HAB 621 Instrumentation and Measurement in Biomechanics

Çizim: De Motu Animalium G.Borelli (1680)

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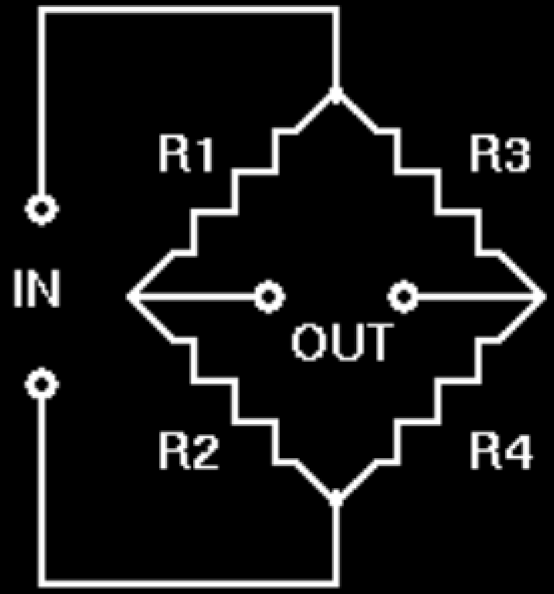
Wheatstone Bridge

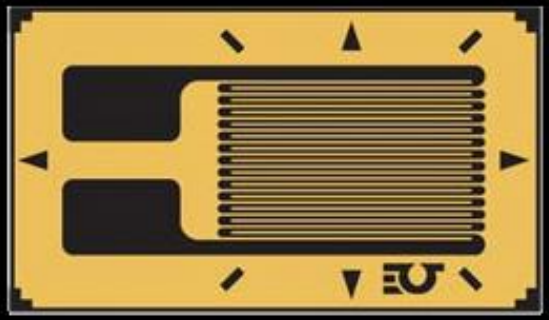
A good way of taking small changes in resistance and turning it into something more measurable is using a wheatstone bridge. A wheatstone bridge is a configuration of four resistors with a known voltage applied like this

