Load Cell Technical Information

Highlights

- Introduction to load cells
- Glossary of terms

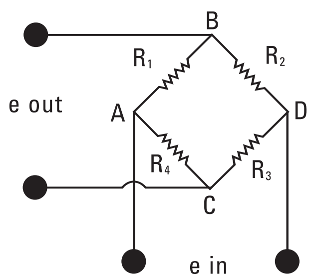

Figure 1.
Wheatstone Bridge

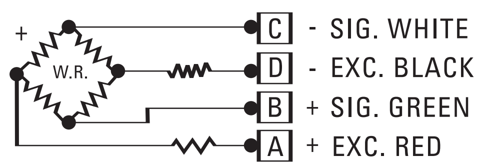

Figure 2.
Load Cell Wiring Code

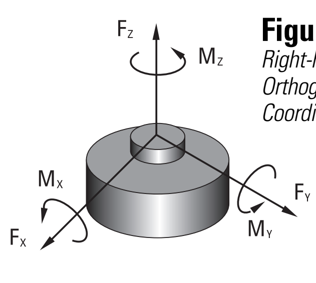

Figure 3.
Right-handed Orthogonal Coordinate System

Principal of Operation

PCB® manufactures a wide variety of load cells whose output voltage is proportional to the applied force produced by a change in resistance in strain gages which are bonded to the load cell's structure. The magnitude of the change in resistance corresponds to the deformation of the load cell and therefore the applied load.

The four-arm Wheatstone bridge configuration shown in **Figure 1** depicts the strain gages used in our load cells. This configuration allows for temperature compensation and cancellation of signals caused by forces not directly applied to the axis of the applied load.

A regulated 5 to 20 volt DC or AC rms excitation is required and is applied between A and D of the bridge. When a force is applied to the transducer structure, the Wheatstone bridge is unbalanced, causing an output voltage between B and C which is proportional to the applied load.

Most all PCB® load cells follow a wiring code established by the Western Regional Strain Gage committee as revised in May 1960. The code is illustrated in **Figure 2**.

Axis Definition

Our load cells comply with the Axis and Sense Definitions of NAS-938 (National Aerospace Standard-Machine Axis and Motion) nomenclature and recommendations of the Western Regional Strain Gage committee.

These axes are defined in terms of a "right handed" orthogonal coordinate system as shown in **Figure 3**.

A tensile load exhibits a positive (+) polarity going output, while a compressive load exhibits a negative (-) polarity going output.

The primary axis of rotation or axis of radial symmetry of a load cell is the z-axis.

Principal of Operation

PCB® manufactures load cells under two classifications. They are general purpose and fatigue-rated.

General Purpose

General purpose load cells are designed for a multitude of applications across the automotive, aerospace, and industrial markets. The general purpose load cell, as the name implies, is designed to be utilitarian in nature. Within the general purpose load cell market there are several distinct categories. They are: precision, universal, weigh scale, and special application. PCB® primarily supplies general purpose load cells into the universal and special application categories. Universal load cells are the most common in industry. Special application load cells are load cells that have been designed for a specific unique force measurement task.

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Special application load cells can be single axis or multiple axis. They include but not limited to:

- pedal effort
- steering column
- crash barrier
- hand brake
- femur
- skid trailer
- tire test
- gear shift

Fatigue-rated Load Cells

Fatigue-rated load cells are specially designed and manufactured to withstand millions of cycles. They are manufactured using premium fatigue-resistant steel or aluminum and special processing to ensure mechanical and electrical integrity, as well as accuracy. Fatigue-rated load cells manufactured by PCB® are guaranteed to last 100 million fully reversed cycles (full tension through zero to full compression). An added benefit of fatigue-rated load cells is their extreme resistance to extraneous bending and side loading forces.

Error Analysis

PCB® typically supplies accuracy information on its products in the form of individual errors. They are: non-linearity, hysteresis, non-repeatability, effect of temperature on zero, and effect of temperature on output.

The customer can combine individual errors to establish the maximum possible error for the measurement, or just examine the applicable individual error. If the temperature remains stable during the test, the temperature related errors can be ignored. If the sensor is used for increasing load measurement only, ignore the hysteresis error. If the load measurement is near the full capacity, the linearity error can be ignored. If the capability exists to correct the data through linearization-fit or a look-up table, the error in the measurement can be minimized. A sophisticated user can get rid of all the errors except for the non-repeatability error in the measurement.

