

This effect is most noticeable when the excitation voltage is first turned on. The obvious solution for this effect is to allow the load cell to stabilize by operating it with 10 VDC excitation for the time required for the gage temperatures to reach equilibrium. For critical calibrations this may require up to 30 minutes.

Since the excitation voltage is usually well regulated to reduce measurement errors, the effects of excitation voltage variation are typically not seen by users except when the voltage is first applied to the cell.

Remote Sensing of Excitation Voltage

Many applications can make use of the four-wire connection shown in Figure 3. The signal conditioner generates a regulated excitation voltage, V_x , which is usually 10 VDC. The two wires carrying the excitation voltage to the load cell each have a line resistance, R_w . If the connecting cable is short enough, the drop in excitation voltage in the lines, caused by current flowing through R_w , will not be a problem.

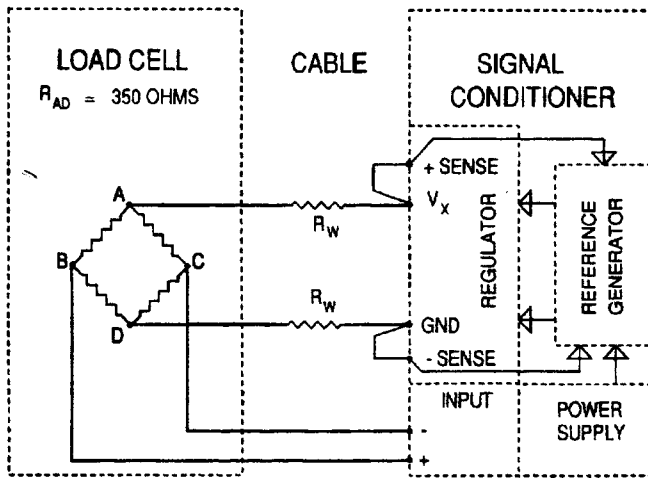


Figure 3. Four-Wire Connection

Figure 4 shows the solution for the line drop problem. By bringing two extra wires back from the load cell, we can connect the voltage right at the terminals of the load cell. Thus, the regulator circuit can maintain the excitation voltage at the load cell precisely at 10 VDC under all conditions.

This six-wire circuit not only corrects for the drop in the wires, but also corrects for changes in wire resistance due to temperature.

Figure 5 shows the magnitude of the errors generated by the use of the four-wire cable, for three common sizes of cables.

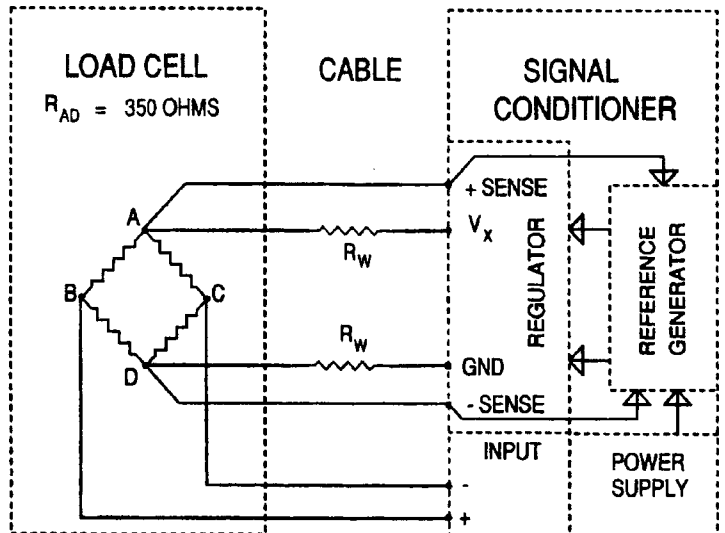


Figure 4. Six-Wire Remote Sense Connection

The graph can be interpolated for other wire sizes by noting that each step increase in wire size increases resistance (and thus line drop) by a factor of 1.26 times. The graph can also be used to calculate the error for different cable lengths by calculating the ratio of the length to 100 feet, and multiplying that ratio times the value from the graph.