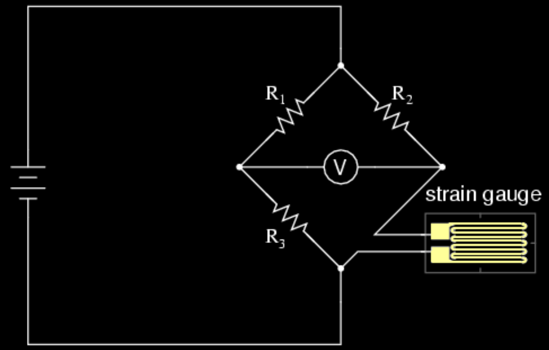


Vout = [(R3/(R3+R4) - R2/(R1+R2))]*Vin

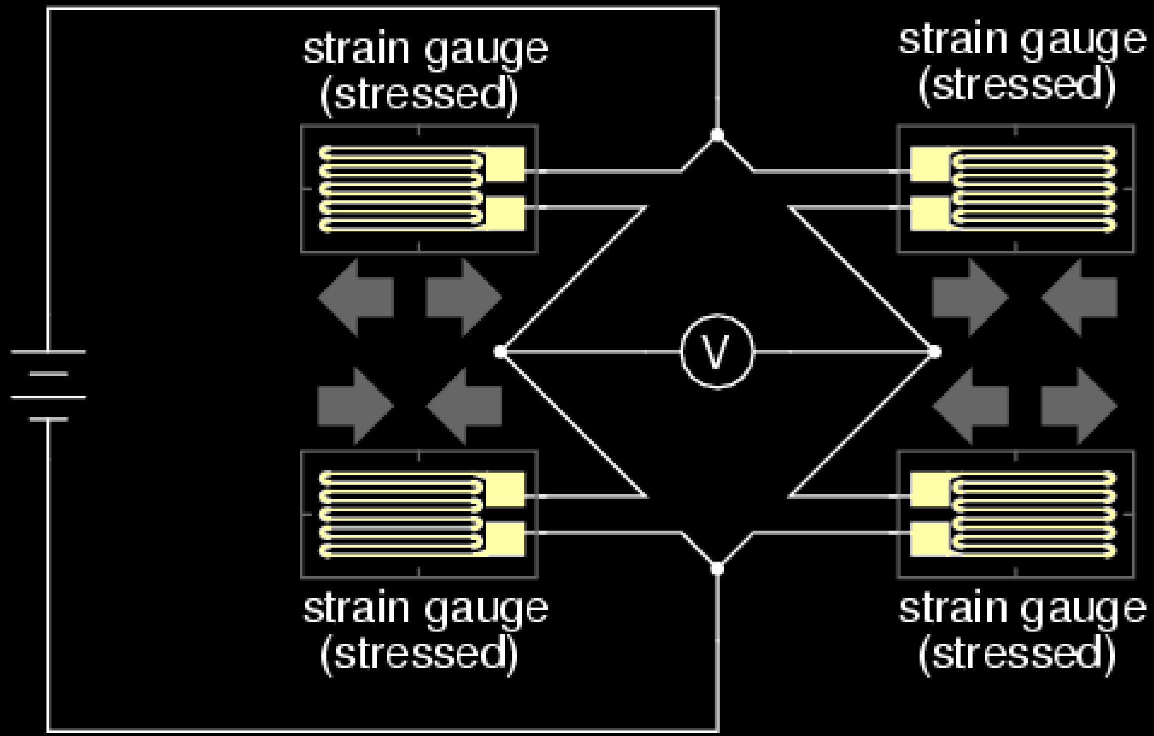
Strain Gauge

A **strain gauge** consists of a thin metal foil with a **zig-zag** pattern of parallel conductors. The foil is mounted on a plastic backing and cemented to the object (such as a steel beam) that is under strain, with the conductors parallel to the direction of greatest stress. When a load is applied to the object, so that it becomes under strain, the conductors become stressed in the same way. They are made longer and therefore become thinner, and their resistance increases. By measuring their **resistance** (generally with a bridge) we ,are able to determine the amount of strain.





