Static Equilibrium*

A Mechatronics

Demonstration Project
By

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Abstract

The intent of this project is to provide a visual demonstration of a standard static equilibrium problem that high school physics students are responsible for. The use of servomotors, sensors and basic programming further demonstrates how concepts of physics, mechanical engineering, electrical engineering and computer programming are interrelated and interdependent. This project provides students with a model of a real world problem in which concepts they are learning in school are applied.

Outline

1   Curriculum Correlation – Taken from NY State standards - Physics

STANDARD 1—Analysis, Inquiry, and Design

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.
Key Idea 1:
Abstraction and symbolic representation are used to communicate mathematically. Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints) which is used to develop technological solutions to problems within given constraints. (*Note: The design process could apply to activities from simple investigations to long-term projects.*)

STANDARD 2

Students will access, generate, process, and transfer information, using appropriate technologies.
Key Idea 1:
Information technology is used to retrieve, process, and communicate information as a tool to enhance learning.
Students will access, generate, process, and transfer information, using appropriate technologies.

STANDARD 6—Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology
and apply the themes to these and other areas of learning.
Key Idea 2:
Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design
Key Idea 4:
Equilibrium is a state of stability due either to a lack of change (static equilibrium) or a balance between opposing forces (dynamic equilibrium).

STANDARD 7—Interdisciplinary Problem Solving

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

2. Introduction

      Road side and store signs are at times hung from a horizontal structural member that is attached to a vertical member at one end, a cantilever beam. This beam will undergo bending, tension in along the top surface and compression along the bottom surface. To reduce the size weight and cost of a cantilever beam a cable can be used to support the free end. This project addresses the science, math and engineering associated with this type of structure

      When designing and constructing a building, engineers have to consider many factors. They need to know how a structure will respond to things like earthquakes, wind, explosions and impacts. Two forces that act on these structures are *Compression* and *Tension*. Compression is the force when two things are pushed together and tension
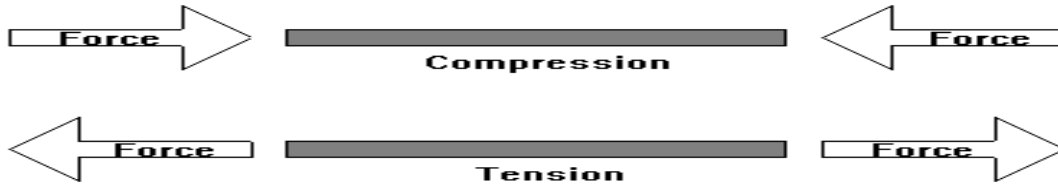

is the force formed when something is pulled apart. A good example of this is a spring. Imagine pushing a spring together. It will try to return to its original state, that's compression. Now imagine pulling that same spring apart. That force is tension.

    Materials can have both tension and compression applied at the same time. When an object is bent, on the inside of the arc the object is being squeezed. This is compression, while on the outside of the arc, the object is being stretched.
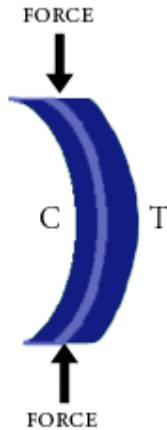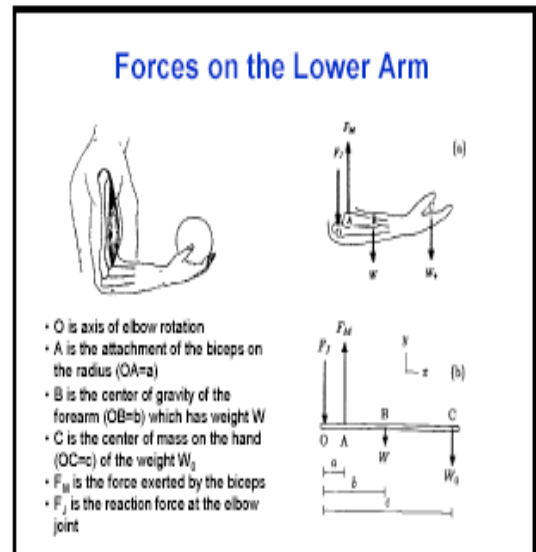

COMPRESSION & TENSION

This is tension. A good analogy for this behavior can be seen with a handful of linguini. [Linguini and concrete are both brittle !]   Grab a handful of linguini with both hands and flex it. At first it will bend slightly but then it starts to break. Where does it break first?
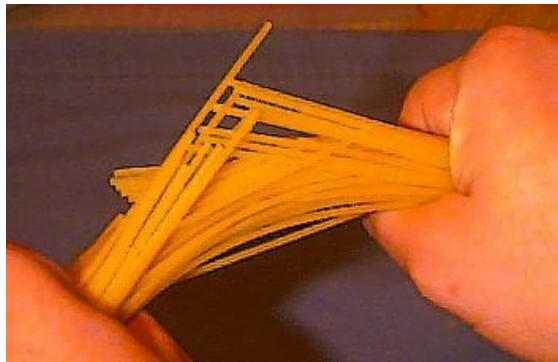
It breaks on the outside first where the fibers are in tension. The brittle materials fail at the point of tension not at the point of compression.

