Conceptual Design of Weigh Scale

Advanced Solid Mechanics and Stress Analysis

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Abstract:

A digital weight scale is one of the most precise analog instruments. It uses force sensors to measure the load offered by an object. Weigh scales are used in a multitude of applications ranging from point of sales terminals to industrial measurement equipment. The most common method for implementing weigh scale designs uses a resistive load cell configured as wheat stone bridge. However, the sensor interface is complex due to precision requirements. In the load cells, the signal levels are low and the effect of noise is prominent.

This article discusses how to design a cheapest and yet a very reliable weigh scale for heavy load weighing of as high as 40000lbs. We initially present a brief description on related work in the literature. Then we present the theoretical background summarising the topics covered in the design. We then discuss the two design aspects mentioned in the assignment. We evaluate each mentioned topic and design the project accordingly.

Based on the requirements various designs can be adopted for the weigh scale. For the project to be cheap and reliable quarter bridge circuit is used. All the assumptions are mathematically analysed with design considerations. Further, in the end an electrical circuit is explained for converting the obtained mechanical voltage to real time implication of weight. We then explicitly explain the chosen design and its usage in the next section. Further a detailed stress analysis is presented

The draft is organised as follows:

We initially explain existing literature work on the topic in Section 2. Then we present theoretical background in the section 3, which includes all the theoretical analysis needed for understanding the document. Then we present the block diagram and the layout of the project design in section 4. We present a detailed analysis of resolution, stress, sensitivity in section 5. Further the design aspects mentioned in the assignment are considered in section 6. We present the Electrical engineering requirements in section 7. Then a conclusion is presented in section 8.

Related Work:

In [1], author presents a clear analysis of each of the topics related to stress analysis and transducer design for strain gauges. All the weigh scale designs consider the strain gauges and hence the mentioned literature covers a wide area of the topics related to weigh scale.

[2] is technical report of Acromag regarding the stress and the stress analysis. They clearly define the straing gauge, possible design aspects, and explain with an example a practical desgn scenario.

In [3], authors present whetstone bridge measurement circuits considering the straing gauge configurations.

In [4]. authors present the conversion of the estimated output from the wheatstone bridge to the digital weight for practical application. This includes a electric circuit design involving operational amplifiers.

Some other Literature Work:

In a 1996 report, Gyenes and Mitchell detail research conducted at Transport Research Laboratories (TRL) in the United Kingdom (UK), in which the Volvo test facility in Gothenburg was utilized to develop a simulated test to rate suspensions in terms of their potential for causing road wear. This goal was accomplished by comparing simulated wheel load measurements published by TRL in 1993 to actual dynamic behavior of heavy goods vehicle suspensions over the TRL test track.

Middleton and Rhodes' 1994 report detail their research, which was based on previous work conducted by Addis, Halliday, and Mitchell in 1986. In the research performed by Addis et al., a two-axle, semitrailer was instrumented, and results were obtained from one vehicle operating over one instrumented pavement.

Jacob and Dolcemascolo's 1998 report details their investigation into dynamic loads on pavements and their spatial repeatability to assess the sensitivity to pavement profile, road roughness, vehicle characteristics, and traveling conditions.

Theoretical Background:

Strain Gages/Load Cells:

A load cell is a device that converts a force (mass multiplied by gravity) to an electrical signal. This is commonly done through either the piezo-electric effect or with strain gauges. Piezo materials are those which output a small electric signal as they are compressed. While piezocrystals are the best known, there other similar materials that do the same, such as piezoceramics.

A strain gauge is an electrical device made from a material whose resistance changes with strain, usually manifested as deformation. These are used in load cells designed to deflect in response to a load. Most load cells are designed with a beam configuration that bends under load, although some use the expansion in cross-section resulting from longitudinal or axial compression. These generally give a less linear output than the bending configurations, making calibration a consideration.

