Honeywell

Load cell use in aerospace ground and flight test applications

The use of load cells is prevalent in many aerospace ground and flight test applications. In considering this technology, it is important to understand why load cells are an ideal choice for aerospace applications, the basics of load cell technology, the specific benefits of load cell use, and the key considerations in choosing a load cell and supplier.

Why Use Load Cells in Aerospace Applications?

There are four main uses for load cells in the aerospace industry, and they cross over between commercial and military applications. They may be utilized throughout all phases of aircraft development and use.

Initial design and build stages: Load cells may be instrumental in testing generic components for strength, force endurance levels, component longevity, and the like. Components can be anything from seat belts, to individual linkages, to aircraft flaps, to cockpit instruments. For the majority of component-testing applications, a standard load cell design can be utilized.

Pre-flight, structural and fatigue testing: Load cells can be used to test frame structure integrity, endurance and life cycles, with the goal generally being to validate aircraft design and ensure specified criteria are met. For instance, dual bridge load cells are used for airframe testing. See the Load Cell Overview section for more information on load cell varieties.

In-flight testing and monitoring: Load cells can be used to test and monitor airframe structural forces during in-flight testing. For example, bolts and pins used on critical points of the airframe can be redesigned, fabricated and calibrated to perform as load cells and can be used to ensure that structural integrity is maintained.

Flight-qualified force monitoring and control: After new builds or designs pass the necessary performance testing and are ready for commercial or military applications, load cells can be used in the monitoring of the flight control system. In commercial uses, strain gaged load cells are designed for pilot force input. Another example is the measurement of the pilot's touch to the control stick. The force is measured and the data is stored in the Flight Data Recorder "Black Box." A redundant load path is used to ensure the mechanical integrity of the linkage.

In demanding military applications, a highly customized strain gaged load cell can be used in the flight control system. These load cells can be used in many extreme applications such as in-flight tanker refueling operations where the load cell is on the extreme end of a boom and exposed to harsh environmental conditions. The boom system is used to track the aircraft being re-fuelled and the load cell, as part of that system, measures the force the aircraft exerts on the boom assembly.

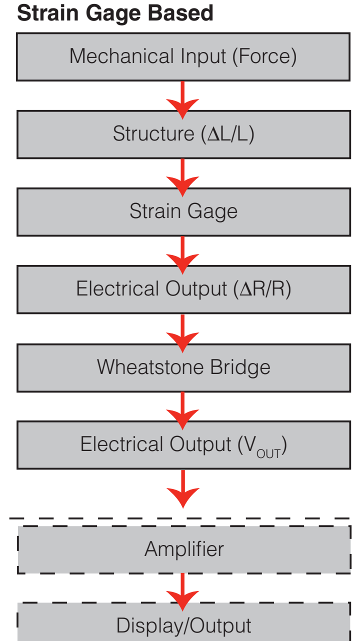
Basic Load Cell Theory

Load cells consist of specially designed structures, which perform in a predictable and repeatable manner when force is applied (i.e., a very slight deflection). This force is translated into a signal voltage by the resistance change of the strain gages, which are organized in an electrical circuit and, in turn, are applied to the load cell structure. A change in resistance indicates the degree of deflection and, in turn, the load on the structure.

The electrical circuit consists of strain gages, which are typically connected in a 4 arm (Wheatstone Bridge) configuration. This acts as an adding and subtracting electrical network. The Wheatstone Bridge lends itself to allowing for compensation for temperature effects as well as cancellation of signals caused by extraneous loading.

The basic output is a low level voltage signal (i.e., mV), but thru the use of signal conditioning and amplifiers, this signal can become a higher level Voltage or Current (i.e., 0 V to 5 V, 0 V to 10 V or 4 mA to 20 mA). These signals can be used to drive a digital/analogue display, be part of a monitoring system, or form part of a closed loop feedback control system.

Electromechanical Transducer Strain Gage Based

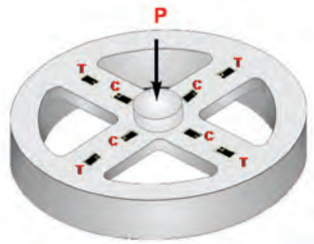


The low level signal can also be converted into a digital output (i.e., RS-232, RS-485). USB is becoming increasingly popular.