Another good example of these forces is the bones in the human body. The arm bones are subjected to these same tensions and that is one reason why we wrap sprained knees and ankles in a simple elastic bandage. The bandage keeps the bone from bending and helps eliminate tension by keeping the bone in compression.

Forces on the Lower Arm

- O is axis of elbow rotation
- A is the attachment of the biceps on the radius (OA=a)
- B is the center of gravity of the forearm (OB=b) which has weight W
- C is the center of mass on the hand (OC=c) of the weight W_a
- F_M is the force exerted by the biceps
- F_j is the reaction force at the elbow joint

[Notice how similar this diagram is to our experiment]

3. Background

3.1. <u>STATIC EQUILIBIUM THEORY</u>

An object is considered to be in equilibrium when it is either moving at a constant velocity or is at rest. When a system is at rest (not moving) it is considered to be in static equilibrium. In order for a system to be in static equilibrium the summation of forces in each direction must add up to zero as well as the summation of torque must be zero.

$$\Sigma\, F_x = 0 \qquad \Sigma\, F_y = 0 \qquad \Sigma\, F_z = 0 \qquad \Sigma\, \tau = 0$$

F_x is the force in the X direction
F_y is the force in the Y direction
F_z is the force in the Z direction
τ is the torque about a reference point

Force is a push or a pull that is acting on an object having units of newtons (N). Torque can be defined as a force times a distance (r) about a point causing the object to rotate.
The standard equation for torque is
$$\tau = F\, r \sin \theta$$
 F is the force (N)
r is the distance from the reference point about which the force is acting
θ is the angle between the force vector and the distance
An easier way in which torque can be understood is that it is a force acting about a reference point through a moment arm (distance from the reference point) with the moment arm perpendicular to the force. Torque has unit of N-m or N-cm
$$\text{Torque} = (\text{force})(\text{moment arm}) \quad [\, F{\perp}r\,]$$
By convention a torque causing a clockwise rotation is considered negative torque and a torque causing a counterclockwise rotation is considered positive torque.

3.2 CANTILEVER BEAM SUPPORTED BY A CABLE AT THE FREE END

This project demonstrates static equilibrium of a cantilever beam simply supported at the wall by a pin and by a cable at the free end.   The angle of the beam from the horizontal and the position of one of the weight (W2) can be varied thereby producing a range of different problems that can be studied. A diagram of the cantilever beam and a photo of the mechanism are shown below.
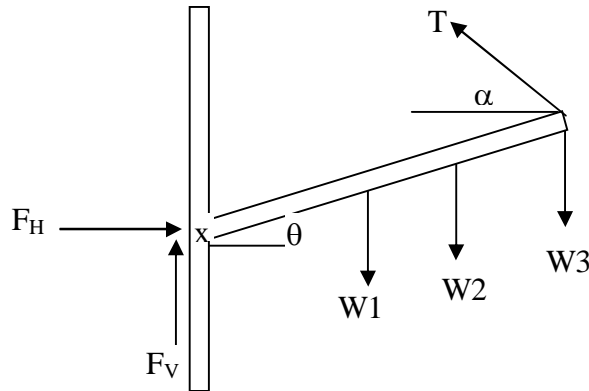
T – is the tension of the cable supporting the free end (newtons) [measured with a load cell]
F_H – is the horizontal reaction force at the wall (newtons)
F_V – is the vertical reaction force at the wall (newtons)
W_1 – is the weight of the beam and all attached hardware located at the center of gravity of the Beam (4 Newton)
W_2 – movable weight (1 newton)
W_3 – fixed weight located at the end of the beam (0.6 Newton)
θ - boom angle measured from the horizontal
α - Cable angle measured from the horizontal

Applying the equation for static equilibrium:

$\Sigma \, \tau = 0$

$\Sigma \, \tau = \ T L_3 \sin(\alpha+\theta)+ - W_1 L_1 \cos \theta - W_2 L_2 \cos\theta - W_3 L_3 \, \cos \theta$
 The torque is calculated about the pivot point of the beam, the reaction forces in the wall
F_H and F_V drop out of the calculation. Their moment arms are zero.