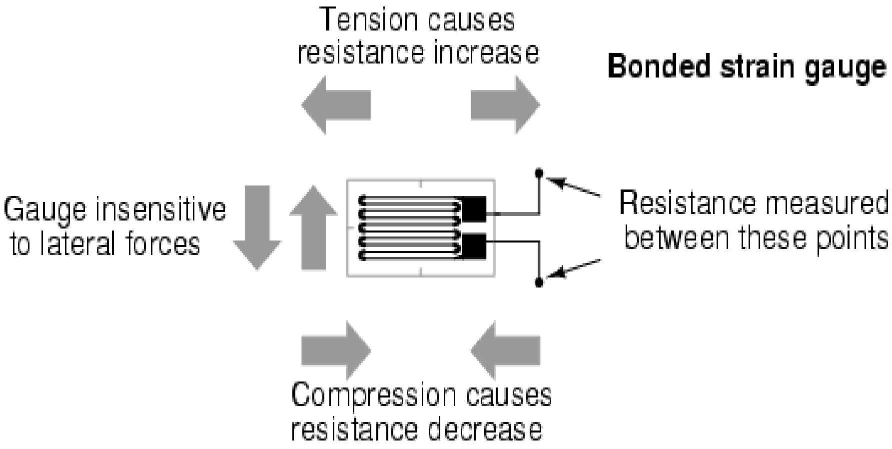

Figure 1 Strain Guage

Strain gauges are widely employed in sensors that detect and measure force and force-related parameters, such as torque, acceleration, pressure, and vibration. The strain gauge is the building block for strain sensors that often employ multiple strain gauges in their construction. A strain gauge will undergo a small mechanical deformation with an applied force that results in a small change in gauge resistance proportional to the applied force. Because this change in resistance with applied force is so small, strain gauges are commonly wired using a Wheatstone Bridge. The resultant output voltage of the bridge is directly related to any imbalance between resistances in each leg of the bridge and the bridge excitation voltage. The output of the bridge is normally specified in terms of millivolts of output voltage per volt of applied excitation (mV/V), and this is usually referred to as its rated output or sensitivity. The actual maximum or full-scale output of a strain gauge bridge at its full-rated load is the product of a bridge's sensitivity (mV/V) and the applied excitation voltage.

Sensors/Transducers:

Strain gages which also fulfill the extreme demands of accuracy for calibrated load cells are of the same type as the strain gages in the Selection criteria "G" series. The carrier for the measuring grid consists of glass-fiber reinforced phenolic resin.

The discovery of the principle upon which the electrical-resistance strain gage is based was made by Lord Kelvin, who observed from an experiment that the resistance of a wire increases with increasing strain according to the relationship (Dally and Riley, 1978)

$$R = \rho \frac{L}{A}$$

where R is the measured resistance in the wire of length L and cross-sectional area A having a specific resistance ρ.

From this relationship, it can be shown that the strain sensitivity of any conductor derives from the change in its dimensions during loading and the change in specific resistance according to the relation

$$\frac{dR/R}{\varepsilon} = 1 + 2\nu + \frac{d\rho/\rho}{\varepsilon}$$

where ν is the Poisson's ratio of the conductor, ε is the strain and the other terms are as previously defined. In practice, the strain sensitivity is also referred to as the gage factor Sg.

$$S_g = \frac{dR/R}{\varepsilon} \approx \frac{\Delta R/R}{\varepsilon}$$

Wheatstone Bridge:

Figure below shows two different illustrations of the Wheatstone bridge which are however electrically identical: Figure a shows the usual rhombus type of representation which Wheatstone used; Figure-b is a representation of the same circuit which is more clear for the electrically untrained person. The four arms or branches of the bridge circuit are formed by the resistances R1 to R4. The corner points 2 and 3 of the bridge designate the connections for the bridge excitation voltage Vs; the bridge output voltage Vo, the measurement signal, is available on the corner points 1 and 4. If a supply voltage Vs is applied to the two bridge supply points 2 and 3 then this is divided up in the two halves of the bridge R1, R2 and R4, R3 as a ratio of the corresponding bridge resistances, i.e. each half of the bridge forms a voltage divide.