Understanding Load Cells

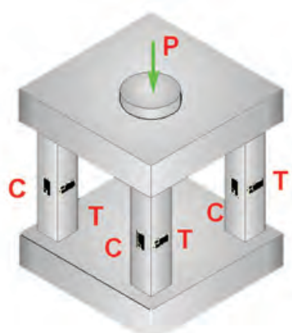
Load cells measure force directly and accurately. Strain gages are the measurement tools within the cell. (You will find more details on this topic in the next section under Wheatstone Bridge.) The most critical mechanical component in any load cell or strain gage transducer is generally the structure (spring element). The function of the structure is to serve as the reaction for the applied load; and, in doing so, to focus the effect of the load into an isolated uniform strain field where strain gages can be placed for load measurement.

There are three common load cell structure designs: multiple-bending beam, multiple-column and shear-web, which in turn form the basic building blocks for all possible load cell profiles and/or configurations. The load cell structure (spring element) materials are typically, but not limited to, carbon steel, stainless steel or aluminum.



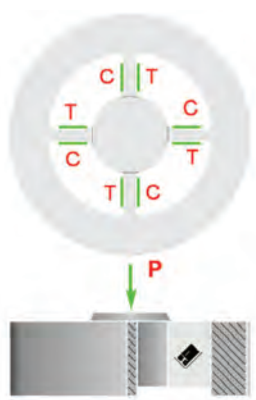
Multiple-Bending Beam Load Cells

Multiple-Bending Beam load cells are low capacity (between 20 Newtons and 22K Newtons) and feature a wheel-shaped spring element, which is adaptable to low profile transducers, and four active gages or sets of gages per bridge arm, with pairs subjected to equal and opposite strains (beam in bending).



Multiple-Column Load Cells

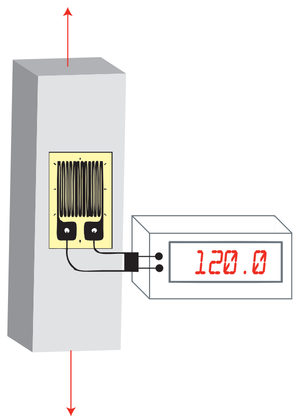
Multiple-Column load cells are high capacity (between 110K Newtons and 9M Newtons) and consist of multiple columns for the increased capacity. In this design, there are four active gages or sets of gages per bridge arm, in a uni-axial stress field -- two aligned with maximum principal strain, and two "Poisson" gages (column).



Shear-Web Load Cells

Shear-Web load cells have a capacity between 2K Newtons and 1M Newtons and feature a structure in a wheel form with radial webs subject to direct shear. There are four active gages or sets of gages per bridge arm, with pairs subjected to equal and opposite strains (beam in bending).

Load cells have "duty cycle" ratings. Fatigue rated load cells are specially designed to withstand many millions of load cycles with no effect on the load cell performance. They are typically designed to achieve 50 to 100 million fully reversed load cycles, depending on the load level and amplitude. General purpose load cells are designed to be used in static or low cycling frequency load applications. They typically survive up to 1 million cycles depending on the load level and transducer material.



Wheatstone Bridge (Electrical Circuits)

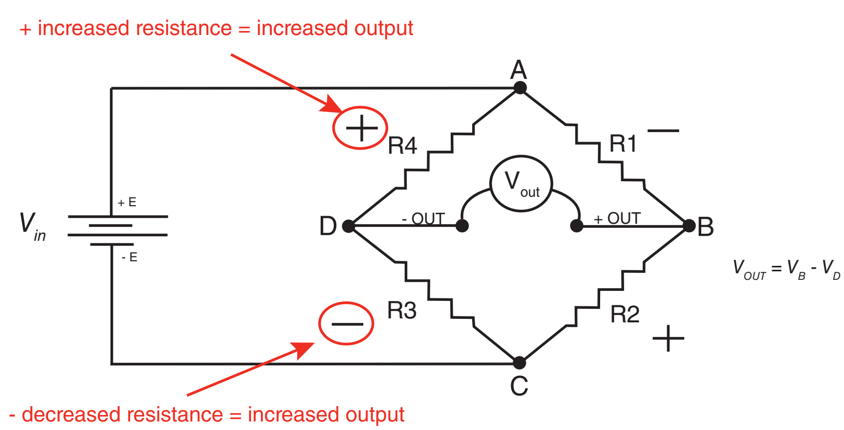
As can be seen on the figure at left, when a force is applied (i.e., in this case a tensile force) to a structure with a single strain gage bonded to it, the induced strain field will cause a resistance change (ΔR) in the gage (i.e., in this case, an increase in resistance). As shown, the strain ε is equal to the change in length of the structure (ΔL) divided by the original length (L) of the structure, which in turn is proportional to the change in resistance (ΔR) divided by the original resistance (R) when no force is applied.

