BE 209 – Group BEW6
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The AD620 Instrumentation Amplifier and the Strain Gauge
Building the Electronic Scale

INTRODUCTION:

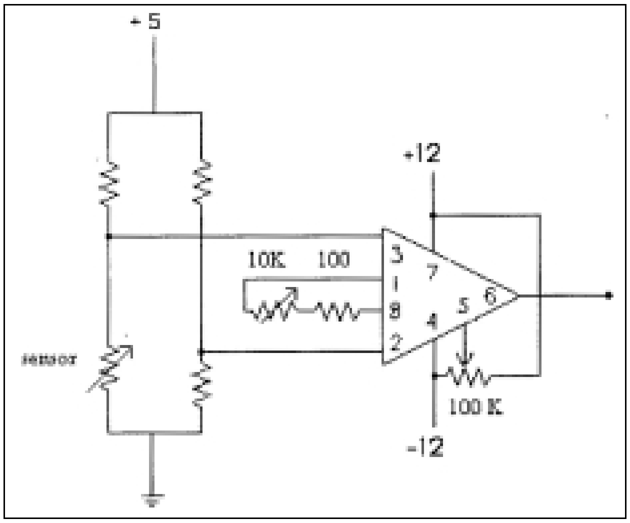
In this experiment, we attempt to build an electronic scale by using the strain gauge and the AD640 Instrumentation Amplifier. The strain gauge is a resistor that changes resistance with elongation, and the Instrumentation Amplifier amplifies the change in voltage. The strain gauge in this experiment is attached to an aluminum bar so that any elongation in the bar due to applied forces will cause a change in the resistance in the strain gauge. This signal emitted by the strain gauge will then be changed to a voltage by a resistance bridge. The Instrumentation Amplifier will then enlarge this small change in voltage. We use the aluminum bar as our "instrument" for attempting to build an electronic scale because we are assuming that the aluminum bar, being malleable, will exhibit a definite relationship between strain and force, such as a linear one. Such definite relationship is essential for building a scale.

Our main objective in the experiment is to correlate change in voltage with change in strain so that we can pinpoint certain voltage change as indicative of a certain amount of force applied. We also need to build the electronic scale as accurately as possible, thus we will also attempt to quantify the uncertainty in the voltage reading by observing the drift and the noise of the signal. Drift is the change in value of the voltage over time. Noise is the interference of the signal due to interruptions from the surroundings. Determination of an appropriate way to correlate change in voltage with change in strain can be further applied to investigate the material property of other materials, such as bone. The determination of such property can then be used toward the building of such device as the artificial bone, which should have material properties comparable to the real bone.

<u>METHODS & MATERIALS</u>:

- Solderless breadboard
- Wire, electronic parts, Wire strippers
- Strain gauge attached to 1-cm cross-sectional aluminum bar
- Resistors (3 – 120 Ω; 1 – 100 Ω)
- Potentiometers (1 – 10 KΩ; 1 – 100 KΩ)
- Voltage Source
- Digital voltmeter
- AD620 Instrumentational Amplifier
- 4 – 2.3kg weights
- Virtual Bench data logger and Virtual Bench oscilloscope
- Ruler

Figure 1:



First, the schematic shown in Figure 1 above was used to build the "bridge amplifier" circuit. The wires of the DC supply is coded in the following way: red = +12V, black = -12V, white = +5V, green = 0V = ground. The white wire is connected to the active area of the breadboard. Two resistors of 120Ω each were connected in that same row. One resistor is connected in series with the strain gauge, which is connected in series to the ground. The other resistor is connected in series to another 120Ω resistor, which is connected in series to the ground. The row containing the strain gauge is connected to pin 3 of the AD620. The row containing the other resistors was connected to pin 2. The 10KΩ potentiometer is connected in series with a 100Ω resistor from pin 1 to pin 8. The 100KΩ potentiometer is connected at one end to +12V at the other end to –12V and the output to pin 5. Pin 6 is connected to the digital voltmeter. The circuit was completed by connecting pin 4 to the black wire (-12V) and connecting pin 7 to the red wire (+12V).

