ME5643

Mechatronics

Final Project Report

Automated Cantilever Strain Measurements

Group 8

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Tables of contents

Abstract

When a load is applied at the end of a beam, it creates a moment, shear stress, and strain on the beam. These factors are critical in designing structures using beams. Many laboratories conduct research on the relationship between the loads and those factors. The cantilever's strain can be measured autonomously using a Parallax Basic Stamp, programmed with PBasic. The Memsic digital accelerometer sensors that comes with the Parallax kit can be used to detect the deflection of the beam. The Parallax continuous rotation servomotor can be used to apply the necessary force to the beam via a rotation to linear gear arrangement. A pushbutton in the integrated circuit serves as the reset button for the user to gather a new set of data. A strain gage is adhered to the beam where it will indirectly measure the strain when a load is applied. With the right integrated circuit and calibration, the strain of the beam can be measured based on the change in the charging time of the capacitor which is proportional to the change of the resistance of the strain gage. In addition, a Liquid Cristal Display is used to display the calculated strain at the user specified angle at which to measure the strain. Due to BS2's inability to perform floating point math some scaling needs to be performed which will give rise to some slight errors in the strain that is measured.

Introduction

Cantilevers can be used in many applications, from the springboard at the pool to the structures in buildings. A cantilevered beam is a beam at is fixed at one end. When a load is applied at the end of the beam, a moment, strain and shear stress are been created, as shown in Figure 1.
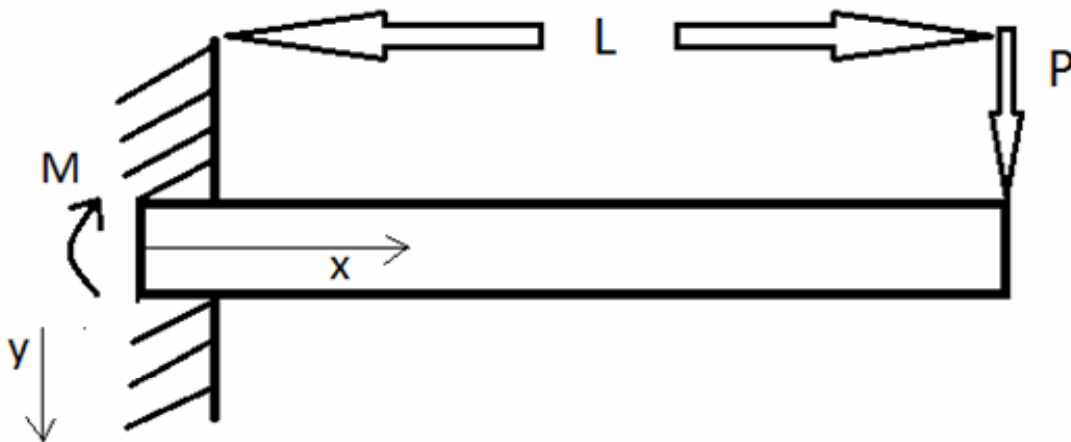
Figure 1: Cantilevered Beam with a length of L, applied force of P at the end of the beam, and the moment M.

The shear stress and the moment can be calculated based on the length of the beam, L, and the forced applied at the beam, P. The strain of the beam can be calculated using the Hooke's law,

$$\text{EMBED Equation.3}\qquad\qquad(1)$$

where σ is the stress, E is the modulus of elasticity, and ε is the the strain. The moment created due to the applied force can be found using

$$M(x) = P(L - x) \qquad\qquad(2)$$

where x is distance of the force is applied from the fixed end of the beam. The govening equation for the beam is

$$EI\frac{d^2v}{dx^2} = M(x) \qquad\qquad(3)$$

where I is the moment of inertia about the neutral axis, and υ is the shear stress. The moment of inertia can be found using

$$I = \frac{bh^3}{12} \qquad\qquad(4)$$
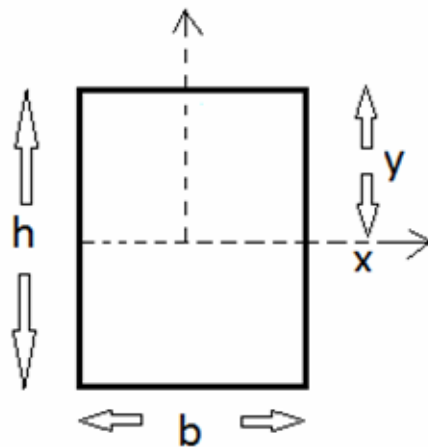
where the variable is shown on Figure 2.

Figure 2: Cross section of the cartilever beam.

