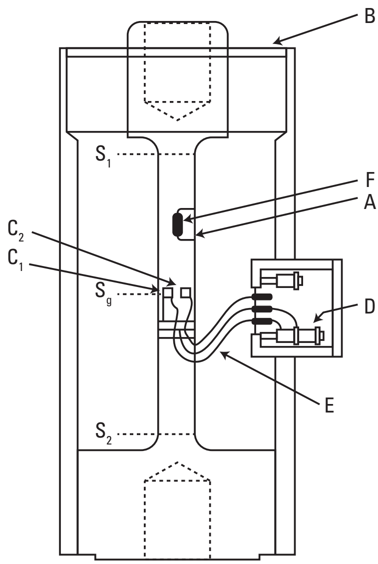

Figure 30. Column Load Cell.

INPUT/OUTPUT CHARACTERISTICS AND ERRORS

GAGE INTERCONNECTION CONFIGURATIONS

Strain gages have been used for many decades for measuring the stresses in mechanical components of aircraft and other active and passive structures.

Sometimes one simple gage can give the necessary information, and in those instances where hundreds or even thousands of gages are needed to implement a large test, use of the quarter bridge configuration of *Figure 31* is a cost control necessity. The only active bridge leg (a strain gage) is shown as (*AC*), and the other three inactive legs (*AB*, *BD*, *& CD*) are fixed resistors, simulating a complete bridge.

In certain cases it is even possible to use the quarter bridge in a load cell. This is the case where temperature compensation and moment compensation are not a necessity, as in a cheap bathroom scale.

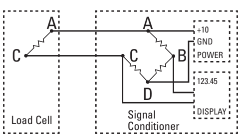

Figure 31. Quarter Bridge Connection

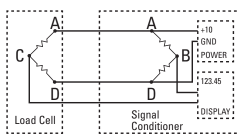

Figure 32. Half Bridge Connection

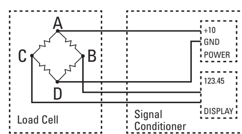

Figure 33. Full Bridge Connection

The half bridge connection is usually used for low-cost load cells that are designed for specific OEM applications when customers can adapt a special design to make use of the cell's unique parameters.

The full bridge is the only one that has enough active legs to allow for easy compensation for temperature coefficients of both zero and span and to allow adjustment of moment sensitivity.

Other parameters being equal, a full bridge has twice the output of a half bridge and four times the output of a quarter bridge.

TEMPERATURE EFFECT ON ZERO AND OUTPUT

Interface® proprietary gages are designed specifically to compensate for the temperature effect on the modulus of elasticity of the flexure material, thus providing essentially a constant output over the compensated temperature range. The specification for each load cell series states the coefficient, which is typically ±0.08% per 100°F.

A small zero balance shift, due to the differences between the temperature coefficient of resistance of the gages, must be tested and adjusted at the factory.

The usual method in the load cell industry uses only two temperatures, ambient room temperature and 135°F. The best result that can be obtained by this method is shown in *Figure 34* as the "room-high compensated" curve.

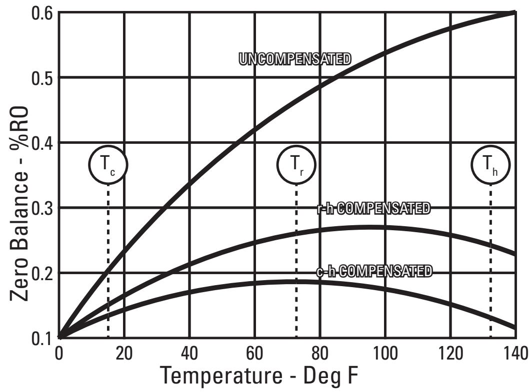

Figure 34. Temperature Compensation, Zero Balance

At Interface®, the test is run at both low and high temperatures. This method is more costly and time-consuming, but it results in the (*C-H Compensated*) curve, which has two distinct advantages.

- The curve's maximum occurs near room temperature. Thus, the slope is almost flat over the most-used temperatures near room ambient.
- The overall variation over the compensated temperature range is much less.

The graphs of *Figure 35* and *Figure 36* show, separately, the effect of temperature on zero balance and output, so it is easier for the reader to visualize what happens to the signal output curve of the load cell as the temperature is varied. Notice that zero shift moves the whole curve parallel to itself: while output shift tips the slope of the output curve.