$\Sigma \, F_x = 0$
$\Sigma \, F_x = F_H - T \cos\alpha$
$\Sigma \, F_y = 0$
$\Sigma \, F_y = F_V - W_1 - W_2 - W_2 + T \sin\alpha$

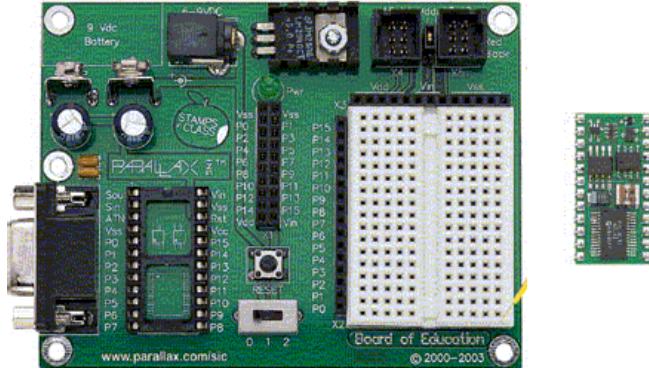L_3 is the moment arm for the cable tension and W_3 and is equal to 29 cm
L_2 is the moment arm for the movable weight W_2 can be varied from 18 to 22 cm
L_1 is the moment arm for the total weight of the beam and is equal to 18 cm

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4.0 Equipment list

*Board of Education (BOE) with Basic Stamp 2 (BS2)*

The Basic Stamp 2 and the Board of Education are the basis for this project. The Basic Stamp 2 is a micro controller with a small amount of memory to store variables and a priority version of BASIC. The Board of Education supplies a regulated +5Volts (Vdd) and ground (Vss) as well as a small breadboard for circuitry and connectors to the 16 pins of the Basic Stamp.
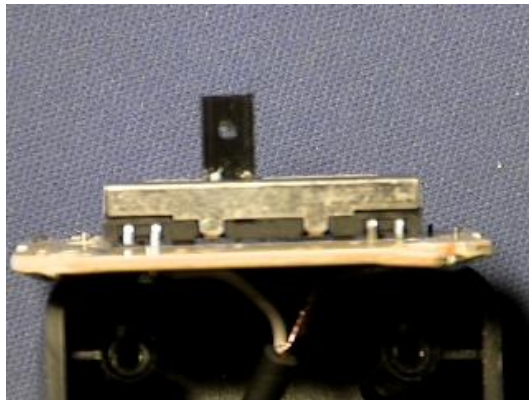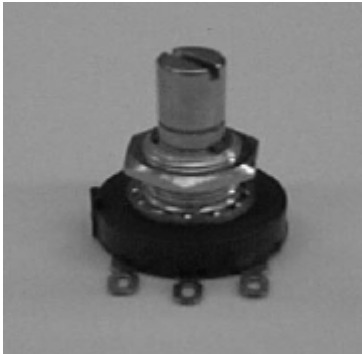

Servo Motors – This is a small DC motor with an attached gearbox and a circuit to allow us to control both duration and speed. We used two of these in our project. One is used to raise and lower the boom. This one is connected to a rotary potentiometer. The other servo is used to move a weight along the boom. This is connected to a slide potentiometer.
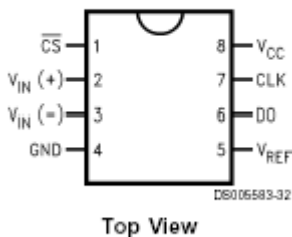

ADC 0831 – 8 bit Analog to Digital Converter
This device samples a voltage and converts it to digital symbol that can be interpreted by the basic stamp