Full-Bridge Strain Gauge Curcuit



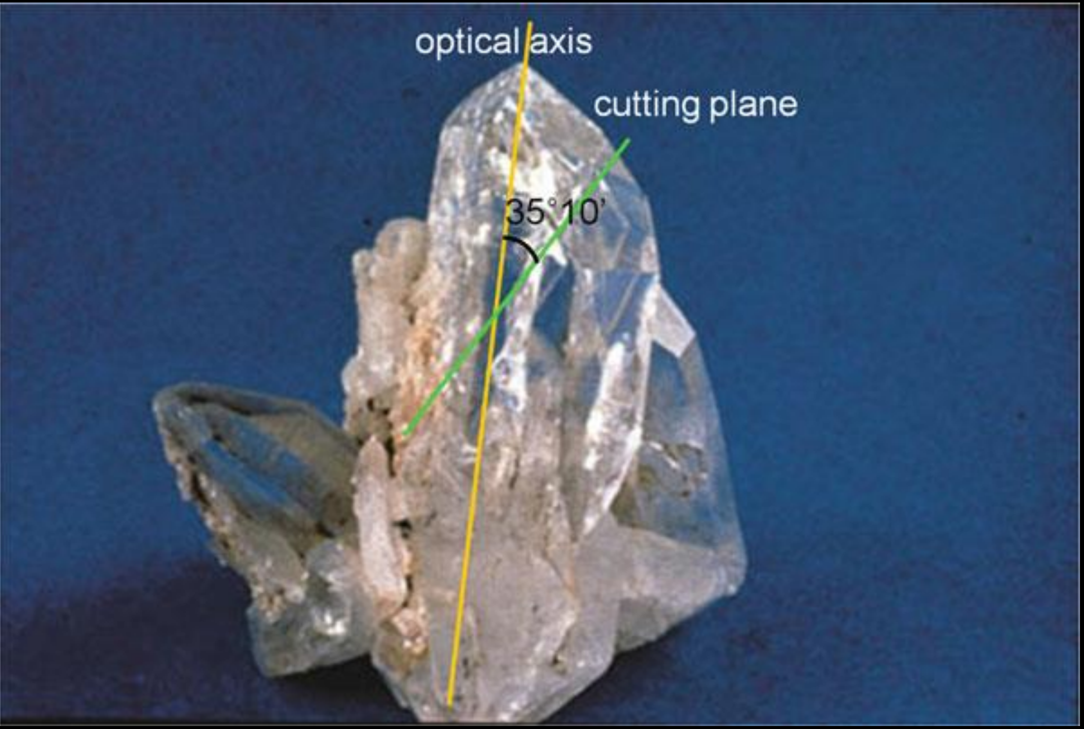
Load Cells

Strain gauges are frequently incorporated into a device known as a load cell.

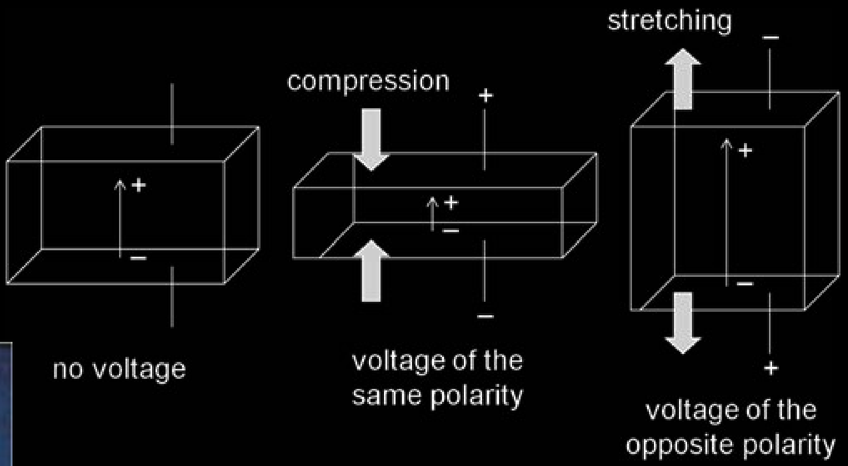
Piezo-Electric Effect

Other forms of strain gauge rely on the piezo-electric effect. In the late nineteenth century, the Curie brothers (the younger brother, Pierre, was Marie Curie's husband) found that an electrical voltage was generated when they compressed or stretched quartz. This is called piezoelectric effect. This effect is reversible, meaning that quartz can be lengthened or shortened when an electrical voltage is applied. Piezoelectricity refers to the material's ability to exhibit this piezoelectric effect. This is measured by a suitable electronic circuit.

