Lab1: AS20 Interface.

KEY
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1 Objective
This lab will give the student experience in designing, building, testing and implementing an interface between an NI 6009 Data Acquisition Module and the AS20 Valve Driver board.

2 Introduction
In electro-hydraulic systems, as the name implies, a hydraulic valve is controlled via electrical signals. Although in the past these may have originated from switches and relays, these days virtually all control is done using computers or microcontrollers, sometimes packaged in Programmable Logic Controllers (PLCs), which are ruggedized versions of small computers. For control in this course, we will use a standard low-cost National Instruments(NI) 6009 Data Acquisition Module. This module has 2 analog outputs, 8 analog inputs in single ended mode or 4 analog inputs in differential mode. The module also has 12 digital inputs/outputs and a counter, neither one of which we use in this lab.

One of the drawbacks of the low-cost 6009 board is that the analog outputs do not have their own clock. This means that the outputs need to be generated one at a time in a loop in software. This seriously limits the output frequency of the board, but for hydraulics applications, it is more than fast enough.

On the hydraulic side, we have a board that drives a solenoid operated proportional valve that has a variable flowrate. To move the spool in the valve, a signal (DC voltage) can be applied either from the front panel of the EH control box or from an external computer with a range of [-1, 1] Volt. In the EH labs we have to generate this signal from the NI6009, but unfortunately, the output range of its analog outputs is [0, 5] Volt. Therefore, we need an electronic circuit that can map a range of [0, 5] Volt onto a range of [-1, 1] Volt. In this lab, we will design, build, test and implement this interface.

3 Procedures
Without building anything, just from a mathematical perspective, we can find out what we need to do to map [0, 5] V onto [-1, 1] V. First, we need to make the input range symmetric
Figure 1: Subtracting OpAmp with function for \( R_1 = R_2 = R_3 = R_4 \implies U_O = U_2 - U_1 \).

by subtracting 2.5 Volt which maps [0, 5]V onto [-2.5, 2.5]V. Then we need to divide by 2.5 and we are done! To put this idea into electronics we need an electronic subtractor, followed by a divider. Luckily for us, these are standard functions: An OpAmp can be used to subtract a constant voltage, and a voltage divider consisting of two resistors can be used to divide a symmetric voltage. In fact, the 6009 has a 2.5 Volt output pin, which is meant for this kind of problem.

3.1 OpAmp subtractor

To subtract signals in real time we use the circuit as shown in Figure 1.

We will again use the Virtual Ground Principle, where \( U^+ = U^- \), but alas since neither of the inverting nor non-inverting terminal is grounded, it is a little more complicated than usual. However, I hope your recognize a simple Voltage Divider at the non-inverting terminal, where we can state that:

\[
U^+ = \frac{R_4}{R_3 + R_4} (U_2 - 0)
\]

This is of course the same voltage at the inverting terminal due to the VGP. To calculate the output, let’s calculate the current \( i \) using Ohm’s Law as follows:

\[
i = \frac{U_1 - \frac{R_4}{R_3 + R_4} U_2}{R_1} = \frac{R_4}{R_3 + R_4} \frac{U_2 - U_O}{R_2}
\]

Multiplying the LHS and RHS by the factors \( R_1 \) and \( R_2 \) gives:

\[
U_1 R_2 - \frac{R_4 R_2}{R_3 + R_4} U_2 = \frac{R_4 R_1}{R_3 + R_4} U_2 - U_O R_1
\]
Solving this equation for $U_O$ gives:

$$U_O = \frac{1}{R_1} \left[ \frac{R_4 R_1}{R_3 + R_4} U_2 + \frac{R_4 R_2}{R_3 + R_4} U_2 - U_1 R_2 \right]$$  \hspace{1cm} (4)

A little cleanup gives:

$$U_O = \frac{1}{R_1} \left[ U_2 \frac{R_4}{R_3 + R_4} (R_1 + R_2) - U_1 R_2 \right]$$  \hspace{1cm} (5)

If we make all resistors the same value, we get: $R_1 = R_2 = R_3 = R_4 = R$ or

$$U_O = \frac{1}{R} \left[ U_2 \frac{R}{R + R} (R + R) - U_1 R \right] \implies U_O = U_2 - U_1$$  \hspace{1cm} (6)

Here is a video where the subtracting OpAmp function is explained using the VGP.

Now we have subtracted the 2.5 Volt we need to divide the output of the OpAmy by 2.5. We can do this with a voltage divider. In general

The function of the OpAmp can be understood, by assuming that the voltages at the inverting and non-inverting input terminals are equal. This is called the Virtual Ground Principle (VGP). This leads to the following equation:

$$\frac{AO_0 - U}{2} = \frac{2.5 - U}{2} \implies U = AO_0 - 2.5$$  \hspace{1cm} (7)

Now the range it outputs is [-2.5, 2.5] Volt. To convert this signal into [-1, 1] Volt we need to divide by 2.5. This is accomplished in the output stage using a Voltage Divider. The ratio of the voltage divider is :

$$\frac{R_2}{R_1 + R_2} = \frac{1000}{1000 + 1500} = \frac{1}{2.5}$$  \hspace{1cm} (8)

The signal that is fed into the driver board is then

$$\frac{AO_0 - 2.5}{2.5} = \frac{AO_0}{2.5} - 1$$  \hspace{1cm} (9)

Check that this effectively maps the range [0, 5] Volt to the range [-1, 1] Volt.

### 3.2 Other inputs to the 6009 board

1. The position of the valve spool is measured using a Linear Variable Differential Transformer. These sensors have an AC voltage output, and are very accurate but they can only measure relatively small displacements. The AS20 board converts this AC signal into a DC signal that can be measured. The LVDT signal is of interest to determine the relationship between the spool location and the flow rate, but it is not useful for direct control of the cylinder position or motor speed.
2. The position of the cylinder is measured using a linear encoder. This encoder is essentially a variable resistor across which a constant DC voltage is applied. Therefore, the output of this sensor is a DC voltage which is linearly related to the position of the cylinder. The output of the sensor is assumed linearly related to the position of the cylinder, but since we do not know its input voltage exactly, and since the encoder does not have a calibration document, we need to calibrate this sensor ourselves to accomplish control.

3. The speed of the motor is measured using a tachometer, which employs a proximity sensor that is measuring pulses on a wheel. This signal is a pulse train that is translated into an RPM reading.

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### 3.3 Assignment

Remember the sequence: Design, Build, TEST, TEST, TEST

AS20 side (7 wires, three to screw terminals.

The color of the wires are given here. In electronics, Red is always positive Power Supply (Vcc), and Black is always Ground. The other wire colors are chosen arbitrarily.

NI6009 side (six wires, connected to screw terminals)

It is VERY important to use this standard, if you hook up wires wrong you could destroy the AS20 Board and these are 25 years old and cannot be replaced. Always make sure the power is off and have your circuit checked by the instructor before you turn the power on.
Figure 2: Interface 6009 AS20 Schematic
Figure 3: OpAmp741

Figure 4: Best Board Front
Figure 5: Worst board to date. Notice how the resistors are not flush with the board, and wires can easily touch and cause short circuits. This is NOT how to build a decent reliable experimentboard.
Figure 6: Breakout strip.