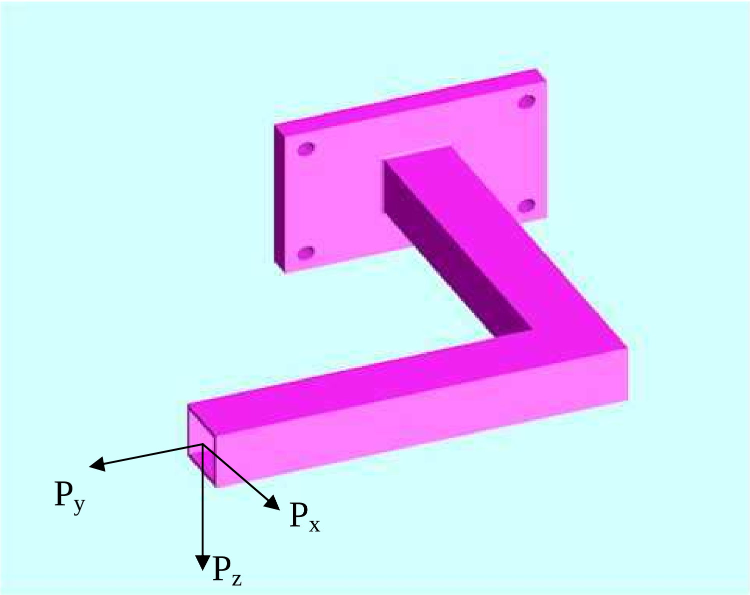
Calibration of the Three-Axis Force transducer

Three L-shaped arms are being used to support a test version of a prototype muon detector chamber being



designed for use on a large particle accelerator at CERN in Geneva. Arms are instrumented with strain gauges so as to be sensitive to three orthogonal force components with directions defined as shown above.

The arms are calibrated by fixing each one in turn to a rigid support and then applying loads at the end in each of the X, Y and Z directions. Strain readings are taken for each of the three strain gauge bridges used to measure the three force components.

Strain Bridges:

A four-arm strain bridge is set up for each direction using Micro-Measurement CEA-13-125UW-120 foil gauges. These are mounted and connected so that each bridge is sensitive to only one of the three force components. Also, they are not sensitive to any of the possible moment components or to temperature. The output from these bridges is measured using the Strain Smart system. This allows one to balance the output from all three bridges under zero load and then to measure the strain output as the force components are applied.

Load Application:

A precision 80 lb. weight is used. With the support arm fixed to a rigid support in an appropriate orientation, this weight is applied in the P_x, P_y and P_z directions. Care is taken to level the arm so that the load direction is correct. The exact placement of the load is not important because of the insensitivity to moments described above. This should be confirmed by moving the load application point around and verifying that the gauge readings are not affected. Strain readings are taken for each of the three load directions. After each test, the load is removed and the gauge zero load values are verified.

Calibration Matrix:

Although, in principle, each strain bridge should be sensitive to only its own load component, in practice there is some crosstalk. The effect of this can be accounted for by using a calibration matrix. Consider the strain readings recorded during calibration:

Define e_{xy} as the strain resulting from the calibration X-direction load (P_x) in the Y strain channel.

The strains due to the load P_x are thus e_{xx}, e_{xy} , and e_{xz} , and similarly for P_y and P_z.

Now define an actual load vector acting on the support as $\mathbf{F}$ and the resulting strain readings as a strain vector $\boldsymbol{\varepsilon}$.

The component ε_x of $\boldsymbol{\varepsilon}$ in the X-direction is then found from:

$$\varepsilon_x = (e_{xx} / P_x)\, F_x + (e_{yx} / P_x)\, F_y + (e_{zx} / P_x)\, F_z$$

and, similarly, for ε_y , and ε_z.

In matrix form we have $\boldsymbol{\varepsilon} = \mathbf{CF}$ where $\mathbf{C}$ is a 3x3 calibration matrix with components given by $C_{ij} = e_{ij} / P_j$

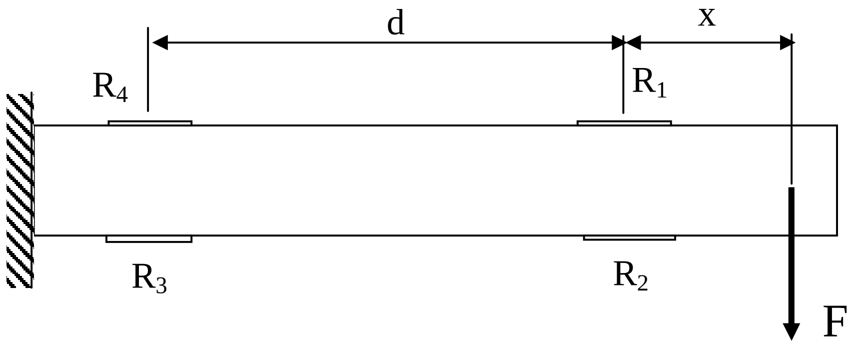
The actual force is then determined from the measured strains using:

$$\mathbf{F} = \mathbf{C}^{-1}\,\varepsilon$$

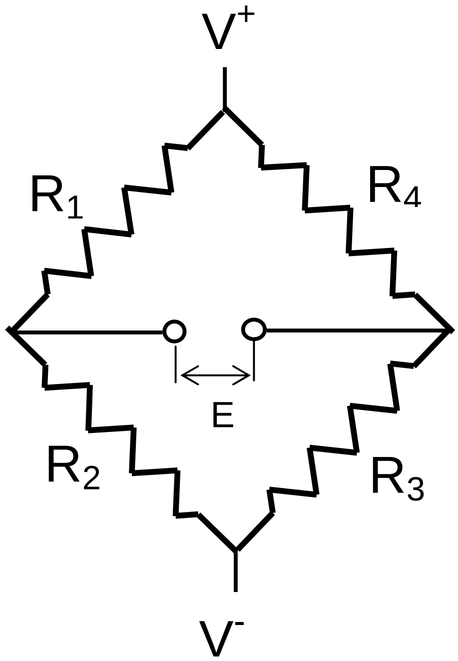
These calculations are easily done on a spreadsheet, using separate worksheets for each of the four calibrated support arms.

Elimination of sensitivity to moments:

Consider a cantilever beam equipped with four strain gauges as shown below:



The gauges are connected in a full bridge as shown below: Gauges R1 and R2 measure the bending moment at distance x from the applied force F and gauges R3 and R4



measure the bending moment at distance (x + d) from the force F. The bridge configuration is such that the output from R_1 and R_2 is subtracted from that from R_3 and R_4. The resulting output is thus proportional to the difference between the bending moments at the gauge locations, i.e. we have:

Output E = constant x [Fx - F(x+d)] which thus Gives:

E = constant x Fd

i.e. E is proportional to Fd and, as d is constant, the bridge output is proportional to the force F only. The position of the force (x) is not important. This implies that a couple applied at the end of the beam would also produce no output from the bridge. Also note that, if the beam has a symmetric cross section (e.g. it is rectangular in section) and the gauges are placed on the neutral axis for bending in a plane at right angles to that shown, then there will be no output for a force component perpendicular to the paper. Finally, an axial force component will produce the same tensile strain in all four gauges and, thus, will produce no bridge output.