Often overlooked by the customer is the error due to the presence of non-measured forces and bending moments. Even though the single axis of measurement sensors are designed and built to withstand these non-measured forces and bending moments (extraneous loads), the errors due to them are present. PCB® engineers can design the set-up to eliminate or minimize these extraneous loads. However, if these extraneous loads are present, the errors due to them should be considered.

Due to cost restraints, PCB®, as with its competition, does not typically measure or compensate for errors due to extraneous loads. If the presences of these extraneous loads are known, the user should request the transducer manufacturer to run a special test, at extra cost, to define and quantify the extraneous load errors. These errors are defined as cross-talk errors.

Typical Application Examples:

Hydraulic Actuators **Life Cycle Testing** **Quality Control**
Material Fatigue Testing **Torque Arm** **Tank Weighing**

Application Questionnaire

Determine the capacity required

A. What is the maximum expected load?

B. What is the minimum expected load?

C. What is the typical expected load?

D. What are the dynamics of the system, i.e. frequency response?

E. What are the maximum extraneous loads to which the load cell will be subjected?

How will the load cell be integrated into the system?

A. What are the physical constraints, e.g. height, diameter, thread?

B. Will the load cell be in the primary load path or will the load cell see forces indirectly?

What type of environment will the load cell be operating in?

A. Maximum temperature?

B. Minimum temperature?

C. Humidity?

D. Contaminants, (e.g. water, oil, dirt, dust)?

What accuracy is required?

A. Non-linearity?

B. Hysteresis?

C. Repeatability?

D. Cross-talk?

Accuracy —
Stated as a limit tolerance, which defines the average deviation between the actual output versus theoretical output.

In practical transducer applications, the potential errors of non-linearity, hysteresis, non-repeatability and temperature effects do not normally occur simultaneously, nor are they necessarily additive.

Therefore, accuracy is calculated based upon RMS value of potential errors, assuming a temperature variation of ± 10 °F (± 5.5 °C), full rated load applied, and proper set-up and calibration. Potential errors of the readout, cross-talk, or creep effects are not included.

Ambient Conditions —
The conditions (humidity, pressure, temperature, etc.) of the medium surrounding the transducer.

Ambient Temperature —
The temperature of the medium surrounding of transducers.

Calibration —
The comparison of transducer output against standard test loads.

Calibration Curve —
a record (graph) of the comparison of transducer output against standard test loads.

Combined Error —
(Non-linearity and Hysteresis) — the maximum deviation from a straight line drawn between the original no-load and rated load outputs expressed as a percentage of the rated output and measured on both increasing and decreasing loads.

Compensation —
The utilization of supplementary devices, materials, or processes to minimize known sources of error.

Creep —
The change of transducer output occurring with time, while under load, and with all environmental conditions and other variables remaining constant.

Note: Usually measured with rated load applied and expressed as a percent of rated output over a specific period of time.

Creep Recovery —
The change in no-load output occurring with time, after removal of a load, which has been applied for a specific period of time.

Cross-Talk —
With one component loaded to capacity, and the other unloaded, the output of the unloaded component will not exceed the percentage specified of its full-scale capacity.

Deflection —
The change in length along the primary axis of the load cell between no-load and rated load conditions.

Drift —
A random change in output under constant load conditions.

Error —
The algebraic difference between the indicated and true value of the load being measured.

Excitation, Electrical —
The voltage or current applied to the input terminals of the transducer.

Fatigue Capacity —
Capacity as percentage of the nominal load limit capacity, and based on 100 X 10^6 cycles (minimum) from zero to full fatigue capacity and 50 X 10^6 cycles (minimum) from full fatigue capacity tension to full fatigue capacity compression load.

Hysteresis —
The maximum difference between the transducer output readings for the same applied load, one reading obtained by increasing the load from zero and the other by decreasing the load from rated load.

Note: Usually measured at half rated output and expressed in percent of rated output. Measurements should be taken as rapidly as possible to minimize creep.

Insulation Resistance —
The DC resistance measured between the transducer circuit and the transducer structure.

Note: Normally measured at 50 Volts DC and under standard test conditions.

Natural Frequency —
The frequency of free oscillations under no-load conditions.

Nominal Load Limit Capacity —
It is the designed normal maximum capacity of a transducer. Output sensitivity of the transducer is based on this capacity unless specified.