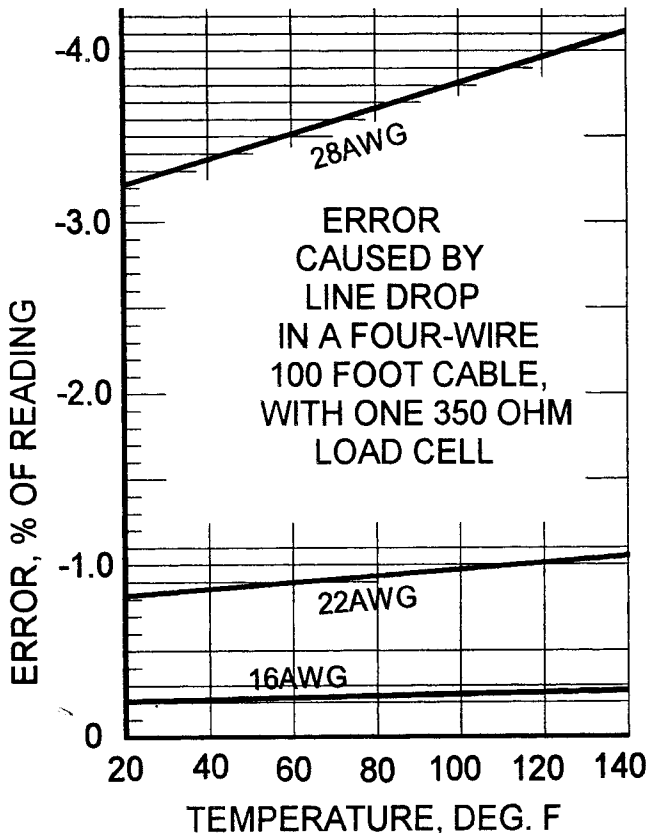


Figure 5. Line Drop vs Temperature for Common Cable Sizes

The temperature range of the graph may seem broader than necessary, and that is true for most applications. However, consider a #28AWG cable which runs mostly outside to a weigh station in winter, at 20 degrees F. When the sun shines on the cable in summer, the cable temperature could rise to over 140 degrees F. The error would rise from -3.2% RDG to -4.2% RDG, a shift of -1.0% RDG.

If the load on the cable is increased from one load cell to four load cells, the drops would be four times worse. Thus, for example, a 100 foot #22AWG cable would have an error at 80 degrees F of:

$$(4 \times 0.938) = 3.752\% \text{ RDG}$$

These errors are so substantial that standard practice for all multiple-cell installations is to use a signal conditioner having remote sense capability, and to use a six-wire cable out to the junction box which interconnects the four cells. Keeping in mind that a large truck scale could have as many as 16 load cells, it is critical to address the issue of cable resistance for every installation.

Simple rules of thumb which are easy to remember:

1. The resistance of 100 feet of #22AWG cable (both wires in the loop) is 3.24 ohms at 70 degrees F.
2. Each three steps in wire size doubles the resistance, or one step increases the resistance by a factor of 1.26 times.
3. The temperature coefficient of resistance of annealed copper wire is 23% per 100 degrees F.

From these constants it is possible to calculate the loop resistance for any combination of wire size, cable length and temperature.

Temperature Effect on Zero and Output: Interface proprietary gages are designed specifically to compensate 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, typically $\pm 0.08\%$ per 100 degrees 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 and 135 degrees F. The best result which can be obtained by this method is shown in Figure 37 as the "room-high compensated" curve.

At Interface, the test is run at both low and high temperature. This method is more costly and time consuming, but it results in the "c-h

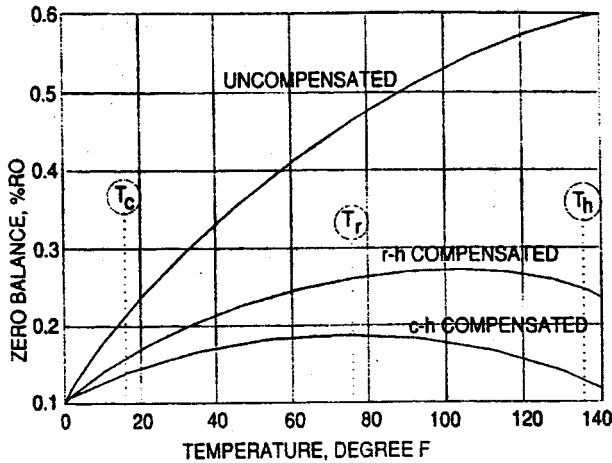


Figure 37. Temperature Compensation, Zero Balance

"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.