Putting equation (2) into (3) gives,

$$EI \frac{d^2v}{dx^2} = P(L-x) \tag{5}$$

When integration is done twice on the both sides, it become

$$EI \frac{dv}{dx} = P(Lx - \frac{1}{2}x^2) + C_1 \tag{6}$$

$$EIv = P(\frac{L}{2}x^2 - \frac{1}{6}x^3) + C_1 x + C_2 \tag{7}$$

where $\frac{dv}{dx}$ is the deflected angle θ. With the boundary condition that there is no deflection initially, C_1 and C_2 can be found to be equal to zero. Therefore the deflection angle and the shear stress can be found

$$\theta = \frac{dv}{dx} = \frac{P}{EI}(Lx - \frac{1}{2}x^2) \tag{8}$$

$$v = \frac{P}{EI}(\frac{L}{2}x^2 - \frac{1}{6}x^3) \tag{9}$$

When the force is applied at the end of the beam, equation (8) and (9) become

$$\theta\big|_{x=L} = \frac{PL^3}{2EI} \tag{10}$$

$$v\big|_{x=L} = \frac{PL^3}{3EI} \tag{11}$$

Using equation (10) and (11), the relationship of the deflection angle and the shear stress can be shown

$$\theta = \frac{3v}{2L} \tag{12}$$

The stress and strain of the beam can be found using

$$\sigma = \frac{My}{I} = \frac{3PL}{bh^2} \tag{13}$$

$$\varepsilon = \frac{My}{EI} = \frac{3PL}{Ebh^2} \tag{14}$$

A strain gage is a transducer that used to measure the strain in a mechanical component. When the strain gage deflected, stretched or compressed, the resistance in the strain gage changes accordingly. The relationship between the changes in resistances and strain is governed by

$$\varepsilon = \frac{\Delta R / R}{F} \qquad (15)$$

where R is the resistance and F is the gage factor.

The gage factor of the strain gage is 2.135.