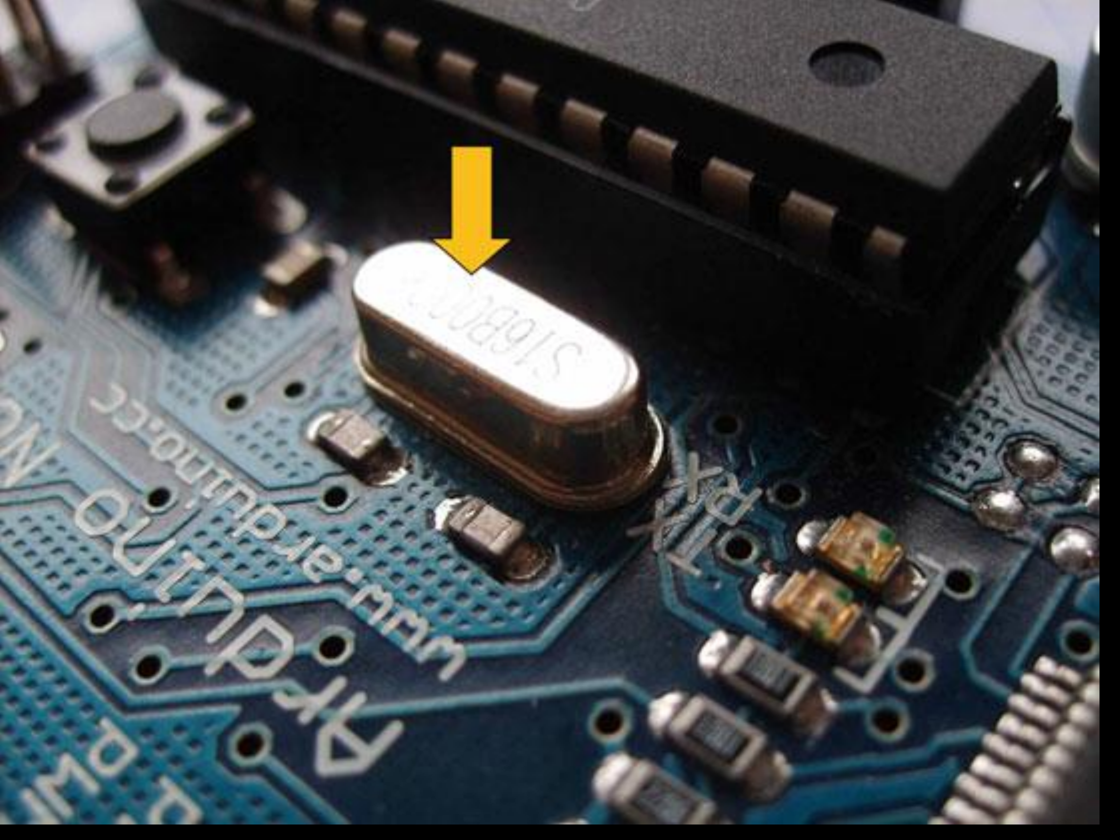
AT-cut quartz crystal. Image adapted from USGS (public domain).



The most widely used angle is 35100, called AT-cut.

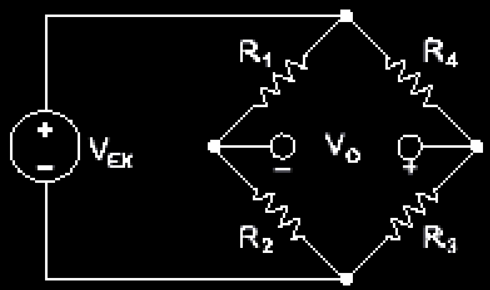


Piezoelectric effect of an AT-cut quartz crystal



A quartz crystal oscillator in the Arduino board

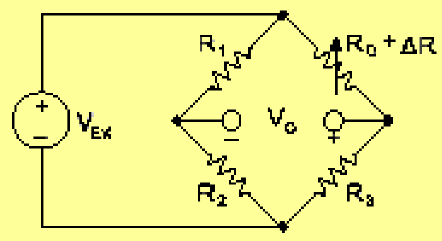
In practice, the strain measurements rarely involve quantities larger than a few millistrain (e x 10^{-3}). Therefore, to measure the strain requires accurate measurement of very small changes in resistance. To measure such small changes in resistance, strain gauges are almost always used in a **bridge configuration with a voltage excitation source**. The general Wheatstone bridge, illustrated below, consists of four resistive arms with an excitation voltage, V_{EX}, that is applied across the bridge.



$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right] \cdot V_{EX}$$

From this equation, it is apparent that when R1/R2 = R4/R3, the voltage output VO will be zero. Under these conditions, the bridge is said to be balanced. Any change in resistance in any arm of the bridge will result in a nonzero output voltage.

Therefore, if we replace R4 with an active strain gauge, any changes in the strain gauge resistance will unbalance the bridge and produce a nonzero output voltage. If the nominal resistance of the strain gauge is designated as RG, then the strain-induced change in resistance, ΔR, can be expressed as ΔR = RG·GF·ε. Assuming that R1 = R2 and R3 = RG, the bridge equation above can be rewritten to express V_O/V_{EX} as a function of strain. Note the presence of the 1/(1+GF·ε/2) term that indicates the nonlinearity of the quarter-bridge output with respect to strain.