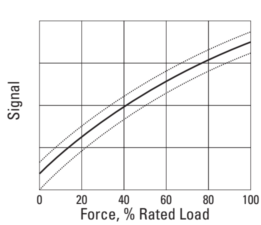

Figure 35. Temperature Effect on Zero

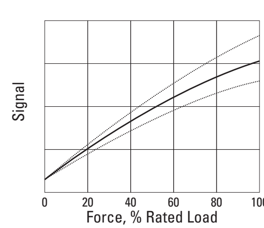

Figure 36. Temperature Effect on Output

LOAD CELL ELECTRICAL OUTPUT ERRORS

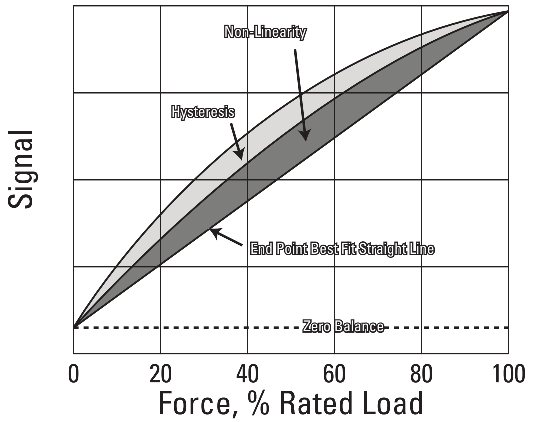

Figure 37. Simplified Error Graph

When a load cell is first calibrated, it is exercised three times to at least its rated capacity in order to erase all history of previous temperature cycles and mechanical stresses. Then loads are applied at several points from zero to the rated capacity. The typical production test for a LowProfile® cell consists of five ascending points and one descending point, which is called the "hysteresis point" because hysteresis is determined by noting the difference between the outputs at the ascending point and corresponding descending point, as shown in *Figure 37*. Hysteresis is usually tested at 40 to 50 percent of full scale, the maximum load in the test cycle.

There are many definitions of "best fit straight line," depending on the reason why a linear representation of the output curve is needed. The end point line is necessary in order to determine non-linearity, the worst case deviation of the output curve from the straight line connecting the zero load and rated load output points (See *Figure 37*).

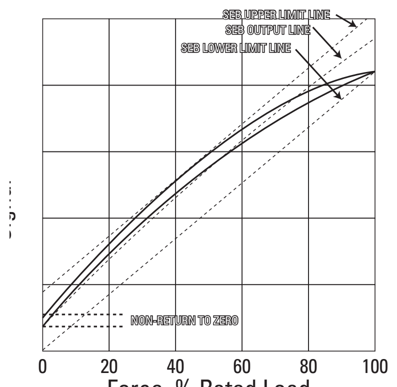

Figure 38. Static Error Band

A more sophisticated and useful straight line is the SEB Output Line, a zero-based line whose slope is used to determine the Static Error Band (*SEB*). As shown in *Figure 38*, the static error band contains all the points, both ascending and descending, in the test cycle. The upper and lower limits of the SEB are two parallel lines at an equal distance above and below the SEB Output Line.

> *NOTE:*
>
> *The reader should keep in mind that the non-linearity, hysteresis, and non-return to zero errors are grossly exaggerated in the graphs to demonstrate them visually. In reality, they are about the width of the graph lines.*

RESISTANCE TO EXTRANEOUS LOADS

All load cells have a measurable response when loaded on the primary axis. They also have a predictable response when a load is applied at an angle from the primary axis. (See *Figure 39* and *Figure 40*.) The curve represents the equation:

“Relative Off-Axis Output”=(“On-Axis-Output”)×(cosΘ)

For very small angles, such as the misalignment of a fixture, the cosine can be looked up in a table and will be found to be quite close to 1.00000. For example, the cosine of ½ degree is 0.99996, which means the error would be 0.004%. For 1 degree, the error would be 0.015%, and for 2 degrees, the error would be 0.061%. In many applications, this level of error is quite negligible. For large angles, it would be advisable to calculate the moment that is induced in the cell in order to ensure that an overload condition will not occur.