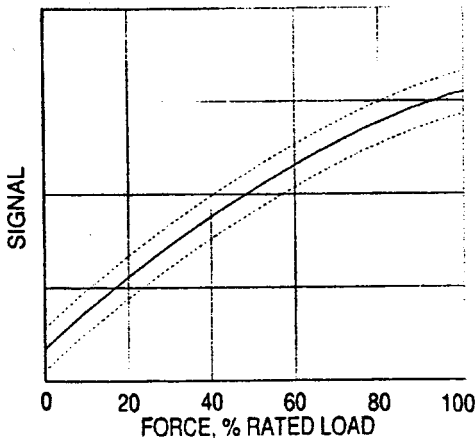


Figure 38. Temperature Effect on Zero

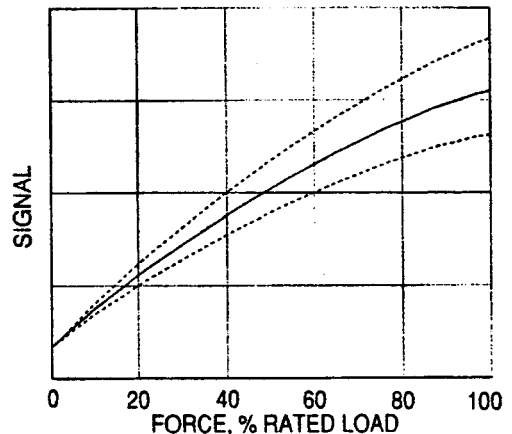


Figure 39. Temperature Effect on Output

The graphs of Figures 38 and 39 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.

Load Cell Electrical Output Errors: When a load cell is first calibrated, it is exercised three times to at least its rated capacity, to erase all history of previous temperature cycles and mechanical stresses. Then, loads are applied at several points from zero to rated capacity. The typical production test for a Low Profile™ cell consists of five ascending points and one descending point, 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 40. Hysteresis is usually tested at 40 to 50 percent of *full scale*, the maximum load in the test cycle.

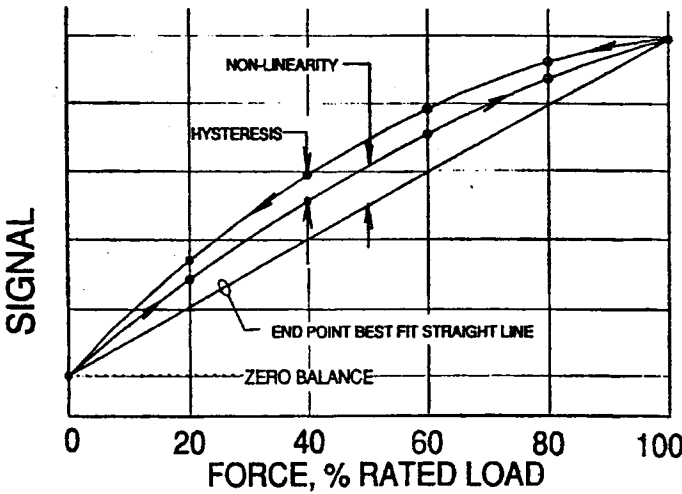


Figure 40. Simplified Error Graph

There are many definitions of "best fit straight line", depending on the reason that 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 40.)

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 41, 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.

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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.