Next, the necessary procedures for constructing the calibration curve were performed. First, we adjusted the 100K potentiometer so that there a zero volts output without weights added. The Virtual Bench program was started. Then we placed a 2.3kg weight at a position that was 24.8 cm from the fulcrum of the aluminum bar and 19.6 cm from the strain gauge. The voltage output was recorded. The weight was then removed to ensure that the voltage output without the addition of weights was still zero. Next, weights were added in 2.3kg increments towards a maximum weight addition of 9.2kg. In order to see what affect the distance from the strain gauge/fulcrum has on voltage output we ran another experiment by positioning the weights at a position that was 8.7 cm from the fulcrum and 8cm from the strain gauge. Weights were added in the same fashion: 2.3kg, 4.6kg, 6.9kg and then 9.2kg. Then we changed the gain by manually adjusting the notch in the 10K potentiometer. The 100K potentiometer was then subsequently adjusted so that the voltage output with no weights attached was zero. Weights were added in the same manner as they were with the first gain: first a distance 24.8 cm from the fulcrum (i.e. 19.6 cm from strain gauge) and then a distance 8.7 cm from the fulcrum (i.e. 8.0 cm from strain gauge).

Finally, the Virtual Bench data logger was used to graphically observe noise and drift of the system. Voltage readings were recorded for approximately 10 minutes while the aluminum bar with the strain gauge was left with no forces being applied. The Virtual Bench oscilloscope was also used to monitor the A.C. noise.

RESULTS:

Figure 2 in the Appendix displays the voltage-force calibration curve for the two different gain settings when the weights were applied at 24.8 cm from the fulcrum. Likewise, Figure 3 displays the same calibration curves for the two gain settings when the weights were applied at 8.7 cm from the fulcrum. Based on calculated Pearson's coefficients of $r > 0.999$, the voltage values demonstrate a near perfect linear relationship with the applied force.

Table 1 below charts the calibration equations from force to voltage for the four different experimental settings. It is observed that as the gain is decreased, the output values for voltage is decreased. Also, as the weights were placed closer to the fulcrum, less strain was applied to the strain gauge resulting in decreased voltage outputs.

Table 1: Conversion Equations (Voltages in Volts, Forces in Newtons)

	Force applied 24.8 cm from fulcrum	*Force applied 8.7 cm from fulcrum*
Initial Gain	Voltage = 0.0128 x Force	Voltage = 0.0053 x Force
Decreased Gain	Voltage = 0.0038 x Force	Voltage = 0.0016 x Force

Figure 4 displays a graph generated from the Virtual Bench data logger. Here, the aluminum bar was left without any forces applied to it for approximately ten minutes. This rough sinusoidal curve represents the varied voltage values due to noise interference, the noise being the amplitude of this curve. The Virtual Bench oscilloscope was used to determine the peak-to-peak value of the curve (i.e. twice the value of the noise) and generated a value of 11.8 mV. Thus, the average noise is calculated to be 5.9 mV. The sinusoidal curve of Figure 4 also shows a general decline in the average voltage value with increasing time. A best-fit line was created for this curve with a slope value (i.e. drift) equaling -7.82×10^{-6} Volts/sec.

DISCUSSION:

The calibration curves show a linear relationship between the force applied to the bar and the voltage output signal. Thus as the force applied was increased (by means of weights) the voltage output increased as well; the data shows that there is a direct relationship between the force and the voltage output.

One focus of this lab was to determine the effect of gain on the voltage output. A comparison between the two calibration curves corresponding to the two different gains, as in Figures 2 and 3, show that the voltage output was affected by a change in the gain produced by an adjustment of the 10KΩ potentiometer. The voltage jumps from one weight addition to the next weight addition are greater in the calibration curve constructed for the first gain (which we will call G1) that was used than the voltage jumps in the calibration curve constructed for the adjusted gain (which we will call G2). A decrease in gain corresponds to a decreased voltage jump. Thus, the gain change from G1 to G2 corresponded to a decrease in gain as can be seen from the graphical analysis of the data.