System

Design – Mechanical Design

The device was constructed with Aluminum 6063 which served as the sturdy cantilever support. The servomotor is mounted on the top middle of the structure. The servomotor has been propped with a gear to transmit rotational motion to another gear which in turn moves the loading rod up or down. When the servomotor turns counterclockwise, the loading rod will go up. When the servomotor turns clockwise, the loading rod will go down which will apply a load on the testing element that is attached in the middle of the structure. The Board of Education is mounted behind the servomotor on top of the structure. Furthermore, the LCD is secured onto the structure at the bottom. The SolidWorks drawings of design of the machine are shown in Figure 3 and 4.
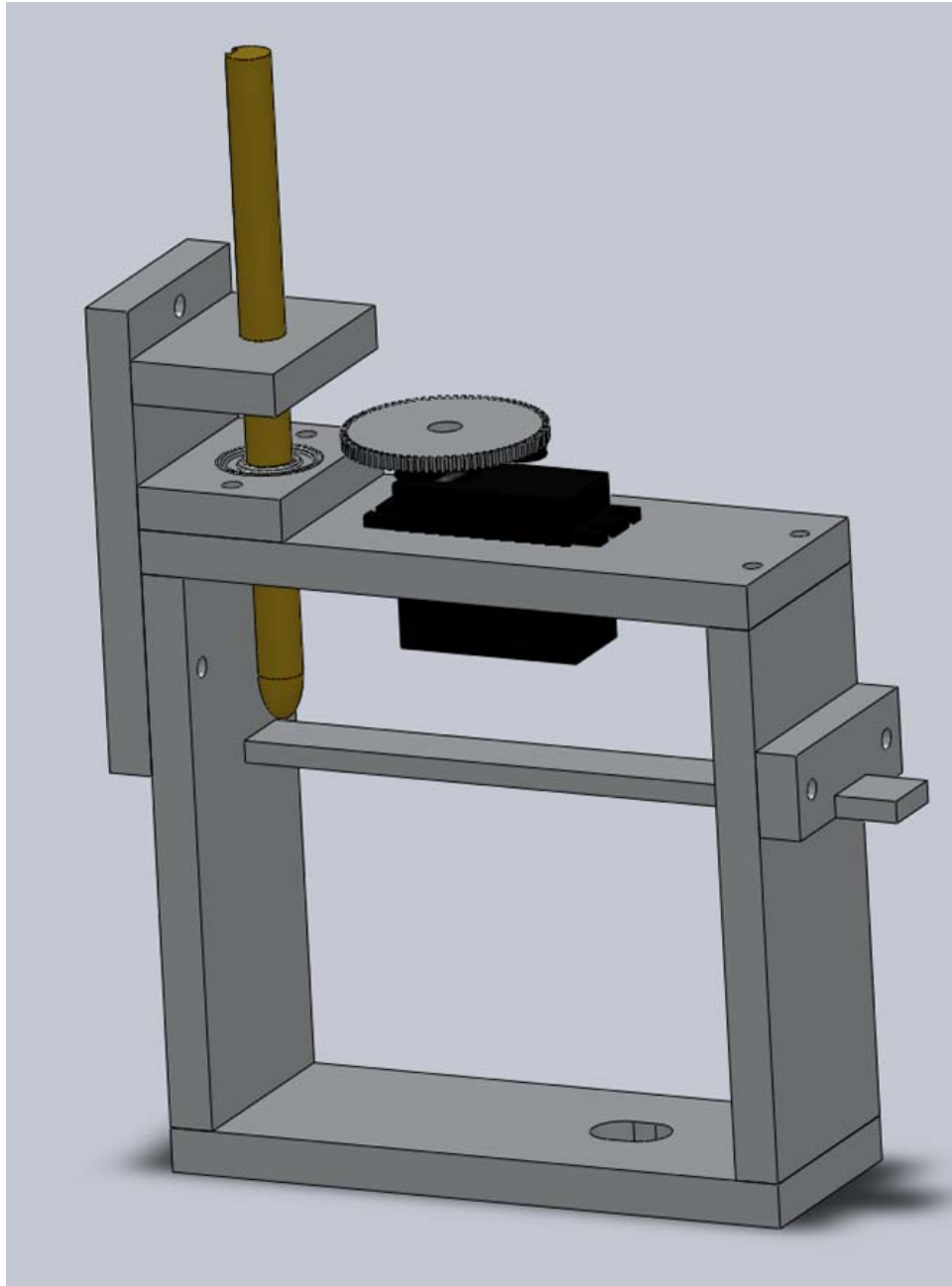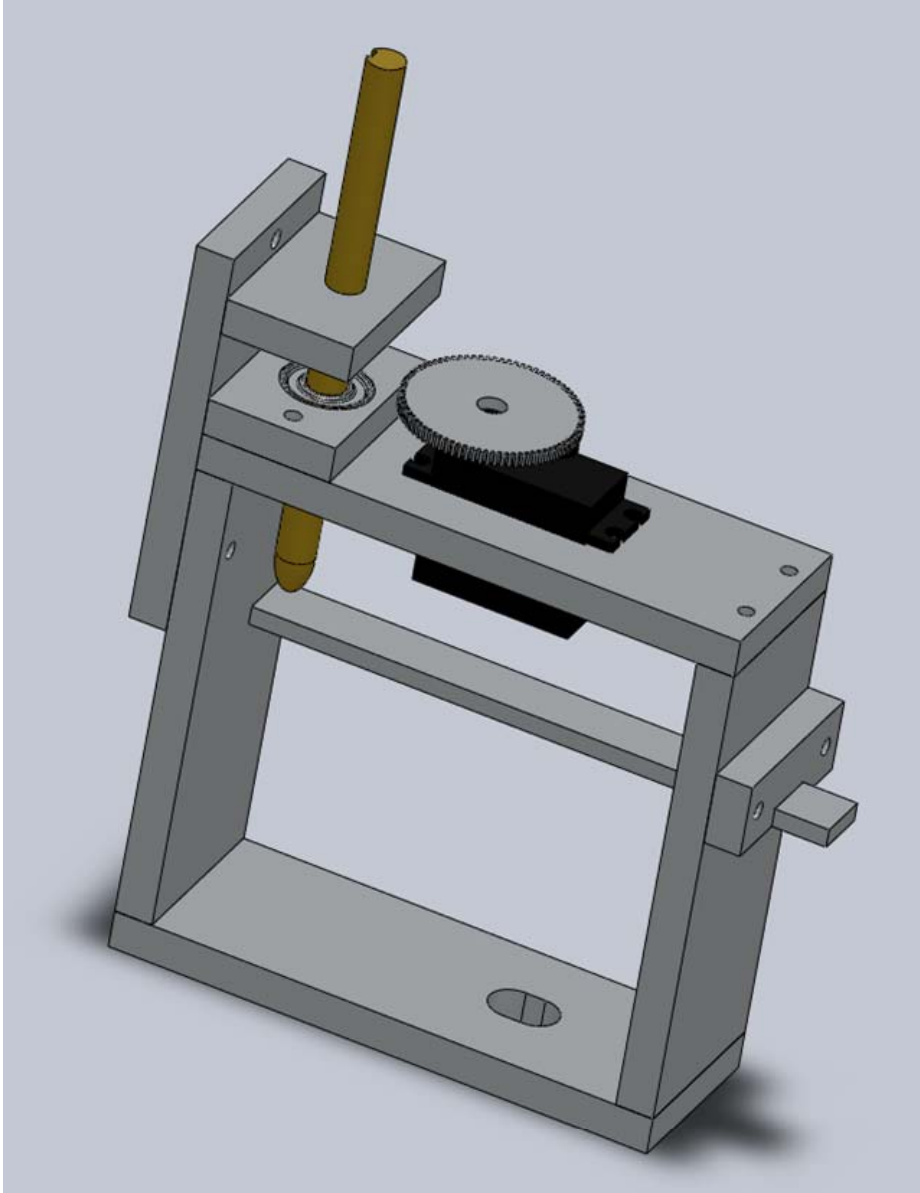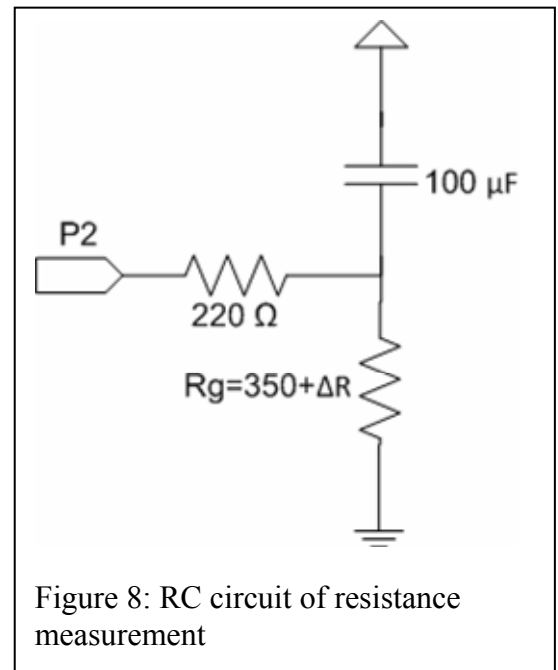
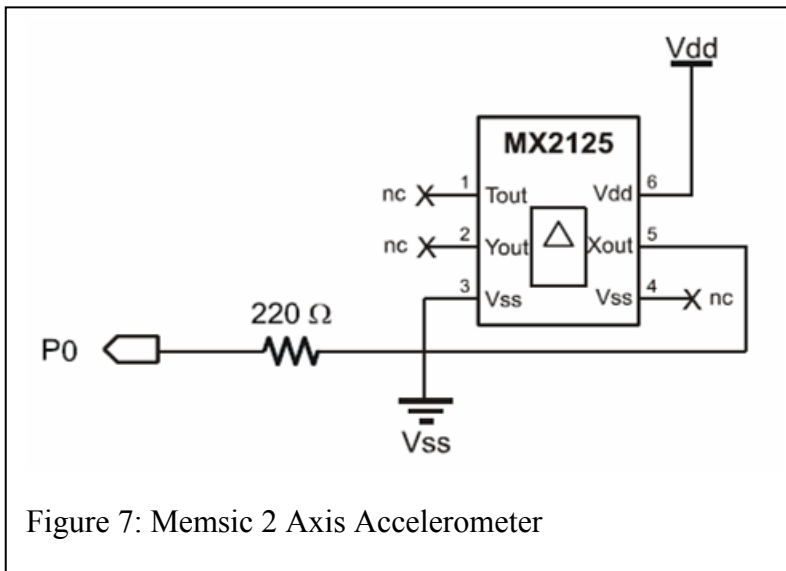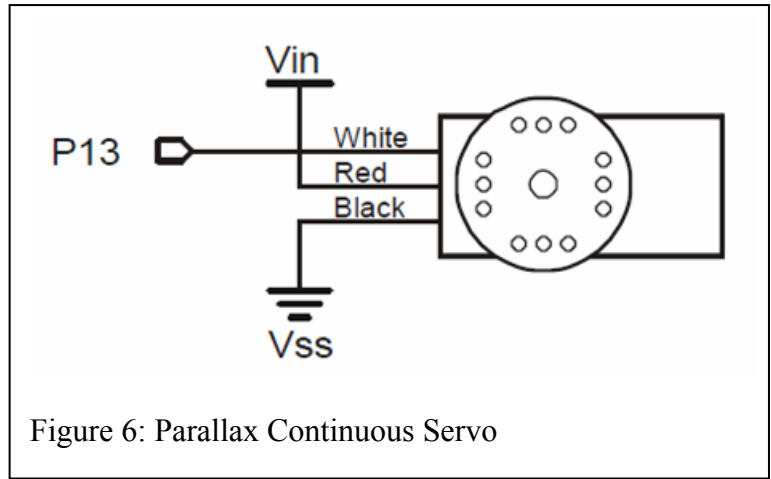Figure: 3: SolidWorks drawing of the design.