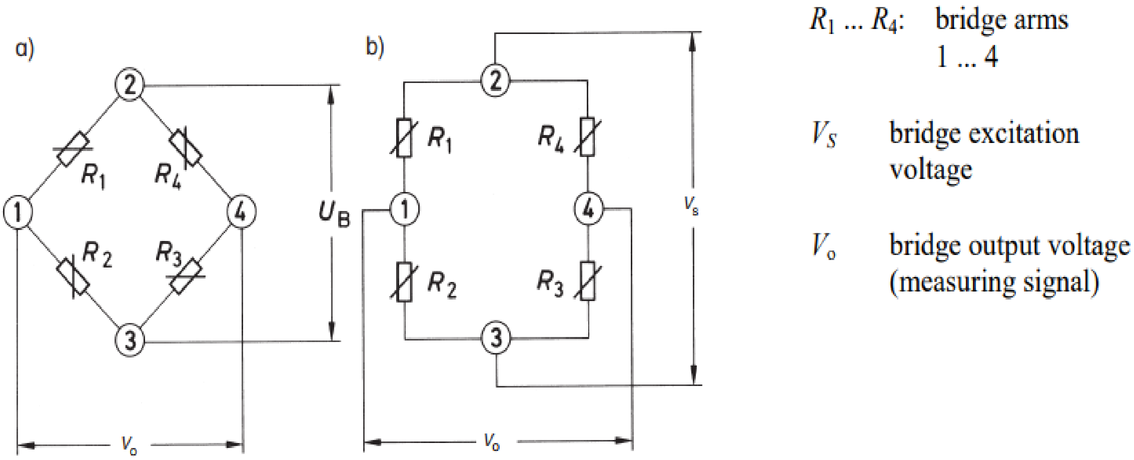

Figure 2 Wheatstone bridge Circuits

$$V_o = V_s\left(\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4}\right)$$

If the bridge is balanced

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Stress Analysis:

Gage Factor:

The relationship between the resultant fractional change of gauge resistance to the applied strain (fractional change of length) is called the Gauge Factor (GF), or sensitivity to strain. Specifically, the Gauge Factor is the ratio of the fractional change in resistance to the strain:

GF = (dR / R) / (dL / L) = (dR / R) / ε.

Circuits Available:

Quarter Bridge circuit- Very Cheap, Reliable. A quarter-bridge that uses one active gauge to make uniaxial tensile or compressive strain measurements

Half Bridge Circuit- Cheap, Reliable. A half-bridge that uses two active gauge to make uniaxial tensile or compressive strain measurements

Full Bridge- Costliest, Very Reliable. A full-bridge that uses four active gauge to make uniaxial tensile or compressive strain measurements.

We next present the block diagram and layout of the project.

Block Diagram and Layout:

Block diagram for the project design:

The following is the most trivial block diagram of the weigh scale project design.