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Potentiometers – This is a variable resistor. We used two different types in our project. A rotary one is used to change the resistance in the line based on the angle of the boom. A Linear or Slide potentiometer is used to move a weight along the boom. Potentiometers have 3 leads. The wiper is used to connect between the resistant material.
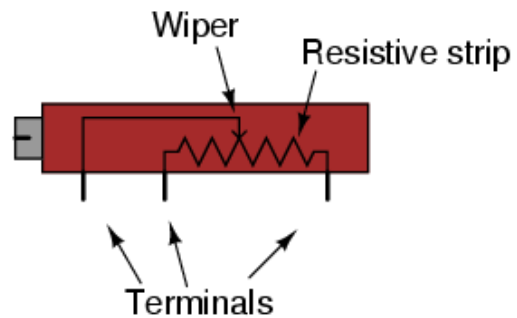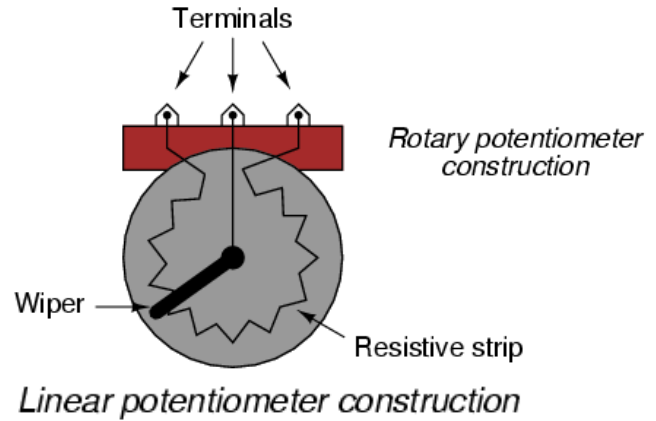
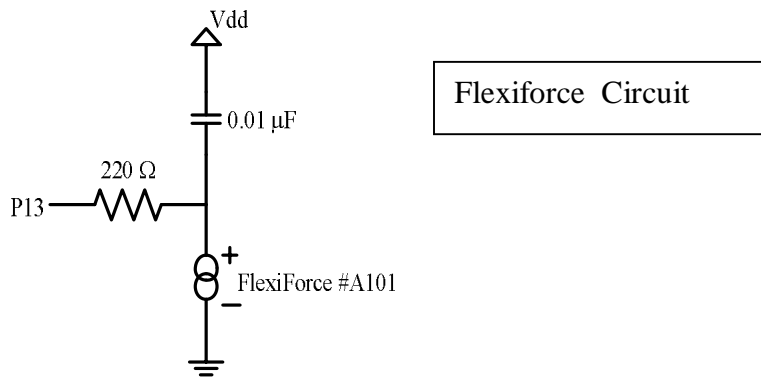

Flexi force – We used this to create a load cell. This measures pressure exerted verses resistance. See the appendix for more information on this.
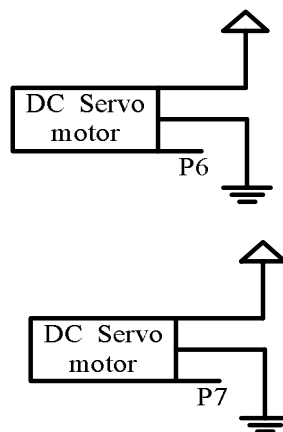
4.1 Electrical Schematics

ADC wiring

Flexiforce Circuit
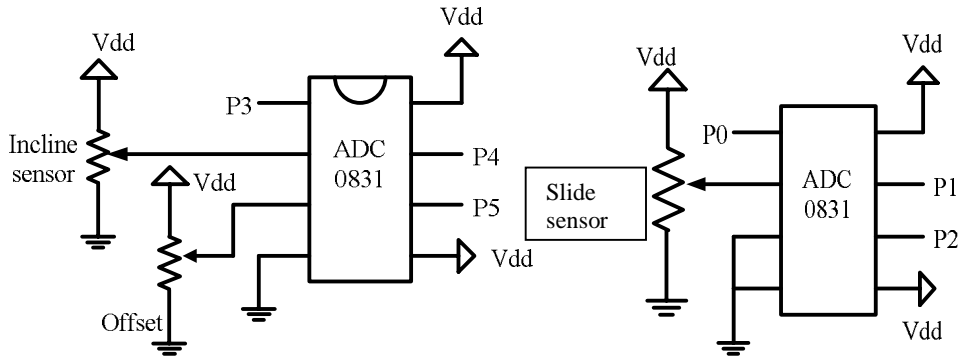
DC Servos-
P6 – Boom
P7 - Slide

5. Experimental procedure

5.1   BOOM ANGLE

The program will first ask for a boom angle, which can be any value from 0 to 60 degrees, to be inputted.   A servomotor will then rotate the boom to the specified angle to within one degree. This level of accuracy is obtained through the use of feedback. A single turn rotary potentiometer senses the boom angle in terms of voltage. An ADC0831 integrated circuit then converts the analog data into digital data that is processed by the BS2 microchip displaying the data on the computer screen.

5.2   SLIDE WEIGHT

There are three weights that must be taken into account. Two of these have fixed locations, the weight of the boom and a weight placed at the end of the boom. A third weight has been designed to have variable location, 17 to 22 cm from the pivot point of the boom.