Non-linearity —
The maximum deviation of the calibration curve from a straight line drawn between the no load and rated load output, expressed as a percentage of the rated output and measured on increasing load only.

Output —
This signal (voltage, current, etc.) produced by the transducer.

Note: Where the output is directly proportional to excitation, the signal must be expressed in terms of volts per volt, volts per ampere, etc., of excitation.

Output, Rated —
The algebraic difference between the outputs at no-load and at rated load.

Overload Rating —
The maximum load in percent of rated capacity, which can be applied without producing a permanent shift in performance characteristics beyond those specified.

Primary Axis —
The axis along which the transducer is designed to be loaded; normally its geometric centerline.

Rated Capacity (Rated Load) —
The maximum axial load that the transducer is designed to measure within its specifications.

Repeatability —
The maximum difference between transducer output readings for repeated loading under identical loading and environmental conditions.

Resolution —
The smallest change in mechanical input, which produces a detectable change in the output signal.

Sensitivity —
The ratio of the change in output to the change in mechanical input.

Shunt Calibration —
Electrical simulation of transducer output by insertion of known shunt resistors between appropriate points within the circuitry.

Shunt-to-load Correlation —
The difference in output readings obtained through electrically simulated and actual applied loads.

Standard Test Conditions —
The environmental conditions under which measurements should be made, when measurements under any other conditions may result in disagreement between various observers at difference times and places. These conditions are a follows:

Temperature 72 °F ± 3.6 °F (23 °C ± 2 °C)

Relative Humidity: 90% or less

Barometric Pressure: 28 to 32 inch Hg

Static Extraneous Load Limits —
Static Extraneous Load Limits are calculated such that only one extraneous load (Fx or Fy or Mx or My or Mz) can be applied simultaneously with 50% of the nominal load limit applied.

Temperature Effect on Output —
The change in output due to a change in transducer temperature.

Note: Usually expressed as a percentage of load reading per degree Fahrenheit change in temperature.

Temperature Effect on Zero Balance —
The change in zero balance due to a change in transducer temperature.

Note: Usually expressed as the change in zero balance in percent of rated output per degrees Fahrenheit (change in temperature).

Temperature Range, Compensated —
The range of temperature over which the transducer is compensated to maintain rated output and zero balance within specified limits.

Temperature Range, Usable —
The extremes of temperature within which the transducer will operate without permanent adverse change to any of its performance characteristics.

Terminal Resistance —
The resistance of the transducer circuit measured at specific adjacent bridge terminals at standard temperature, with no-load applied, and with the excitation and output terminals open-circuited.

Terminal Resistance, Excitation —
The resistance of the transducer circuit measured at the excitation terminals, at standard temperature, with no-load applied, and with the output terminals open-circuited.

Terminal Resistance, Signal —
The resistance of the transducer circuit measured at the output signal terminals, at standard temperature, with no-load applied, and with the excitation terminals open-circuited.

Traceability —
The step-by-step transducer process by which the transducer calibration can be related to primary standards.

Zero Balance —
The output signal of the transducer with rated excitation and with no-load applied, usually expressed in percent of rated output.

Zero Return —
The difference in zero balance measured immediately before rated load application of specified duration and measured after removal of the load, and when the output has stabilized.

Zero Shift, Permanent —
A permanent change in the no-load output.

Zero Stability —
The degree to which the transducer maintains its zero balance with all environmental conditions and other variables remaining constant.

Application Notes and Technical Articles

To order copies of the following application notes, call PCB® toll-free at 888-684-0004.

Application Notes

AP-1001 Extraneous Loads

AP-1002 Equivalent Force of a Falling Object

AP-1003 Mechanical Installation of PCB® Torque Transducers

AP-1004 Installation of PCB® Driveline Torque Transducers

AP-1007 Dynamometer Installation of PCB® Model 1401 Load Cell

AP-1008 Spline Lubrication PCB® Model 4115A & K, Preliminary Release

AP-1009 Explosive Environment

AP-1011 Effects of Thrust and Bending Moment on The Torque Output of Torque Disk. Model 5304-101-01

AP-1012 Grease Lubrication

AP-1015 Effects of Extraneous Loads on TORKDISC® Series 5308 and 5309

AP-1016 Shunt Calibration of a Strain Gage Sensor

Technical Articles

TA-1001 What is a Transducer?

TA-1002 Cross-talk in a Multi-Component Sensor

TA-1003 Accuracy