$$\textbf{Strain} = \varepsilon = \frac{\Delta L}{L} \propto \frac{\Delta R}{R}$$

A measure of this conversion from strain to resistance is called the Gage Factor (F), and it can be defined as the ratio of change in resistance, divided by the ratio of change in length of the structure, which is in fact the strain induced in the element.

$$\textbf{Gage Factor} = F = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} = \frac{\frac{\Delta R}{R}}{\varepsilon} \longrightarrow \Delta R = RF\varepsilon$$

In a load cell, these strain gages are placed on the force sensing element, and wired in such a fashion to make up the electrical circuit called a Wheatstone Bridge (as seen below). The gages are placed to ensure that some of the resistance changes are increasing (+ resistance), and some are decreasing (- resistance). The end result is to unbalance the output of the bridge which will be proportional to the force applied to the load cell structure. The Wheatstone Bridge is powered by a fixed input voltage (*V in*), which is typically (but not limited to) 0 Vdc to 10 Vdc applied across points A and C, and the output from the bridge is measured as a voltage between points B and D. In the unloaded condition, the output voltage (*V out*) measured between points B and D will be approximately 0, and when the full scale load is applied, the output voltage (*V out*) is measured in milli Volts. Typically the sensitivity of a load cell is 2 mV/V (i.e., if the input voltage was 10 V, then the output would be 20 mV in the fully loaded condition). However, load cells are designed with varying sensitivities, depending on such factors as the material of the load cell structure and the application.



Benefits of Load Cell Use in Aerospace Applications

There are many benefits to using load cells in aerospace applications. This paper highlights the most apparent benefits.

Pre-Build Test

Static Test

In-Flight Test

Pilot Force Input

Throttle Control

Effectiveness

Load cells measure forces and transmit data needed to validate components, products, or complete aircraft to help ensure integrity and safe operation.

Long Life Cycles

Load cells, when required, can be designed with a high fatigue life. They can be built for reliability and longevity of use. Often, they can maintain performance through more than 100 million force/load cycling tests.

Robust Design

Load cells can be designed to compensate for varying operational factors, particularly useful in flight applications. They can be built to withstand environmental factors such as g-forces and vibrations, as well as temperature and humidity fluctuations, chemicals and even physical impacts. Load cells are typically encased by all-metal construction to protect the sensor from harsh environmental conditions or operating environments, without degrading the sensing capabilities. As a result, key operating parameters and performance are maintained.

Redundancy

Redundancy can be designed into the load cell and is a key benefit within aerospace applications. A back-up mechanism can be built-in to maintain the mechanical integrity of the flight control system.

Effective in Imperfect Conditions

Load cells can be designed to compensate for off-center loading, again allowing sensor functionality and performance despite imperfect conditions. One example is in helicopter lift operations. Several hook load sensors can be used to confirm a safe lift. The load cell design compensates for uneven loading, so even if the load is not applied directly through the primary axis of the load cell, it will still perform to specification.

Testing Flexibility

Customized dual-bridge designs also offer flexibility in testing, performing as two independent force measurements from the same load cell. For example, in airframe testing, the first force measurement can be used to control the loads applied to the aircraft. The second independent force measurement verifies what the load actually is, which is collected for data analysis, along with various other measurements on the airframe being tested. Basically, it provides independent verification of the load. This is a key feature and benefit in certain applications. Typically load cells in airframe testing have to compensate for off-center loading because they are mounted directly in-line with the hydraulic cylinder providing the force.