Once the boom has been moved to the desired location the program will ask for slide weight position to be selected. A servomotor driving a lead screw (threaded rod) will move the weight to the specified location. Feedback data is obtained through the use of a slide potentiometer. A second ADC0831 integrated circuit then converts the analog data into digital data that is processed by the BS2 microchip displaying the data on the computer screen.

5.3   TENSION

The tension in the cable supporting the free end of the boom is sensed by a load cell (Parallax Flexiforce compression load cell). A load cell is basically a wheatstone bridge in which the resistance varies as the load changes.   A Pbasic routine called RCTime was used to sense the change of resistance and convert it to digital data. This digital data was then converted to newtons through the use of a calibration curve.

5.4   FINAL CALCULATIONS

Once the boom and the slide weight have been move to the desired locations the program will then perform a series of calculation as outlined in section 2. The following data will then be displayed on the computer screen

Tension (ounces) =   " measured by the load cell"
Tension (Newton) = "converted from ounces"
Specified slide weight position = " 17 – 22 cm"
Actual slide weight position =   "as measured by the slide potentiometer "
Specified boom angle =   " inputted by user 0 - 55 degrees"
Actual boom angle   =   " as measured by the rotary potentiometer"
Cable angle (α) = " calculated by BS2"
Vertical reaction force at pivot = " calculated by BS2"
Horizontal reaction force at pivot = " calculated by BS2"

6.0 Results

6.1 Experimental Results

Hand Calculations	BS2 results
Boom angle = 29 degrees	Boom angle = 29 degrees
Slide position = 18 cm	Slide position = 18 cm
W 1 = 14 OUNCES	W 1 = 14 OUNCES
W 2 = 4 OUNCES	W 2 = 4 OUNCES
W 3 = 2 OUNCES	W 3 = 2 OUNCES
L 1 = 18 CM	L 1 = 18 CM
L 2 = 18 CM	L 2 = 18 CM
L 3 = 29 CM	L 3 = 29CM
CABLE TENSION = 13 OUNCE (3.6 N)	CABLE TENSION = 13 OUNCE (3.6 N)
CABLE ANGLE (α) = 12.8	CABLE ANGLE (α) = 13
HORIZONTAL FORCE = 3.5N	HORIZONTAL FORCE = 3.37N
VERTICAL FORCE = 4.8 N	VERTICAL FORCE = -5.6 N

* precision of the calculated results depends on the calibration of the instruments

6.2 ERROR ANALYSIS

ROTARY POTENTIOMETER

 This potentiometer is used to measure the angle of the boom. The calibration of the potentiometer is very sensitive and reliable only in the upward movement of the boom. This is why the boom always moves to an angular position below horizontal at the end of each problem. It was also found that this pot had a large dead near the extreme positions of travel.

SLIDE POTENTIOMETER

 This potentiometer was found to be very linear and trouble free, always giving accurate and repeatable measurements. The limitation being that it had only six cm of travel.

PARALLAX SERVO MOTORS

 Two of these motors were used and both performed consistently well.

PARALLAX FLEXFORCE (LOAD CELL)
The data from this sensor was a key input to the calculated cable angle and reaction forces at the pivot point. It was found that the calibration data was not always repeatable and the measured data was dependent on the orientation of the cell. If the cell that was in line with the cable became tilted the measured data was altered. To correct for this, two guide wires were attached to the cell yielding an improvement in the repeatability of the data. The RCTime Pbasic function as recommended by Parallax was used to convert the change in resistance in the cell to digital data. In retrospect better result may have been obtained by sensing a change in voltage and using an ADC0831 integrated chip to convert the analog data to digital.

7   Conclusions

The original intent of the project was to provide a visual demonstration of a standard static equilibrium problem that high school physics students are responsible for.   The use of servomotors, sensors and basic programming further demonstrates how concepts of physics, mechanical engineering, electrical engineering and computer programming are interrelated. Although there may be some sources error and accuracy in the overall design the project does meet the primary goal of the project.