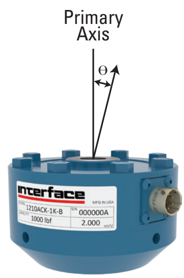

Figure 39. Off-Axis Loading

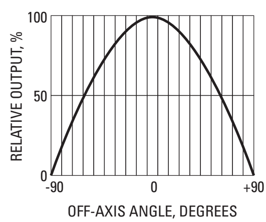

Figure 40. Relative Output vs Angle

Because of the close tolerance machining of flexures, the matching of gages; and precision assembly methods, all

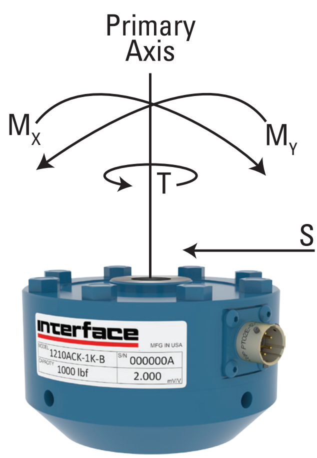

Figure 41. Extraneous Load Vectors

Interface® load cells are relatively insensitive to the extraneous loads shown in *Figure 41*: moments (M_X & M_Y), torques (T), and side loads (S). In addition, the resistance to extraneous loads of the LowProfile® Series is augmented by an additional step in the manufacturing process, which adjusts the moment sensitivity to a tighter specification.

CAUTION:

Take care not to exceed the torque allowances in the specifications. The torque figures for attaching fixtures to a load cell are much less than the Mechanics Handbook values for the same sized threads.

SYSTEM ERRORS

Customers frequently ask, "What are the resolution, repeatability, and reproducibility of Interface® load cells?" The answer is, "Those are system parameters, not load cell parameters, which depend on (1) the proper application of the load cell, (2) the forcing systems and mechanical fixtures used to apply the loads, and (3) the electrical equipment used to measure the load cell output."

Load cell resolution is essentially infinite. That is to say that if the user is willing to spend enough money to build a temperature-stable, force-free environment and to provide extremely stable, high-gain electronics, the load cell can measure extremely small increments of force. The most difficult problems to solve are temperature variations from heating/cooling systems, forces such as air motion and building vibration, and the inability of hydraulic forcing systems to maintain a stable pressure over time. It is very common for users to demand, pay for, and receive too much resolution in measuring equipment. The result is outputs that are difficult to read, because the display digits are continually rolling due to instabilities in the overall system.

Nonrepeatability is frequently blamed on the load cell, until the user takes the trouble to analyze and track down all the causes of so-called "erratic" readings. Under optimum mechanical and electrical conditions, repeatability of the load cell itself can be demonstrated to be at the same order of magnitude as resolution—far better than is necessary in any practical force measurement system.

Repeatability is affected by any one of the following factors:

- Tightness of the mechanical connection of fixtures
- Rigidity of the load frame or force application system
- Repeatability of the hydraulic forcing system itself
- Application of a dead weight load too quickly, causing over-application of the force due to impact
- Poor control of reading times, introducing creep into the data
- Unstable electronics due to temperature drift, power line susceptibility, noise, etc.

Reproducibility is the ability to take measurements on one test setup and then repeat them on a different test setup. The two setups are defined as different if one or more element in the setup is changed. Therefore, inability to repeat a set of measurements could be found in a facility where only one fixture was changed. Or, a discrepancy could be uncovered between two test facilities, which could become a major problem until the differences between the two are analyzed and corrected.

Reproducibility is a term not heard very often, but it is the very essence of the calibration process by which a cell is calibrated at one location and then used to measure forces at another location.

Reproducibility is achieved most easily by using Interface® Gold Standard® load cells. The low moment sensitivity makes them less susceptible to misalignments in load frames. That, combined with the permanently installed loading stud, high output, and low creep, makes them the cell of choice with users who cannot compromise—those who need the very best.

Interface® is the trusted The World Leader in Force Measurement Solutions®. We lead by designing, manufacturing, and guaranteeing the highest performance load cells, torque transducers, multi-axis sensors, and related instrumentation available. Our world-class engineers provide solutions to the aerospace, automotive, energy, medical, and test and measurement industries from grams to millions of pounds, in hundreds of configurations. We are the preeminent supplier to Fortune 100 companies worldwide, including; Boeing, Airbus, NASA, Ford, GM, Johnson & Johnson, NIST, and thousands of measurement labs. Our in-house calibration labs support a variety test standards: ASTM E74, ISO-376, MIL-STD, EN10002-3, ISO-17025, and others.

You can find more technical information about load cells and Interface®'s product offering at www.*interfaceforce.com*, or by calling one of our expert Applications Engineers at *480.948.5555*.