Automated Cantilever Strain Measurements

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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, 

\[ \sigma = E \varepsilon \]  

where \( \sigma \) is the stress, \( E \) is the modulus of elasticity, and \( \varepsilon \) is the strain. The moment created due to the applied force can be found using 

\[ M(x) = P(L - x) \]  

where \( x \) is distance of the force is applied from the fixed end of the beam. The governing equation for the beam is 

\[ EI \frac{d^2v}{dx^2} = M(x) \]  

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

\[ I = \frac{bh^3}{12} \]  

where the variable is shown on Figure 2.

Figure 2: Cross section of the cartilever beam.

Putting equation (2) into (3) gives,
\[ EI \frac{d^2v}{dx^2} = P(L - x) \quad (5) \]

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

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

\[ EIv = P(\frac{L}{2}x^2 - \frac{1}{6}x^3) + C_1x + C_2 \quad (7) \]

where \( \frac{dv}{dx} \) is the deflected angle \( \theta \). 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

\[ \theta = \frac{dv}{dx} = \frac{P}{EI}(Lx - \frac{1}{2}x^2) \quad (8) \]

\[ v = \frac{P}{EI}(\frac{L}{2}x^2 - \frac{1}{6}x^3) \quad (9) \]

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

\[ \theta \bigg|_{x=L} = \frac{PL^3}{2EI} \quad (10) \]

\[ v \bigg|_{x=L} = \frac{PL^3}{3EI} \quad (11) \]

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

\[ \theta = \frac{3v}{2L} \quad (12) \]

The stress and strain of the beam can be found using

\[ \sigma = \frac{My}{I} = \frac{3PL}{bh^2} \quad (13) \]

\[ \varepsilon = \frac{My}{EI} = \frac{3PL}{Ebh^2} \quad (14) \]
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

$$\varepsilon = \frac{\Delta R}{R F}$$

(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.

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

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.

<table>
<thead>
<tr>
<th>1 degree</th>
<th>Ohm Meter R</th>
<th>Basic Stamp R</th>
<th>Basic Stamp Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R1</td>
<td>R2</td>
<td>Strain</td>
</tr>
<tr>
<td>Trial 1</td>
<td>350.3</td>
<td>350.5</td>
<td>0.000267</td>
</tr>
<tr>
<td>Trial 2</td>
<td>350.3</td>
<td>350.7</td>
<td>0.000535</td>
</tr>
<tr>
<td>Trial 3</td>
<td>350.3</td>
<td>350.7</td>
<td>0.000535</td>
</tr>
<tr>
<td>Average</td>
<td>0.000446</td>
<td></td>
<td>0.000490</td>
</tr>
</tbody>
</table>

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

Plot 1: Graph for deflection of 1 degree.
### Table 3: Results for an angle deflection of 2 degree.

<table>
<thead>
<tr>
<th>2 degree</th>
<th>Ohm Meter R</th>
<th>Basic Stamp R</th>
<th>Basic Stamp Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R1</td>
<td>R2</td>
<td>Strain</td>
</tr>
<tr>
<td>Trial 1</td>
<td>350.3</td>
<td>350.7</td>
<td>0.000535</td>
</tr>
<tr>
<td>Trial 2</td>
<td>350.3</td>
<td>350.8</td>
<td>0.000669</td>
</tr>
<tr>
<td>Trial 3</td>
<td>350.3</td>
<td>350.8</td>
<td>0.000669</td>
</tr>
</tbody>
</table>

Average

| 0.000624 |

| 0.000668 |

| 0.000680 |

Plot 2: Graph for deflection of 2 degree.
<table>
<thead>
<tr>
<th>3 degree</th>
<th>Ohm Meter R</th>
<th>Basic Stamp R</th>
<th>Basic Stamp Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R1</td>
<td>R2</td>
<td>Strain</td>
</tr>
<tr>
<td>Trial 1</td>
<td>350.3</td>
<td>351.1</td>
<td>0.001070</td>
</tr>
<tr>
<td>Trial 2</td>
<td>350.3</td>
<td>351.0</td>
<td>0.000936</td>
</tr>
<tr>
<td>Trial 3</td>
<td>350.3</td>
<td>350.9</td>
<td>0.000802</td>
</tr>
<tr>
<td>Average</td>
<td>0.000936</td>
<td>0.001648</td>
<td>0.001480</td>
</tr>
</tbody>
</table>

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}
' {SPBASIC 2.5}

'------[ REQUIRED 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 necessary data

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

GOSUB Get_Resistance 'Calculate gage resistance

_t =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