8   Project Cost Analysis

ELECTRICAL		HARDWARE	
Servo motors (2)	$24.00	¾ inch square aluminum tube	$10.00
ADC 0831 (2)	$5.00	¾ inch aluminum L channel	$5.00
100K Rotary Pot	$3.00	Lead screw	$3.00
10K Slide Pot	$7.00	Plexiglas	$5.00
Flexiforce load cell	$13.00	Weights	$3.00
220 ohm resistor	$0.25	Wood base	$4.00
.1 microfarad capacitor	$0.25	Assorted fasteners	$5.00
Parallax Board of Ed	$65.00		
BS2 chip	$49.00		
Breadboard	$4.00		
15 Pin D-connector	$4.00		
Assorted wire	$5.00		

Total Cost $214.50

9 Suggested Projects

 This basic project could be expanded to simulate
- the motion of an elbow
- the motion of a knee
- the motion of certain types bridges (Draw Bridge)

10 Acknowledgements
We wish to thank the following people without whom this project would not be possible.
Sang Hoon Lee for his guiding lectures and parts procurement.
Saul Harari for his help with the circuit diagrams and his computer expertise
Hong Wong for his explanations of DC motors
Yvonne Li for her patience and help with Pbasic and
Professor Vikram Kapila for his overall assistance, the use of his lab and selecting us for this program.

11. References

Static Equilibrium. We have ... over half! To summarize the analysis of the conditions for static equilibrium: Identify the force vectors;. ...
www.rwc.uc.edu/koehler/biophys/2h.html cached | more results from this site

Physics 18a Fall 2002 Introductory Laboratory - Physics 18a Mr. Bensinger, Fall 2002 STATIC EQUILIBRIUM : Static Equilibrium , Torque , and Young ' s Modulus . ...
www.physics.brandeis.edu/phys18a_2002/Lab_4/4-Static%20Equilibrium.pdf view as html

next up previous contents index Next: Moment of inertia Up: Torque Previous: Torque. Static Equilibrium. ... Figure 5.4: Static equilibrium for a teeter-totter. ...
theory.uwinnipeg.ca/mod_tech/node48.html cached | more results from this site

Static Equilibrium. We have seen that objects do not move when the sum of the forces acting on them is zero. We can use this fact ...
www.physics.uq.edu.au:8001/ph128/2h.html cached

Static Equilibrium -- from Eric Weisstein's World of Physics
... Static Equilibrium, A system is in static equilibrium when the sum of external torques is zero and the sum of external forces is zero. Equilibrium, Statics. ...
scienceworld.wolfram.com/physics/StaticEquilibrium.html cached | more results from this site

Parallax
Primary source of components and BS2
www.parallax.com

Rotational Equilibrium
... This often simplifies things. Linear Static Equilibrium of the Center of Mass: * The vector sum of all the forces acting on the object must be equal to zero. ...
www.ac.wwu.edu/~vawter/PhysicsNet/Topics/RotationalDynamics/RotEquilibrium.html cached

Static Equilibrium.
 A body of mass M immersed in a fluid will not move if the forces (and their moments) acting on the body add to zero. ...
www.mas.ncl.ac.uk/~sbrooks/book/nish.mit.edu/2006/Textbook/Nodes/chap02/node19.html cached | more results from this site

STATIC EQUILIBRIUM τ (PDF)
ftm; revised fwk 11-8-2000 printed 11/02/01 PHYS 152 Lab STATIC EQUILIBRIUM The purpose of this experiment is to study the conditions for a two-dimensional ...
webphysics.iupui.edu/152/152f02/Labs/Statics_Lab.pdf view as html

Appendix A   DOCUMENTED CODE

```
'{$STAMP BS2}
'{$PBASIC 2.5}
adcbits VAR Byte     'SIGNAL FROM ADC 0831 CHIP
v       VAR Byte     ' VOLTAGE FRON POT
v1      VAR Word
r       VAR Byte     ' REMAINDER
v2      VAR Byte     ' USED TO CAL VOLTAGE AS A DECIMAL
v3      VAR Byte     ' USED TO CAL VOLTAGE AS A DECIMAL
angle   VAR Word     ' CALCULATED ANGLE OF BOOM WITH RESPECT TO HORIZONTAL
fixangle VAR Word    ' INPUT BOOM HORIZONTAL ANGLE
'x       VAR Byte     ' COUNTER FOR MULTIPLE PROBLEM ITERATIONS


FORCEH   VAR Byte   '  HORIZONTAL REACTION FORCE AT WALL
FORCEV   VAR  Byte  'VERTICAL REACTION FORCE AT WALL
TENSION  VAR  Byte   ' TENSION IN CABLE
ALPHA    VAR  Byte   ' CABLE ANGLE  TOTAL = APLHA+ THETA
WEIGHT1  CON  14     ' BOOM WEIGHT (ounces)   must smaller than 15
WEIGHT2  CON  4    ' MOVABLE WEIGHT (ounces)  must be smaller than 15
weight3  CON  2    ' weight at end of boom (ounces)
'THETA     VAR  Byte   ' BOOM ANGLE
REPLACED WITH ANGLE
L1       CON  18 ' CENTER OF GRAVITY OF BOOM
L2       VAR  Word   ' POSITION OF MOVABLE WEIGHT
L3       CON  29   ' POSITION OF CABLE

SINTOTAL   VAR  Word
SINALPHA   VAR  Word
SINE       VAR  Word
COSINE     VAR Word


'fixSLIDE VAR Word    ' WAS A WORD
x        VAR Byte
'  RAWFORCE VAR  Word    REPLACED WITH V1
'  TENSION  VAR Word      REPLACED WITH FIXANGLE
SENSORPIN   CON 11
'T1 VAR Word              REPLACED WITH SINE
'T2 VAR Word              REPLACED WITH COSINE


OUTPUT 6
OUTPUT 7
cs      PIN  0
clk     PIN  1
dataoutput  PIN 2
```