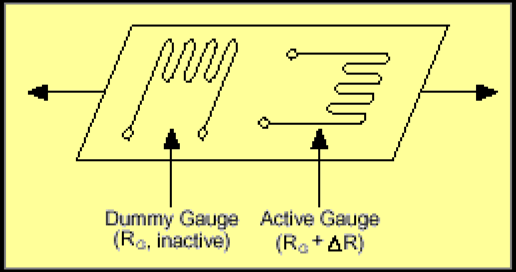


$$\frac{V_O}{V_{EX}} = -\frac{GF \cdot \varepsilon}{4}\left(\frac{1}{1 + GF \cdot \frac{\varepsilon}{2}}\right)$$

Eliminate Temperature Effects

Ideally, we would like the resistance of the strain gauge to change only in response to applied strain. However, strain gauge material, as well as the specimen material to which the gauge is applied, will also respond to changes in temperature. Strain gauge manufacturers attempt to minimize sensitivity to temperature by processing the gauge material Measuring to compensate for the thermal expansion of the specimen material for which the gauge is intended. While compensated gauges reduce the thermal sensitivity, they do not totally remove it.

By using two strain gauges in the bridge, the effect of temperature can be further minimized. For example, illustration (below) a strain gauge configuration where one gauge is active (RG + ΔR), and a second gauge is placed transverse to the applied strain. Therefore, the strain has little effect on the second gauge, called the dummy gauge. However, any changes in temperature will affect both gauges in the same way. Because the temperature changes are identical in the two gauges, the ratio of their resistance does not change, the voltage V_O does not change, and the effects of the temperature change are minimized.



Strain gauge vs Piezoelectric

Strain gauge (AMTI, Bertec)

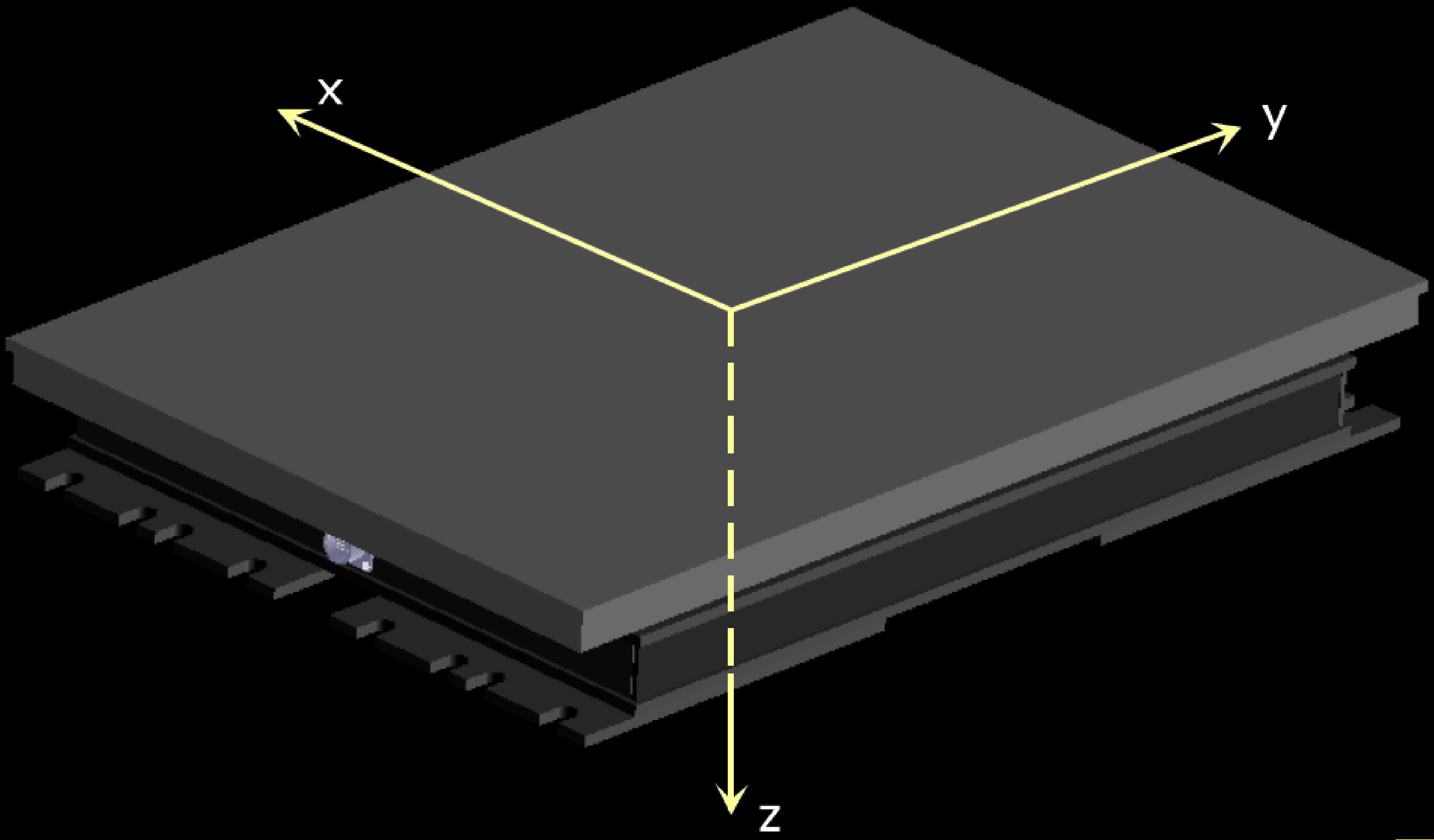
- inexpensive
- low frequency response
- no drift, there better for posture and balance
- needs regular balancing
- limited range