The bridge amplifier circuit in conjunction with the strain gauge has many useful real-world applications. For instance, electrocardiography traces the electrical activity of the heart by means of a cardiograph. The EKG is a record of this activity. Deviations in the EKG correspond to abnormalities in the patient's cardiovascular system and thus are an aid in diagnosing heart diseases. Analogously, the deviations shown in a patient's EKG are similar to the drift that resulted in the voltage output that was seen in the graphs produced by the Virtual Bench logger. Furthermore, a bridge amplifier circuit helps to condition the small voltage signals produced by electrocardiography as well as those produced by the strain gauge.

The strain gauge can also be used to investigate the material properties of chicken bone. Chicken bone, in comparison to the aluminum bar used in this experiment, is more rigid and therefore more susceptible to breaking than aluminum, which is prone to bending. Also, chicken bone is hollow while the aluminum bar is solid. If it were possible to conduct the experiment using a chicken bone with the same shape and size as the aluminum bar, the graphs produced by the Virtual Bench logger would provide an indication of the material properties of chicken bone. Since there is a direct correlation between the elongation of the bone and the output signal, a study of the change in voltage output signals as the weights are increased would indicate elongation of the bone due to force applied. Such elongation would be an intrinsic property of the bone sample. In comparison to the aluminum bar, the bone would eventually break when the force reaches a certain "breaking force", whereas the aluminum bar would bend and would not be susceptible to fracture. If a chicken bone was used instead of the aluminum bar, the stresses and strains incurred on the bone via the weights applied could be analyzed to determine material properties such as Young's modulus.

Electronic apparatuses such as the one utilized throughout this experiment accommodate a superior accuracy reading of the strains present within a system relative to simple mechanical measurements, thus the ability to transduce a mechanical force into electrical resistance is crucial for accurate expression of data. Despite its efficiency, however, strain gauge systems are by no means perfect, and sources of error are, in fact, inherently more numerous than those exhibited within mechanical experimentation. Perhaps the most prevalent of these errors is that due to electrostatic noise. Electronic systems such as the circuit utilized throughout the procedure of this examination are subject to numerous sources of noise simply due to the fact that almost all electronic equipment generate considerable quantities of electrostatic interference. This interference induces the flow of current throughout the circuit, thus skewing the signals interpreted by the sensors. In order to dampen such effects, ground wires may be utilized to filter excess noise out of the system, however the use of more than one ground wire can create added interference; a system implementing two ground wires which have disparate charges will attempt to balance charge through the system, thus creating added external current and further skewing the true voltage values. Due to the small size of our circuit, it was unnecessary to have more than one ground wire, thus such error was averted.

Numerous electrical devices generated noise encountered throughout the experiment, including computer monitors, radio waves, and halogen lighting within the room (which runs at an approximate frequency of 60 Hz). The induced interference prevalent throughout the system can be verified graphically by observing the fluctuations of the blue line around the straight black line represented in Figure 4. Such noise creates a situation in which a representative line passing through the center of the averaged noise values (empirical assumption of an ideal system) is difficult to determine, thus rendering the jumps in voltage due to added weight inaccurate. Although it is virtually impossible to completely eradicate all traces of electrostatic interference, decreased noise can be achieved by turning off the monitors and lights within the room.

It was also determined that most of the noise encountered in data collection was present in the system before amplification of voltage by gain. This was determined by changing the resistors attached to the gain. It was found that decreasing the resistance at this point not only amplified the voltage jump, but also the noise to the point that the ratio between these two values remained very similar. This implies that the noise in the system was subject to amplification and thus must have been introduced prior to it.

The other quantified source of error present in this experiment is drift. Drift is the change in voltage value of the circuit due to external environmental changes such as temperature, noise, friction, and static electricity. Drift is graphically represented by the decreasing average value of voltage over time, shown in Figure 4 by the negatively sloped line of best fit.

Another ever-present source of error is the accumulation of the imperfection of the cables, and voltmeter. The wires utilized to construct the apparatus are not ideal and therefore carry a small amount of resistance; these individually insignificant resistances created by wires, once combined, form a considerable aggregate resistance throughout the system. Furthermore, the lack of perfection of the resistor facilitates a small absorption of current, where an ideal resistor has infinite resistance and therefore absorbs no current. This small loss of current, combined with the resistance throughout the adjoining wires, creates added error within the system. This error is reasoned to be even larger, due to the minute values of current collected by the apparatus; the smaller the current value the larger effect such imperfections have throughout the system. Although this error is assuredly present, it exists only as a diminutive source of deviation. The remaining error is most likely due to a combination of noise and drift.