Minimal Deflection; High Force Sensitivity

Load cells, by design, have minimal deflection when fully loaded, but still retain high force sensitivity. A typical example are load cells used in throttle, wheel or pedal linkages detecting pilot input forces on the aileron, rudder and elevator. Highly sensitive load cells allow the pilot to retain direct, active feedback to control the plane, while providing data to the black box and throttle control. The sensing element provides a direct linkage between the pilot's touch and immediate feedback to the plane's control systems.

Another example is in autopilot situations on aircraft. If required, a pilot need only take hold of the throttle to disengage the autopilot and take direct control of the aircraft.

Versatility

Perhaps the greatest benefit of load cell technology is versatility. While there are many standard product designs, custom designs are often needed for specific applications. Depending on the application, load cells can be created in different sizes and profiles, with varying ranges, and for specific accuracy and sensitivity needs.

Choosing a Load Cell and Supplier

With all the benefits load cell technology can provide in aerospace, it can be overwhelming to choose the right one for a specific application. More importantly, how does one go about choosing the right supplier for the job? The following checklist should help.

The Application

- Do your homework. Understand the application needs and parameters; it is critical in determining the correct design (i.e., multiple-bending, multiple-column or shear web design), as well as what size and configuration will be needed.
- What are the temperature ranges?
- What kind of operating conditions and environmental factors will be endured?
- What are the capacity ranges required?
- Don't settle. Insist on an accurate, reliable and robust product, and look for a standard product first -- there are hundreds available. If none seem to fit the bill, you'll want to look for a supplier that can customize designs to fit your needs. Easy customization is another benefit of load cell technology – it can be adapted as required.

Supplier Credentials

- Look for a supplier with a proven track record and a solid brand reputation.
- Look for a supplier that has worked with load cells in multiple markets and has years of knowledge and experience, particularly in aerospace flight test and flight-rated applications.
- Ensure the company has quality, dedicated and experienced engineers who understand customer applications and needs. Fundamental product design knowledge is essential.

- Inquire about the supplier's custom engineering experience. Look for mature, proven technology within all custom packages offered. Honeywell offers sophisticated and extensive custom engineering capabilities in the test and measurement industry, which allows "outside the catalog" product range expansion.
- Ask the supplier about its evaluation and simulation capabilities, as well as its quality and reliability testing. Request customer testimonials or case studies. Honeywell Sensing and Control has fully integrated design, manufacturing and testing capabilities. The company's Columbus, Ohio facility is the center of expertise for Sensing and Control's Test & Measurement product group, and it is supported by a Juarez, Mexico facility. Both are certified to ISO 9001: 2000, and the Juarez facility is also AS9100. The Honeywell Quality team has a significant experience base to achieve and maintain these standards.
- Ensure the supplier has the capability to deliver quickly to meet your time frame. For example, Honeywell's load cells are manufactured as 'Fast Track,' 'Quick Trip' and 'Build to Order' to provide the fast delivery to meet specific customer requirements.
- Consider a supplier's customer service reputation and process. Honeywell Sensing and Control takes a consultative partnership approach with customers and strives to be accessible and responsive to customer needs. Customer service is an on-going effort, continuing far beyond an initial product sale. When you choose Honeywell, you choose a business partner who is committed to providing solutions.

Consider Honeywell for load cells and other sensor products for aerospace applications

Honeywell Sensing and Control offers a wide variety of switching and sensing products applicable for use in many aerospace and military test applications, including test and measurement during design and manufacturing as well as within the final product.

Honeywell's test and measurement products include load cells, pressure/differential pressure sensors, torque transducers, accelerometers, wireless telemetry, and instrumentation, just to name a few.

Honeywell also offers electromechanical and sensor systems — from discrete components to pilot interface and controls. Products include: RVDT, LVDT, resolver, synchro, potentiometer, and switches as the standard sensing elements most accepted in the Aerospace industry.

No matter if your needs are large or small, if you need a standard product or a fully custom design, look to Honeywell for solutions to meet your specific needs.

For more information, visit Honeywell online:

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