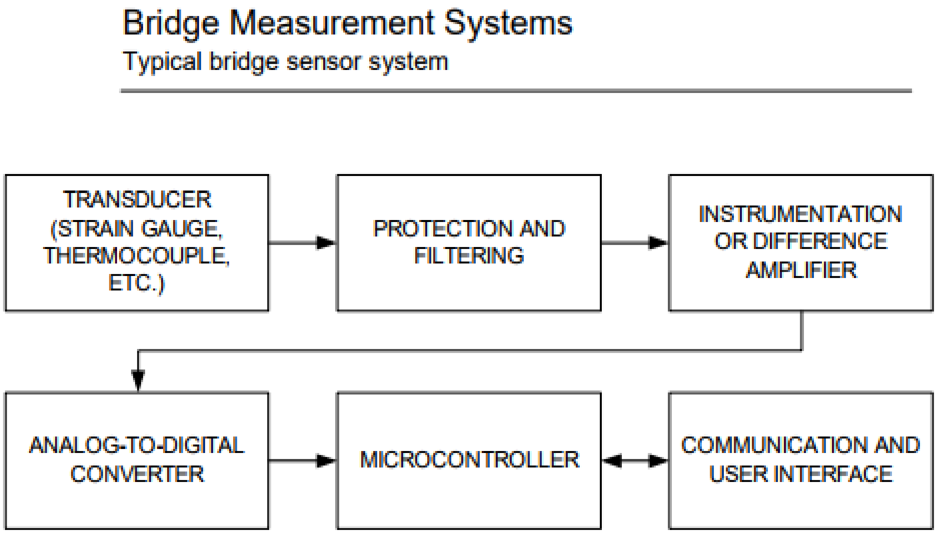

Figure 3Block Diagram

- Initialy it requires a transducer, where a strain gages are used for calculating the mechanical stress and a circuit is used for the same to convert the estimated stress to electrical volts.
- Then we need a filtering design to remove the noise added during the calculation procedure. The design can be anything which removes the ambient temperature noise, weight miscalculations etc..
- An operational amplifier is needed to convert the analog voltages to a digital voltage and then converted voltage is mapped to a prescribed weight. This procedure includes an analog to digital converter.
- Further we need an communication interface which conveys the information to a LCD screen for the users to view the calculated weight.

We next present the layout considered for the project design in Figure 4.

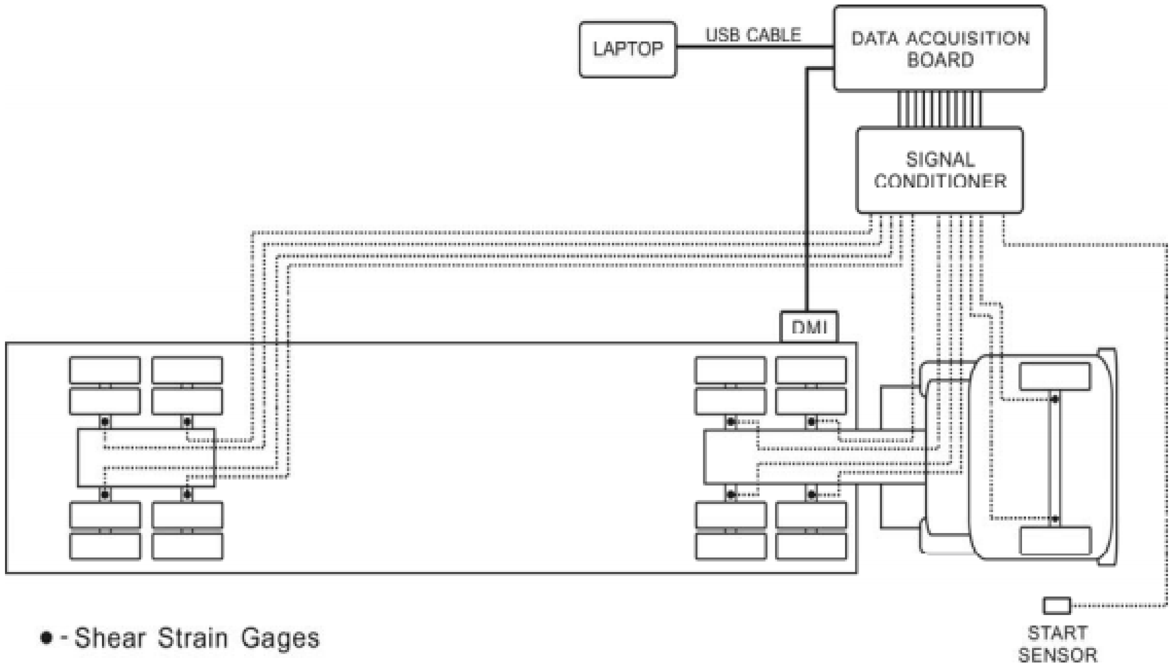

Figure 4 Layout

The main components of the layout are:

• a chassis unit containing the power supply and signal interface modules,

• two laser/accelerometer modules mounted on the front of the test vehicle,

• a Model Data Translation board for data acquisition,

• a distance encoder,

• a start sensor, and

• a notebook computer.