Figure: 4: SolidWorks drawing of the design.

Design – Electrical Design

Figure 5: Push Button Circuit

Figure 6: Parallax Continuous Servo

Figure 7: Memsic 2 Axis Accelerometer

Figure 8: RC circuit of resistance measurement
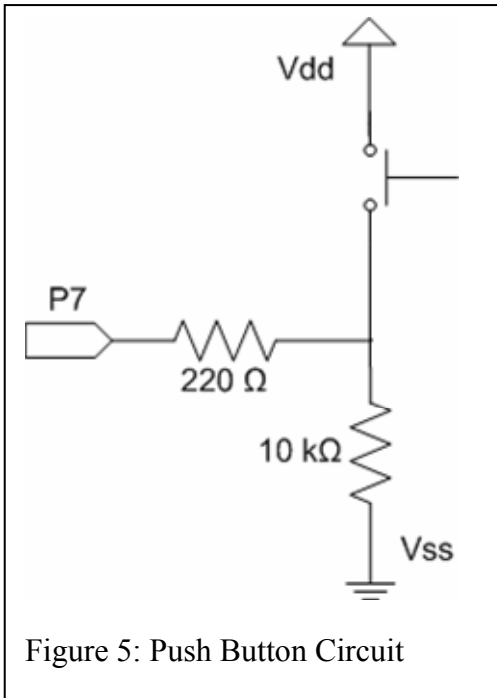
Materials