Appendix A

```
INITALIZE:

    angle = 0

'cs1      PIN  3
'clk1     PIN  4
'dataoutput1  PIN 5

DEBUG  HOME
'      x=0
'-------------- MAIN ROUTINE ----------------------
main:
  DEBUG " ENTER BOOM ANGLE    5 - 55    = " ,CR
  DEBUGIN DEC FIXANGLE

  DO
  GOSUB adc_data
  GOSUB calc_volts
  '----------------------
  GOSUB motor_control

   '------------------

  GOSUB display
   LOOP



 MAINS:
  GOSUB MEASURE
  GOSUB Calculation_routine
  fixangle = 8
  DO
  GOSUB adc_data
  GOSUB calc_volts
  GOSUB motor_control
  LOOP
  END

adc_data:
  HIGH cs
  LOW  cs
  LOW  clk
  PULSOUT clk,210
  SHIFTIN dataoutput,clk,MSBPOST,[adcbits\8]
  RETURN

  calc_volts:

  v = 5*adcbits/255
  r = 5*adcbits//255
  v2 = 100*r/255
  v3 = 100*r//255
  v3 = 10*v3/255
```

Appendix A

```
'-------------------------------------------
'
v1 = v*100+v2                ' MEASURED VOLTAGE OF POT
 angle = ((36*v1-2479)/100)   ' CALIBRATED ANGLE
'--------------------        ----------------------

  IF (v3>=5) THEN v2 =v2+1
  IF  (v2>=100) THEN
     v=v+1
     v2=0
    ENDIF

  RETURN

  '---------------------------
    motor_control:
    IF ANGLE = fixangle  THEN nextstep
    IF ANGLE < fixangle  THEN forward_pulse
    GOTO back_pulse

    forward_pulse:
    PULSOUT 6, 500
    PAUSE 10
    RETURN

    back_pulse:
    PULSOUT 6, 1000
    PAUSE 10
    RETURN

   stop_motor:
  PULSOUT 6, 755
  RETURN

   nextstep:
   PAUSE 2000
  GOTO SLIDEMAIN
 '----------------------

  display:
  DEBUG HOME
'
  DEBUG CR,CR, "MEASURED  AT BOOM POTENTIOMETER   ", DEC3 v, "." , DEC2 v2
,"Volts"

  DEBUG CR,CR, " INPUT BOOM ANGLE + ", DEC FIXANGLE,"  MEASURED BOOM ANGLE
=", SDEC ANGLE,".",CR
  RETURN
```

Appendix A

```
'----------------------------------------------------------------
' SLIDE WEIGHT POSITION ROUTINE
'--------------- MAIN ROUTINE ----------------------
SLIDEMAIN:

cs1      PIN  3
clk1     PIN  4
dataoutput1  PIN 5
  DEBUG " SLIDE POSITION  17 TO 22 CM", CR
  DEBUGIN DEC FIXANGLE
  fixangle = fixangle - 17
  FIXANGLE=FIXANGLE*100
  DO
  GOSUB adc_dataS
  GOSUB calc_voltsS

  '----------------------
  GOSUB motor_controlS

  '-------------------
  GOSUB display1
  LOOP


adc_dataS:
  HIGH cs1
  LOW  cs1
  LOW  clk1
  PULSOUT clk1,210
  SHIFTIN dataoutput1,clk1,MSBPOST,[adcbits\8]
  RETURN

  calc_voltsS:

  v = 5*adcbits/255
  r = 5*adcbits//255
  v2 = 100*r/255
  v3 = 100*r//255
  v3 = 10*v3/255

'-------------------------------------------
 v1 = v*100+v2   ' SLIDE POTENIOMETER VOLTAGE
 L2 = v1         ' SLIDE POSITION
'---------------------     ----------------------

  IF (v3>=5) THEN v2 =v2+1
  IF  (v2>=100) THEN
     v=v+1
     v2=0
     ENDIF

  RETURN
```