Figure shows the layout of the sensors, signal conditioning, and data acquisition devices on the test vehicle. All strain gages were wired to the same signal conditioner used in the small-scale trailer testing. This conditioner amplifies the gage readings and measured the voltage changes in all strain gage channels. Data from all channels (including the distance encoder, start sensor, and thermocouples) fed into a 16-bit Data Translation module with a 500 KHz maximum sampling rate. This module will be connected to a notebook computer for data collection via a USB cable. A general purpose data acquisition program was used to read and record data from all channels during testing. Researchers in literature specified a sampling rate of 4 KHz for each channel on test runs made to collect dynamic load measurements on in-service pavement sections.

The design mainly consists of two parts:

a. Mechanical Engineering using Straing Gauges,
b. Electrical Engineering using op-amps

Stain Gauge Designs

The design considered in the project is as follows:

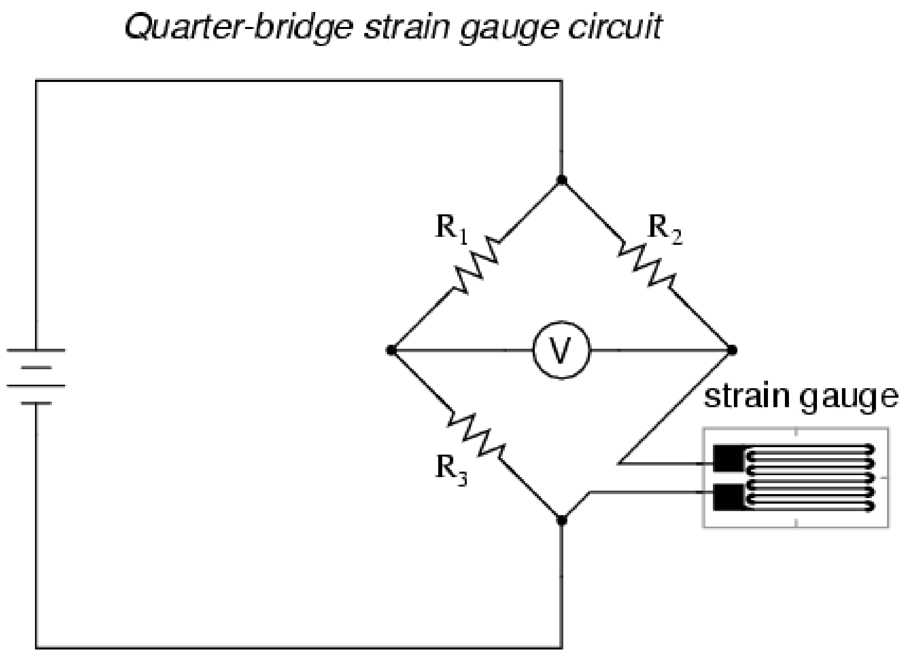

Figure 5Quarter bridge Strain Gage circuit

Design and Description:

The principle of operation of the device is basically on the fact that resistance of an electrical conductor changes with the ratio of dR/R is a stress applied such that its length changes by a factor dL/L.

Design:

We have considered a Quarter Bridge Circuit for the design. This is very cheap as only one strain gage is required. And is also reliable enough. The design of the same is as follows:

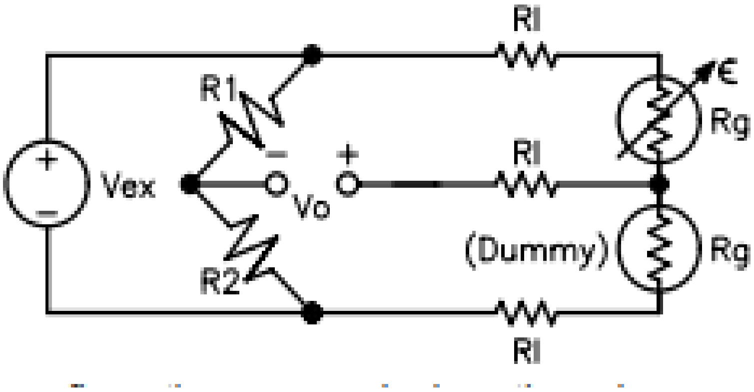

Figure 6 Quarter Bridge Circuit Design

Description:

The second quarter-bridge configuration (Type II) or the above mentioned design is the commonly used to measure compression found in many of the weigh-scale applications. This configuration uses a single active, plus a passive or "dummy" gauge mounted transverse to the applied strain. The dummy gauge doesn't measure any strain, it is provided for temperature compensation only. That is, the applied strain has little effect on the dummy gauge as it is mounted in the transverse (perpendicular) direction (the Poisson's Strain is very small), but the ambient temperature will affect both gauges equally. Since both gauges are subject to the same temperature, the ratio of their resistances are the same, and Vo does not change with respect to temperature.