Aluminum 6063 is used for the support box of the machine the testing element. In order to deflect the testing element, a Parallax Continuous Rotation servo is used. An accelerometer is used to sensor the deflected angle. It measures the tilt angle based on the measurement of the G-force.

|	Part	Quantity
1	Basic Stamp 2 Module	1
2	Aluminum 6063	1
3	LCD	1
4	Pushbutton	1
5	Tilt sensor	1
6	Capacitor	1
7	Resistor	5
8	Parallax Continuous Rotation servomotor	1
9	Jumper Wire	5
10	Strain Gage	1
11	Gear	2
12	Loading Rod	1
13	Extension Wire	3
	Total	24

Table 1: Materials List

Results

The results from the Basic Stamp for three difference angle deflection are noted and are compared to results from the ohm meter. The strain is calculated based on the change in resistance for the ohm meter and Basic Stamp, and also compared to the results from the Basic Stamp.

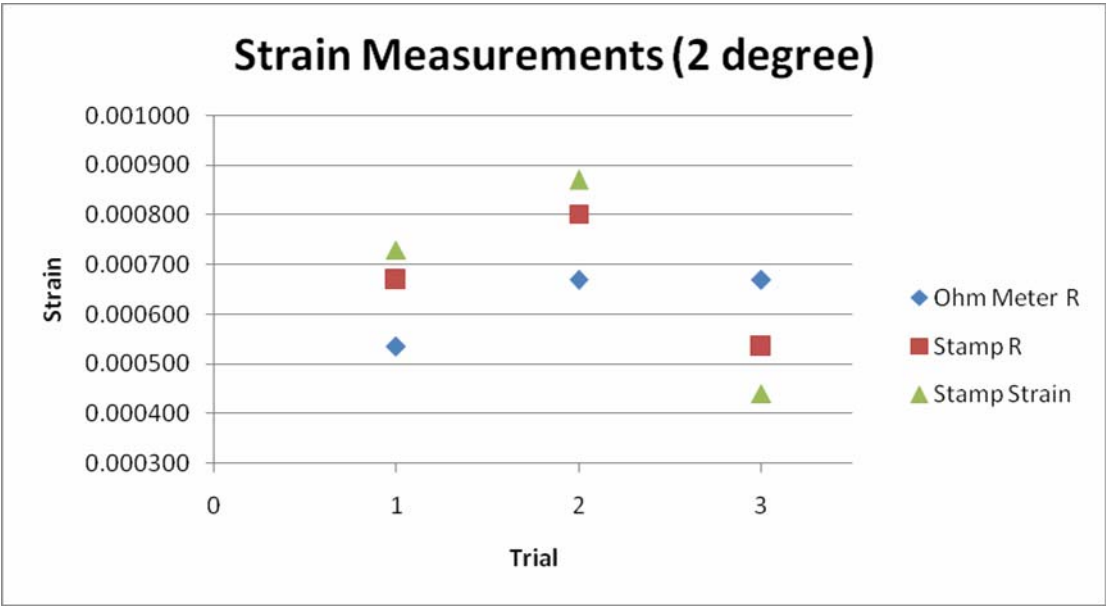| 1 degree	Ohm Meter R			Basic Stamp R			Basic Stamp Strain
	R1	R2	Strain	R1	R2	Strain	
Trial 1	350.3	350.5	0.000267	350.6	350.8	0.000267	0.00016
Trial 2	350.3	350.7	0.000535	349.9	350.4	0.000669	0.00061
Trial 3	350.3	350.7	0.000535	350.3	350.7	0.000535	0.00050
Average			0.000446			0.000490	0.000423