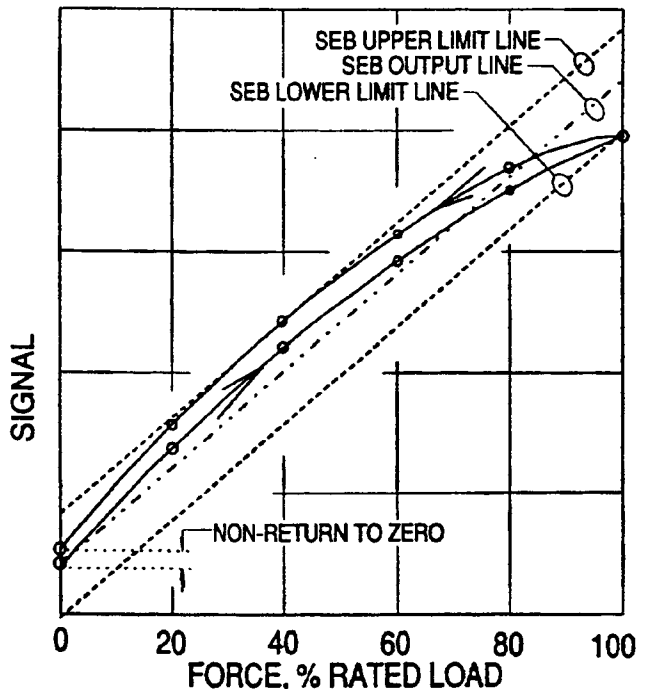


Figure 41. Static Error Band

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 Figures 42 and 43) The curve represents the equation:

$$(\text{Relative Off-axis Output}) = (\text{On-axis output}) \times (\text{cosine } \theta).$$

For very small angles, such as the misalignment of a fixture, the cosine can be looked

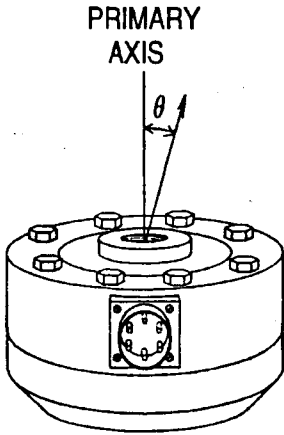


Figure 42. Off-axis Loading

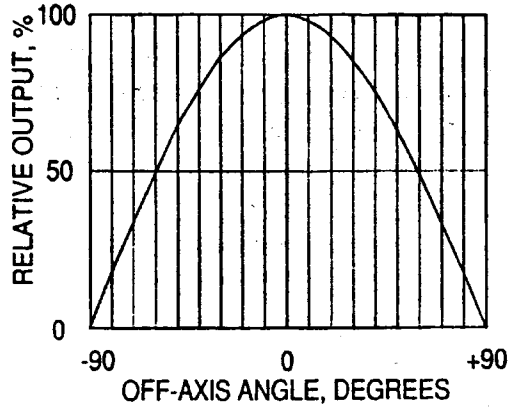


Figure 43. Relative Output versus Angle

up in a table and will be found to be quite close to 1.00000. For example, the cosine of $\frac{1}{2}$ 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 livable. For large angles, it would be advisable to calculate the moment induced in the cell, to insure that an overload condition will not occur.

Because of the close tolerance machining of flexures, the matching of gages, and precision assembly methods, all Interface load cells are relatively insensitive to the extraneous loads shown in Figure 44: moments (M_x and M_y), torques (T), and side loads (S). In addition, the resistance to extraneous loads of the Low Profile™ Series is augmented by an additional step in the manufacturing process which adjusts the moment sensitivity to a tighter specification.

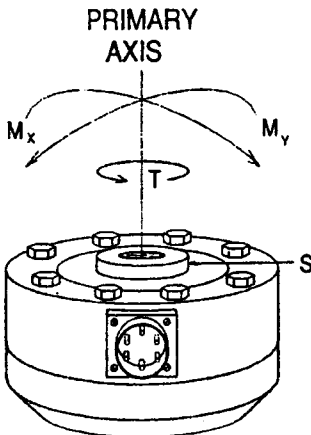


Figure 44. Extraneous Load Vectors

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. and (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 ... 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 get too much resolution in the measuring equipment. The result is readings which are difficult to read, because the display digits are continually rolling due to instabilities in the overall system.

Non-repeatability 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 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 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 one 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, where 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 make them the cell of choice with users who cannot compromise ... who need the very best.