Yet another procedural error occurred due to the fact that the weight could not all be placed at the same point on the bar. Due to the thickness of bother the weights and the rope, the weights had to be hung beside each other, distributing the load over a small area where the ropes hung. Because the load was not applied at a singular point, a truly accurate representation of the strain per given load can only be calculated by performing an integral about the area over which the weight was distributed. Hanging the weights off of one another can easily amend the experimental procedure. This simple modification facilitates the addition of weight while holding the number of ropes attached to the bar constant at one; this decreases the area over which the weight is distributed, thus rendering a point-value approximation of the strain per given load more accurate.

CONCLUSION:

Usage of the strain gauge, coupled with that of a resistor bridge and the AD620 Instrumentation Amplifier, allowed for the correlation of force-induced strain versus voltage change. An electronic scale using an aluminum bar was built using such correlation. Modifications on the location of force applied and the gain was made to investigate the best method for obtaining results that yields relatively little drift or noise. The data shows a linear relationship between force applied and the voltage change, just as expected, with a drift of -7.82×10^{-6} Volts/sec and noise of 5.9 mV. Data also suggests that a decreased gain leads to less voltage change, and that force applied closer to the fulcrum yields less strain and less voltage change. The use of the circuits in this lab allowed for further investigation of the material properties of other substances, such as bone.

APPENDIX:

Figure 1:

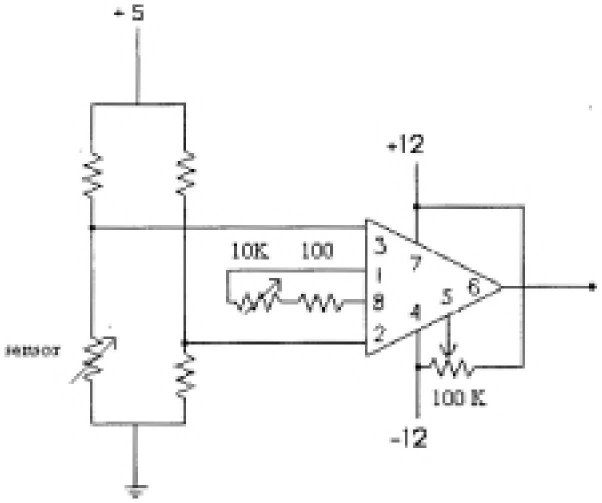


Figure 2: Voltage vs. Force
(Force applied 24.8 cm from fulcrum, 19.6 cm from strain gauge)