Table 2: Results for an angle deflection of 1 degree.
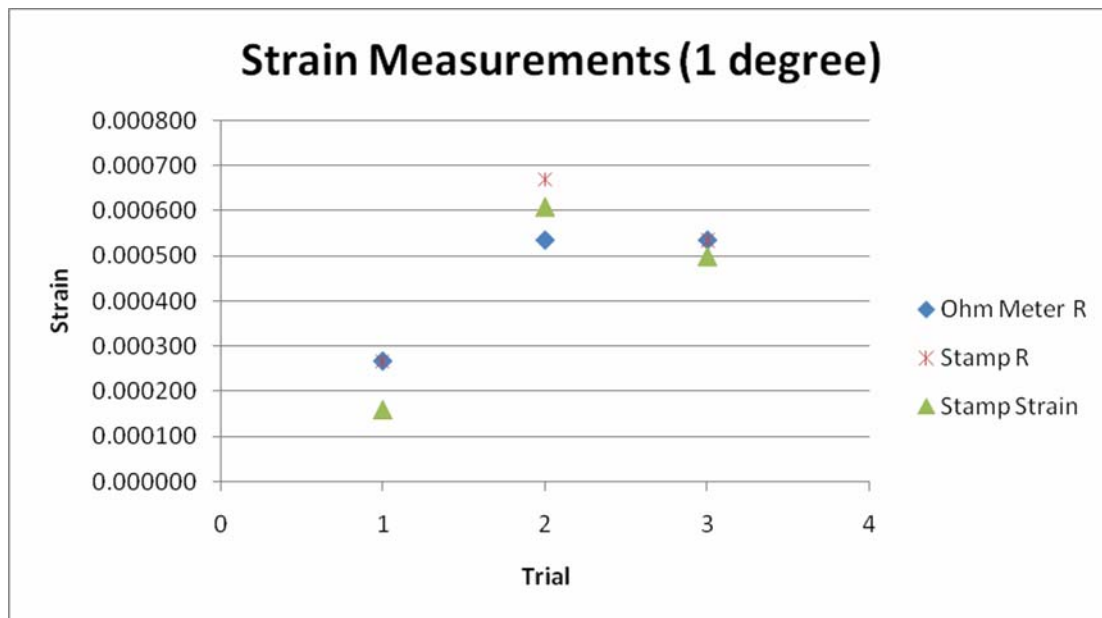
Plot 1: Graph for deflection of 1 degree.

| 2 degree	Ohm Meter R			Basic Stamp R			Basic Stamp Strain
	R1	R2	Strain	R1	R2	Strain	
Trial 1	350.3	350.7	0.000535	350.3	350.8	0.000669	0.00073
Trial 2	350.3	350.8	0.000669	350.2	350.8	0.000802	0.00087
Trial 3	350.3	350.8	0.000669	350.7	351.1	0.000534	0.00044
Average			0.000624			0.000668	0.000680

Table 3: Results for an angle deflection of 2 degree.

Plot 2: Graph for deflection of 2 degree.

3 degree	Ohm Meter R			Basic Stamp R			Basic Stamp Strain
	R1	R2	Strain	R1	R2	Strain	
Trial 1	350.3	351.1	0.001070	350.4	351.6	0.001604	0.00111
Trial 2	350.3	351.0	0.000936	350.3	352.2	0.002540	0.00258
Trial 3	350.3	350.9	0.000802	351	351.6	0.000801	0.00075
Average			0.000936			0.001648	0.001480

Table 4: Results for an angle deflection of 3 degree.
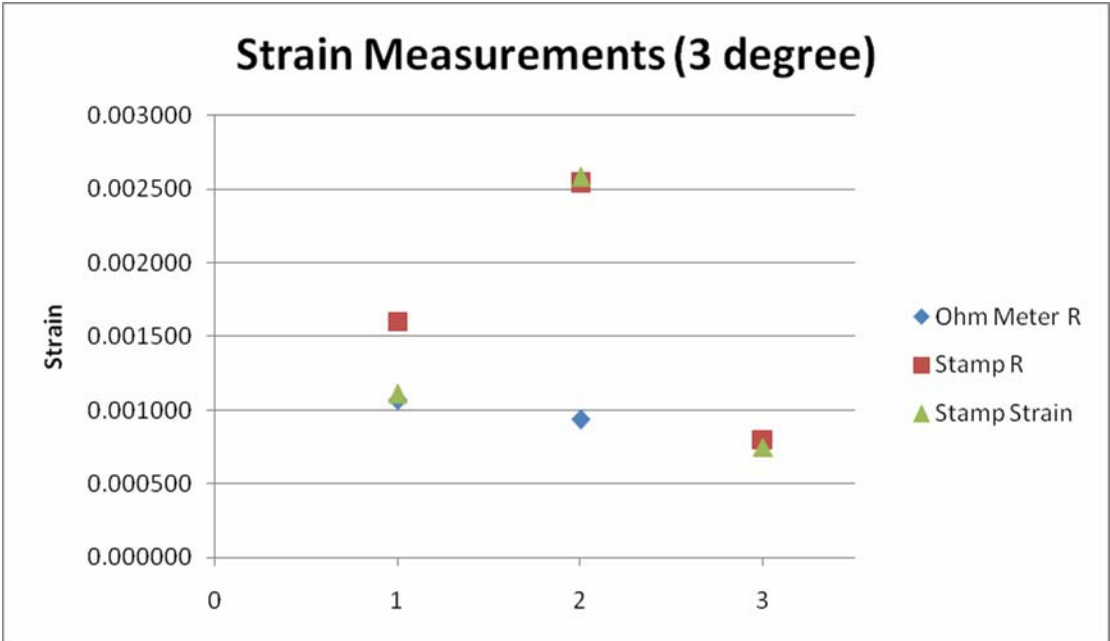
Plot 3: Graph for deflection of 3 degree.