Note that the temperature compensated Quarter-Bridge (Type II) is sometimes incorrectly referred to as a half-bridge configuration due to the presence of the second gauge. But since the second gauge does not measure strain (it is not active), it is in fact a Quarter-Bridge Type II circuit and the quarter-bridge formulation applies. Note further that the quarter bridge technique cannot be used in applications where the direction of the stress field is unknown or changes. If there is any force applied in the direction of the dummy gauge, then the measurement of strain along the direction of the active gauge will be in error. In either case, solving for the resultant strain of the Quarter-Bridge Type I or Type II configuration will yield the following expression (note the absence of Poisson's Ratio):

Analysis:

Resolution of the System:

The resolution of the system is given by dv=0.6e-6 v;

Stress Analysis:

To simplify the equations and account for unbalanced bridges in the nonstrained state, let us consider the ratio

$$V_r = \frac{V_{O(strained)} - V_{O(unstrained)}}{V_{EX}}$$

where VO(strained) is the measured output when strained,

and VO(unstrained) is the initial, unstrained output voltage. Vex is the excitation voltage.

The designation (+ε) and (–ε) indicates active strain gauges mounted in tension and compression, respectively.

The designation (–νε) indicates that the strain gauge is mounted in the transversal direction, so that its resistance change is primarily due to the Poisson's Strain, whose magnitude is given as –νε.

Other nomenclature used in the equations include:

Rg = nominal resistance value of strain gauge

GF = gauge factor of strain gauge

RI = lead resistance

Vex: The Brdige Excitation Voltage=2.5 Volts (Given). The same is seen in Figure 4 where, Vex is the input voltage.

Gage Factor=2.

Rg=Gage Resistance=350 ohms. Rg is also present in Figure 4.

Overload Capacity=400%. Maximum weight for the weigh scale.

Rated Capacity=10000lbs. General weight for the project.

dv=0.6e-6 V; This is given in the specs of the assignment.

I=2.5/350;

dR=dv*I=4e-8;

But according to the design mentioned we have strain factor, ε

ε= -4Vr * (1 + Rl / Rg) / [GF*(1+2Vr)]= -4Vr * (dR) / [GF*(1+2Vr)];

= -4e-8(2.5-0)/[2*(1+2(2.5))];

= 1.2e-6;

- So the device now will work with (2mv/V)*(2.5 V)= 5mV output voltage at a weight of 10000lbs.

- The output may go as high as (5*4=20mV) at a weight of 40000 lbs with an excitation of 2.5 Volt source.

Sensitivity:

Sensitivity is defined as

$k1=(dr/Rg)/\varepsilon=(4e-8/350)/0.6e-6=0.0001;$

We next explain the additional design aspects mentioned in the assignment.

Design Aspect 2:

Mounting:

Mounting materials include the materials used for fixing the strain gage to the measurement object, for connecting up the strain gage and material used for the protection of the measuring point. The mounting of the strain gage itself is a task that requires extreme care. Only correctly mounted strain gages can operate properly. It is therefore essential that the instructions for mounting the strain gage and those for using the mounting materials are followed.

The following mounting techniques are used:

- cold curing adhesives

- hot curing adhesives

- ceramic putty

- flame deposited ceramics

- spot welded joints.

Spot welding is one of the simplest fixing methods. It requires the minimum of equipment, i.e. a small welding unit, only a slight amount of preparation and little practice.

Overload Capability:

As mentioned earlier the weigh scale is designed to operate or bear a maximum of 4 times the normal rated capacity i.e., 40000lbs. This is a safe operating of the weigh scale. Beyond this if a weight is measured will result in damage of the circuit.