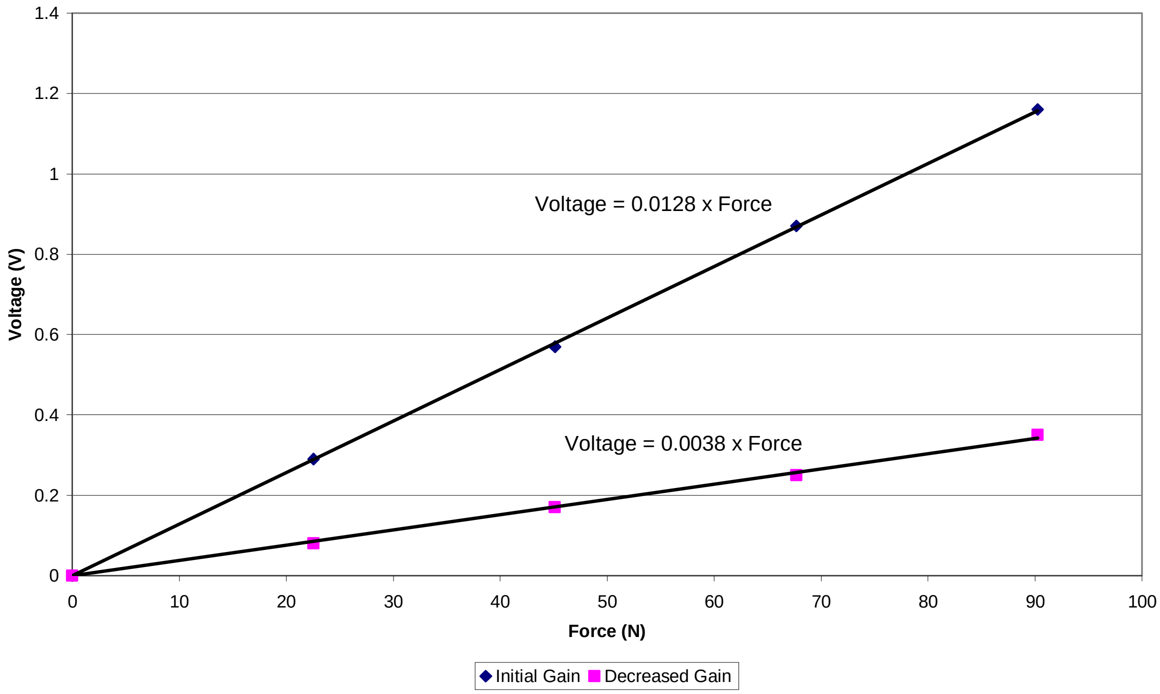


Figure 3: Voltage vs Force
(Force applied 8.7 cm from fulcrum, 8.0 cm from strain gauge)

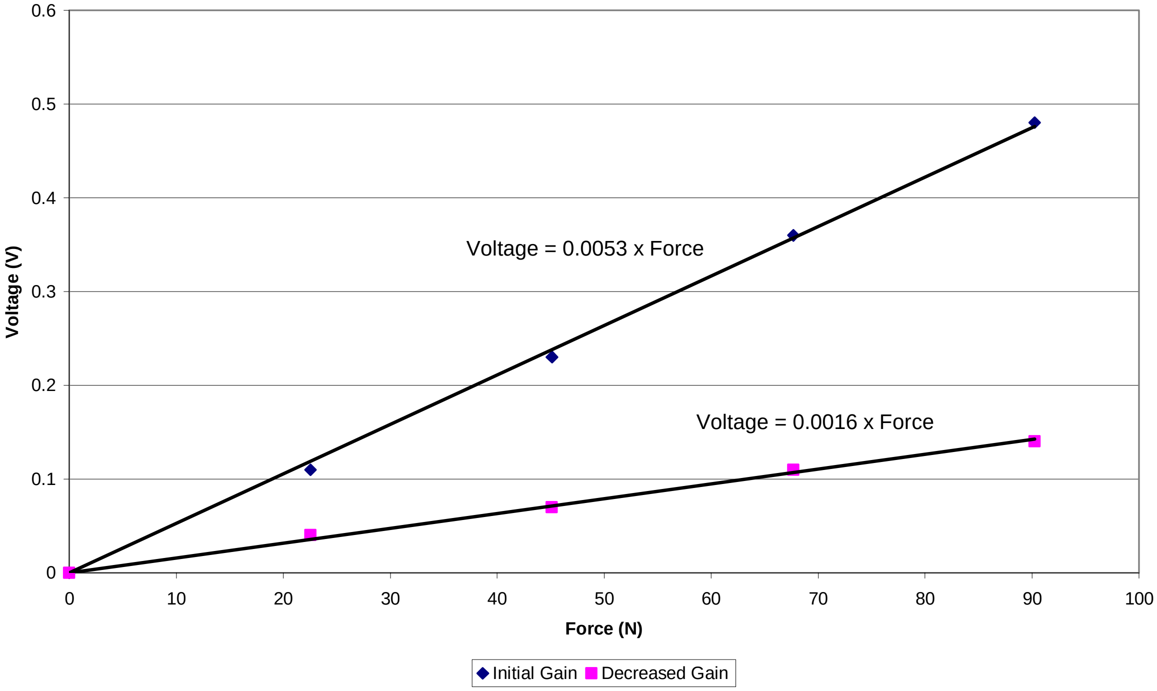


Figure 4: Drift in Voltage