As shown in the graph, the results for the Basic Stamp and the theoretical results were similar. There is a 15% error for 1 degree deflection angle. There is a 1% error for 2 degree deflection angle. In addition, there is a 11% error for 3 degree deflection angle. This error might be due to the fact that the strain gage is temperature dependent. This might caused the change in resistance to be inconsistent. On the other hand, the results for the strain only have a different of 0.000067 for 1 degree deflection, 0.000012 for 2 degree deflection, and 0.000168 for 3 degree deflection. Another reason is because of the scaling factor in the PBasics program. Due to the fact that the Basic Stamp only has 16 bits and that PBasics cannot deal with decimals point, a scaling factor must be used in order to show the experiment.

Final Design

References

http://www.parallax.com/
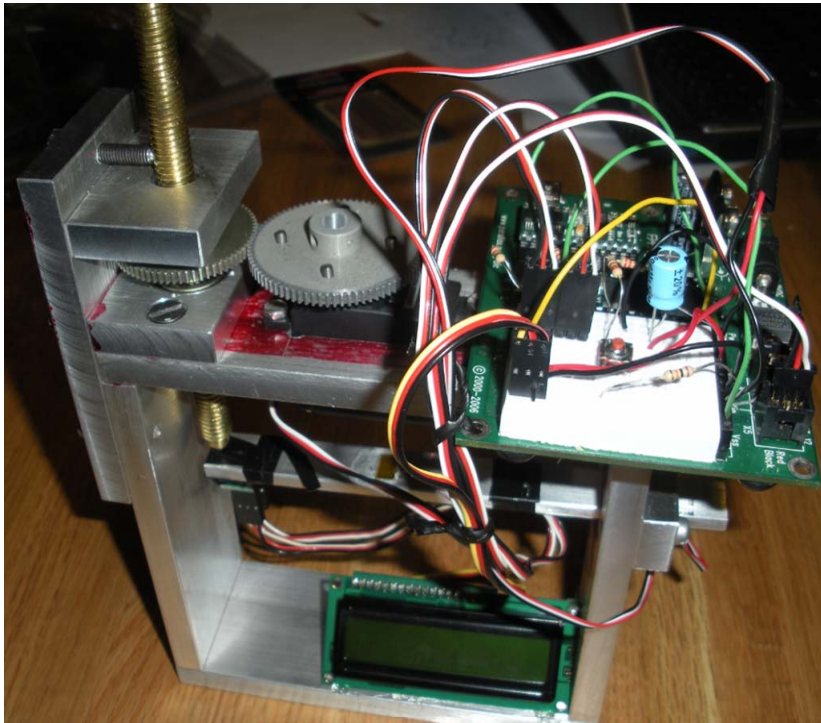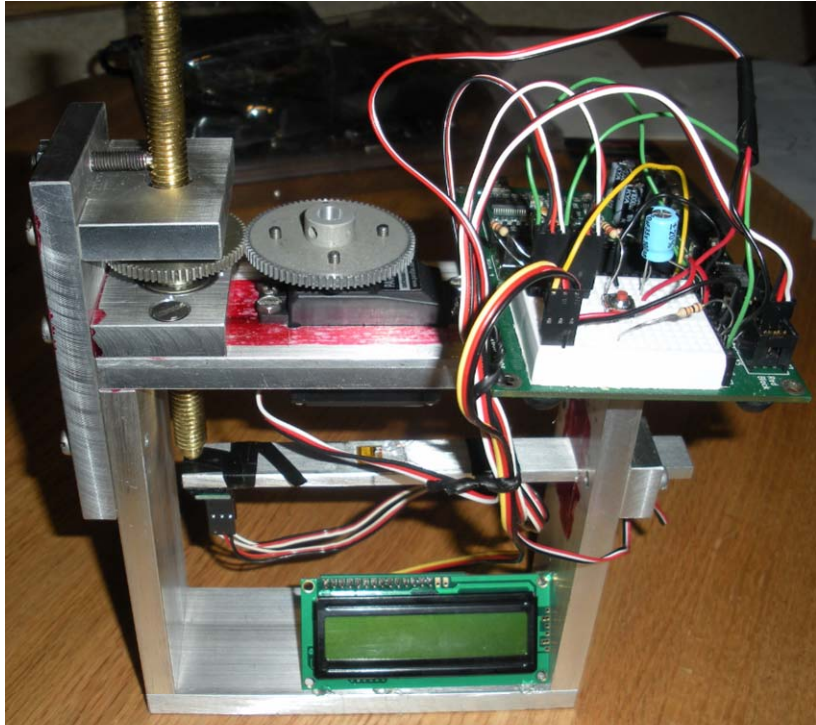
Mechatronics, Lectures 1 – 9; Professor Vikram Kapila