Piezoelectric (Kistler)

- expensive
- high frequency response, therefore better for impacts
- drift must be compensated electronically
- wide range of sensitivities are possible

COORDINATE SYSTEM FOR LOAD MEASUREMENTS

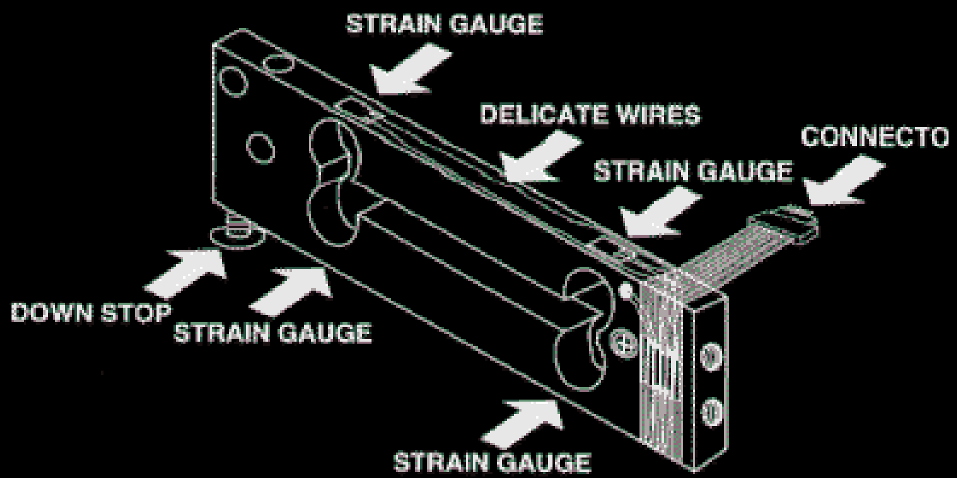
The center of the coordinate system is at the inner corner of the arm block with y-axis forward, x-axis to the left (pointing inwards looking from behind), and z-axis downward.