We next explain the electrical engineering aspects of the design.

Electrical Engineering:

For the weight to be displayed the calculated voltage has to be converted to a digital representation, where the voltage is mapped to a specific weight.

Electric Circuit Design

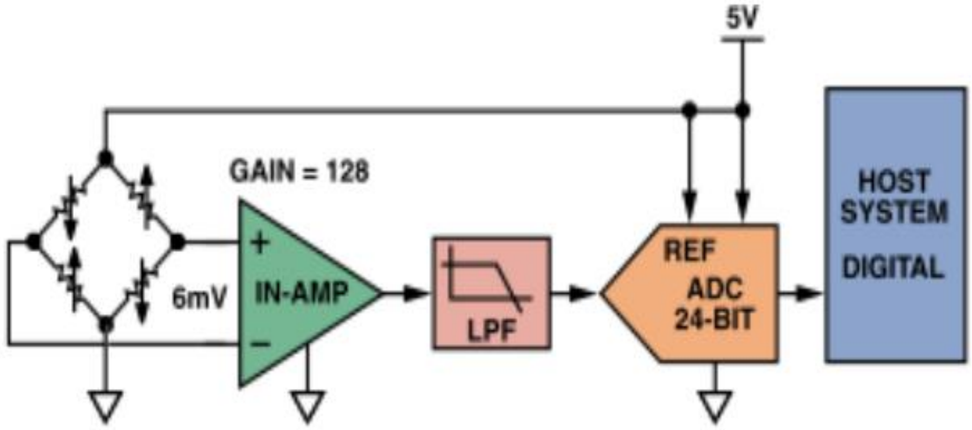

Figure 7Electrical Circuit with ADC set up

In this arrangement, the output is obtained as mentioned with the procedure earlier. This output of the transducer is first amplified using an operational amplifier. The amplified output is then followed by a filtering stage to remove noise due to power supply and mechanical vibrations. Then this filtered output is sampled by a high resolution ADC. ADC stands for Analog to Digital Converter. Load cells are nothing but resistive sensors which provide a ratio metric voltage corresponding to the load applied to them. Most commonly used load cells have strain gauges connected as a wheat stone bridge.

Mechanical and Electrical Noise Removal:

One of the final steps to achieving a noise-free output resides in using a firmware-based mathematical filter to average out noise. An easy filter to implement is a moving average filter. It uses an array where the input values keep getting streamed in from one side and the oldest values fall off the array from the other side. At any given time, the output of the filter is the average of all of the elements in the array. The moving average filter is one of the easiest yet most effective filters to achieving higher noise-free bits from the measurement system. Note that there is a constant delay this filter imposes which is proportional to the depth of the array used. That means for an 'n' element moving average filter, every change is going to take 'n' cycles to reflect itself in the output. This can be a bit misleading if there are larger variations and the output slowly catches up. This condition can be avoided by having a threshold condition check on variations. For example, if the input varies more than a threshold at a specific point of time, the whole filter is flushed and new data is copied in the filter and also into the output, thus reducing the latency for larger variations. Filter size needs to be selected dependent on the required resolution, ADC's sample rate, and response time specification of the weigh scale

Precision Maintenance:

This is one of the most important parameters of a load cell. The sensitivity of a load cell as explained earlier is defined as full load output voltage in relation to the excitation voltage. It is generally expressed in mV/V. This value corresponds to the voltage deviation caused by the load cell at full load when excited by a 1V source. The sensitivity of load cells is very low (generally about 2mV/V). If a system has a 3.3V excitation voltage then at full load, the output voltage will be 6.6mV. It makes the requirement for a high precision ADC mandatory while dealing with load cells. The resolution mentioned earlier 0.6e-6 volts has to be replicated here too. Else the precision though achieved during the strain gage measurements, will be lost during the conversion ADC.

Conclusion

We presented complete design, description for weigh scale project. All the mechanical and electrical aspects required for a reliable, cheap weigh scale design are considered. The design is further analysed with specifications mentioned in the assignment. Enough figures and references are provided for understanding the same.

References-

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