Appendix

```
' {$STAMP BS2}

' {$PBASIC 2.5}

'------[ REQUEIRED USER DATA VARIABLES ]----------------------------------

desired_Angle VAR Nib

DegSym CON 176 ' degrees symbol

Scale CON $200

xRaw VAR Word ' pulse from Memsic 2125

xmG VAR Word ' g force (1000ths)

xTilt VAR Word ' tilt angle

angle VAR Byte ' tilt angle

disp VAR Byte ' displacement (0.0 - 0.99)

counter VAR Byte

t_i VAR Word

t_f VAR Word

mult VAR Word

Resistance VAR Word

time VAR Word

frac VAR Word

answer VAR Word

finish VAR Bit

normTilt VAR Nib

idx VAR Nib

temp VAR Nib

counter=0
```

Main:

```
GOSUB Get_User_Data    'Allow user to enter necesary data

DEBUG CRSRXY, 0,3, "Initial Gage Resistance: "

GOSUB Get_Resistance   'Calculate gage resistance

t_i=time           'Store initial resistance(in basicTime)

DEBUG  CRSRXY, 0,0, "Normalizing tilt..."

PAUSE 3000

normTilt=0

GOSUB Read_X_Tilt

normTilt=xTilt

finish=0

DO

  GOSUB Read_X_Tilt  ' reads G-force and Tilt

GOSUB Angle_Display  ' Display tilt angle

  IF (finish=0) THEN

  GOSUB Servo_Forward_Control  ' Angle controlled actuator

  ENDIF

IF ((ABS xTilt/100)>=desired_Angle AND finish=0) THEN   'Allow angle stabilization before

    counter=counter+1      'taking final resistance

   IF (counter=25) THEN

      DEBUG CRSRXY, 0,5,"Final Gage Resistance: "

      GOSUB Get_Resistance
```

```
        t_f=time

        GOSUB Get_Gage_Strain

        finish=1

      ENDIF

    ELSE

      counter=0

    ENDIF

IF (finish=1 AND IN7=1) THEN

    FOR counter = 1 TO 100

      PULSOUT 13, 800

      PAUSE 100

      NEXT

DEBUG CR,"done"

    GOTO main

    ENDIF

LOOP

Program_End:

DO

IF IN8 = 1  THEN

    FOR counter = 1 TO 200

    PULSOUT 13, 800

     PAUSE 100

     NEXT

     ENDIF

LOOP
```

```
END

' -----[ Subroutines ]-----------------------------------------------

'------[Obtain user data and options]-------------------------------------

Get_User_Data:

  DEBUG CLS,"Enter angle (in degrees) at which to measure the strain: "

  DEBUGIN DEC desired_Angle

    SEROUT 15, 84, [22, 12]

    PAUSE 5

    SEROUT 15, 84, ["Desired Angle:", DEC desired_Angle]

  DEBUG CLS,"Thank you..."

  PAUSE 1000

  DEBUG CLS

RETURN

Get_Resistance:

HIGH 2

  PAUSE 1500

  RCTIME 2,1,time

  Resistance=time**9961+1630

  DEBUG DEC Resistance/10,".",DEC1 Resistance,CR

RETURN

Get_Gage_Strain:

  answer=((46*(t_f-t_i))+((t_f-
t_i)**52429))/(((((t_i/1000)+11)*256)+(((((t_i//10000)/100)*256)/100)+184))/256)
```

```
  IF (answer<100) THEN

    SEROUT 15, 84, [13, " Strain:0.000", DEC answer]

    DEBUG CR,"The experimental strain is: 0.000",DEC answer

  ELSE

    SEROUT 15, 84, [13, " Strain:0.00", DEC answer]

    DEBUG CR,"The experimental strain is: 0.00",DEC answer

  ENDIF

RETURN



Angle_Display:

  Display:

  DEBUG CRSRXY, 0,0, "X Tilt...... "

  DEBUG DEC (ABS xTilt / 100),".", DEC2 (ABS xTilt), DegSym, 11, CLREOL

  PAUSE 20

RETURN

Read_X_Force:

  PULSIN 0, 1, xRaw ' read pulse output

  xRaw = xRaw * 2 ' convert to microseconds

  ' g = ((t1 / 0.01) - 0.5) / 12.5% ' correction from data sheet

  '

  xmG = ((xRaw / 10) - 500) * 8 ' convert to 1/1000 g

RETURN

Read_X_Tilt:

  GOSUB Read_X_Force
```

```
LOOKDOWN ABS xmG, <=[174, 344, 508, 661, 2000], idx

LOOKUP idx, [57, 58, 59, 60, 62], mult

LOOKUP idx, [32768, 10486, 2621, 30802, 22938], frac

xTilt = (mult * (ABS xmG / 10) + (frac ** (ABS xmG / 10)))-normTilt

Check_SignX:

  IF (xmG.BIT15 = 0) THEN XT_Exit ' if positive, skip

  xTilt = -xTilt ' correct for g force sign

  XT_Exit:

RETURN

Servo_Forward_Control:

  IF((ABS xTilt / 100) >= desired_Angle)  THEN

  LOW 15

  ELSE

  PULSOUT 13, 100

  PAUSE 0

  ENDIF

RETURN
```