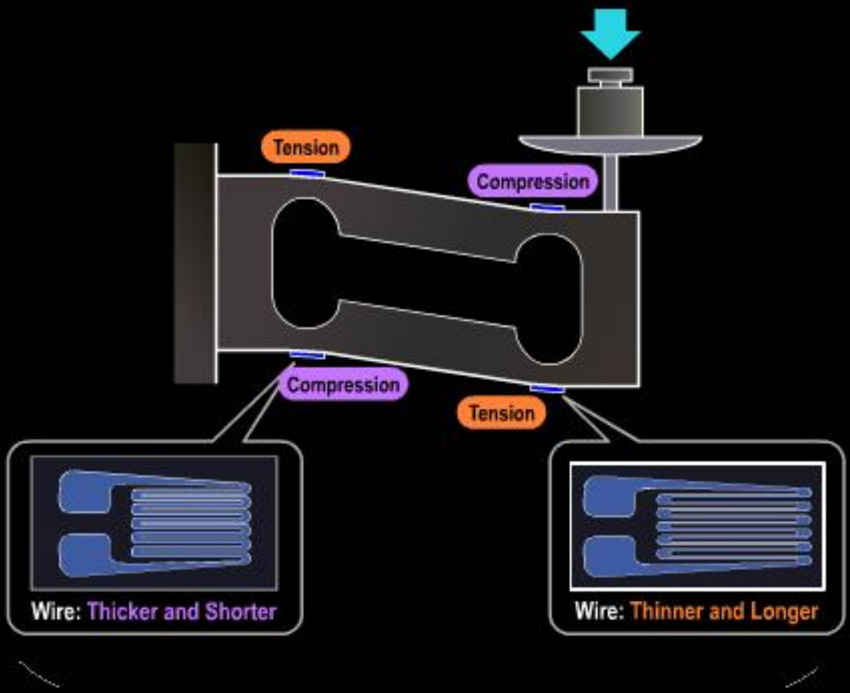


MODEL	SIZE (mm)			WEIGHT (kg)	RATED LOAD (kN)		NATURAL FREQUENCY* (Hz)		
	L	W	H		F_z	F_x, F_y	F_z	F_x	F_y
4060-08	600	400	83	28	10	5	340	550	540
4060-10			100	22.6	20	10	600	580	580
4060-15			150	23.5	20	10	750	570	550
4550-08	508	464	83	26.3	10	5	380	550	540
4060-NC	600	400	100	25.9	10	5	480	500	500
4080-10	800	400	100	25.2	10	5	430	460	460
4080-15			150	26.2	20	10	540	460	460
6090-15	900	600	150	28.8	20	10	400	450	450
9090-15	900	900	150	31.8	20	10	320	410	410
6012-15	1200	600	150	32.5	20	10	250	450	450

* The given values are measured for unmounted force plates. Therefore, the actual value might be higher.

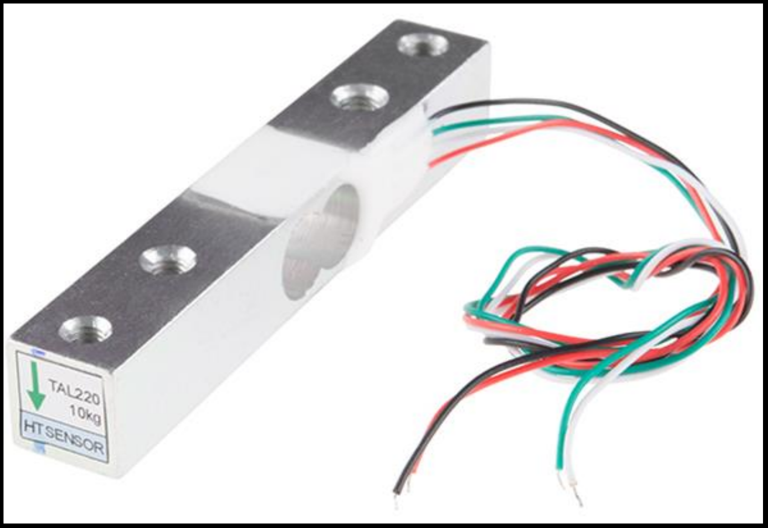
Load Cell Experiment



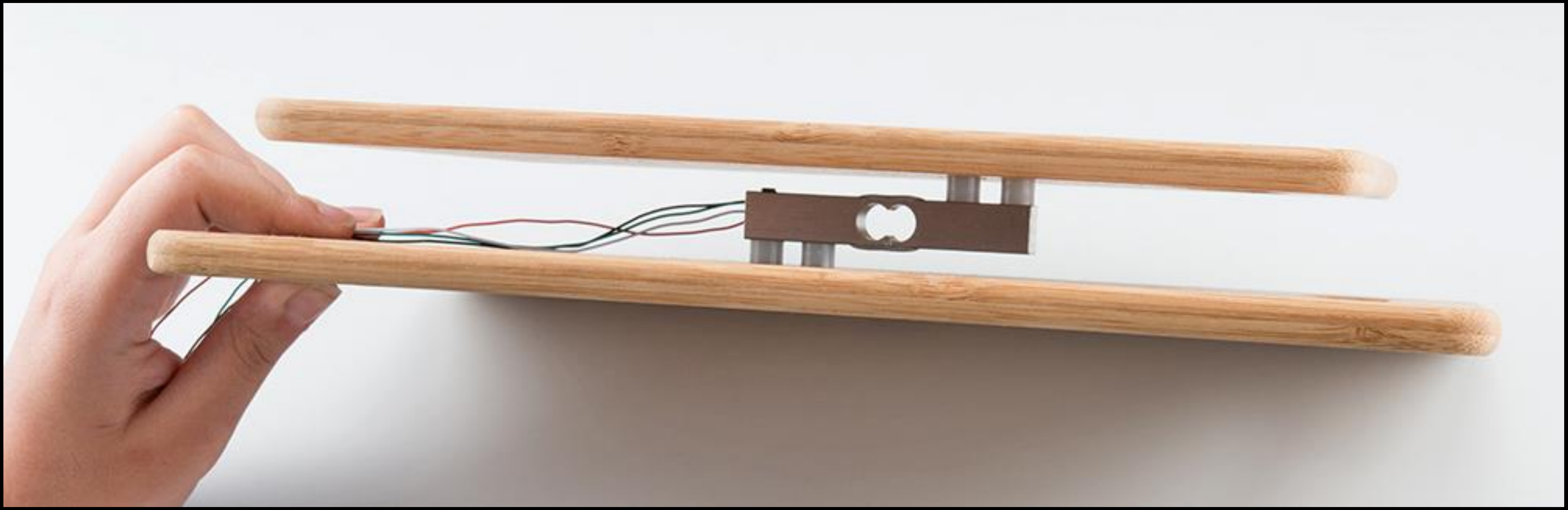


Load Cell Experiment

Features:
◆Capacity： 3~200kg
◆Material: aluminum-alloy or alloy steel
◆Type: Parallel beam type
◆Defend grade: IP65
◆Application : Palm scale, kitchen scale, electronic balance, fishing scale, electronic platform scale and other electronic weighing devices.



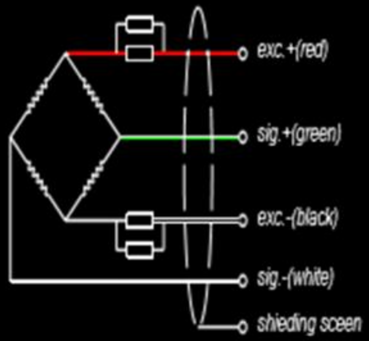
Load Cell Experiment



Load Cell Experiment

Load cells use a four-wire Wheatstone bridge configuration to connect to the HX711. These are commonly colored RED, BLK, WHT, GRN and YLW. Each color corresponds to the conventional color coding of load cells:

Red (Excitation+ or VCC)
Black (Excitation- or GND)
White (Amplifier+, Signal+ or Output+)
Green (A-, S- or O-)
Yellow (Shield)



The YLW pin acts as an optional input that is not hooked up to the strain gauge but is utilized to ground and shield against outside EMI (electromagnetic interference)

Load Cell Experiment

The HX711 (24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales) load cell amplifier is used to get measurable data out from a load cell and strain gauge.

Operation Voltage: 2.7V--5V
Operation Current: < 1.5mA
Selectable 10SPS or 80SPS output data rate
Simultaneous 50 and 60Hz supply rejection ??