Appendix A

```
'----------------------------
 motor_controlS:
 IF L2 >= FIXANGLE -1 AND L2 <= FIXANGLE +1 THEN nextstepS
 IF L2 < FIXANGLE  THEN forward_pulseS
 GOTO back_pulseS

 forward_pulseS:
 FOR X =1 TO 60
PULSOUT 7, 500
 NEXT
 RETURN

 back_pulseS:
 FOR X =1 TO 60
 PULSOUT 7, 1000
 NEXT
 RETURN

 nextstepS:
 PAUSE 1000
 DEBUG  " L2  = ", DEC L2

 GOTO MAINS

  END
'--------------------
 displayl:
 DEBUG HOME ,CR,CR,CR,CR,CR,CR

 DEBUG CR,CR, "SLIDE POTENTIOMETER    ", DEC3 v, "." , DEC2 v2 ,"volts"

 DEBUG CR,CR, " SLIDE POSITION = ", DEC3 L2,"." ,CR
 RETURN


'----------------------------------load CELL MEASUREMENT OF TENSION

MEASURE:
V1 = 0
FIXANGLE = 0         ' FIXANGLE REPLACED  TENSON

FOR x =1 TO 10
HIGH SENSORPIN
PAUSE 20
RCTIME SENSORPIN,1,V1     ' WAS RAWFORCE
FIXANGLE  =(17365 – (9*V1))/1000
NEXT
DEBUG " TENSION OF CABLE (OUNCES) =  ", SDEC FIXANGLE ,CR,CR

v1 = fixangle      ' save the force in ounces
```

Appendix A

```
FIXANGLE =((FIXANGLE *4) + (FIXANGLE*5))/2
    SINE = FIXANGLE/16
  COSINE = FIXANGLE//16
  COSINE = COSINE*100/ 16

DEBUG " TENSION OF CABLE (NEWTONS) = ", DEC SINE , ".", DEC COSINE, CR ,CR

RETURN

'------------------------- CALCULATE ALL FINAL VALUES

Calculation_routine:


L2 = 17 + (L2/100)
SINE = 0
COSINE = 0

' CALCLATE THE ANGLE OF THE CABLE FROM THE BOOM  ALPHA
SINE =   SIN(ANGLE * 128 / 180)*100/127              ' Convert to brads, do SIN
COSINE = COS (ANGLE * 128 / 180)*100/127             ' Convert to brads, do
COS

SINALPHA =((WEIGHT1*L1*COSINE) + (WEIGHT2*L2*COSINE) +(weight3*L3*cosine))/
(v1*L3*4)

' DETERMINE THE ARCSIN OF THE CABLE ANGLE ALPHA
FOR X = 1 TO 90

IF SIN((X* 128 / 180)*100/127) >= SINALPHA THEN CACULATE_FORCE

NEXT

 CACULATE_FORCE :
'  CALCLATE THE HORIZONTAL AND VERTICAL REACTION F0RCES
 GOSUB DISPLAY_DATA
RETURN
'------------------------------------------------------------------------------
------------------
DISPLAY_DATA:

DEBUG "                         INITIAL CONDITIONS",CR
DEBUG " POSITION OF MOVABLE WEIGHT FROM PIVOT IS ",DEC L2, " CM",CR
DEBUG " WEIGHT OF MOVABLE WEIGHT IS (OUNCES)",DEC WEIGHT2,CR,CR
DEBUG "_____FINAL
_RESULTS_____",CR
```
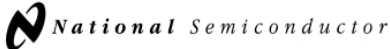
Appendix A

```
   SINE = FIXANGLE/16
 COSINE = FIXANGLE//16
 COSINE = COSINE*100/ 16
DEBUG " TENSION  (newtons) =  ",DEC sine, ".", DEC cosine, CR,CR
 FORCEH = (v1*(COS (X * 128 / 180)*100/127))/100

   forceh =((forceh *4) + (forceh*5))/2
   SINE = Forceh/16
 COSINE = forceh//16
 COSINE = COSINE*100/ 16
 DEBUG "   FORCEH = ",DEC sine, ".", DEC cosine, CR
 FORCEV = WEIGHT1+WEIGHT2+weight3 -(((v1*SINALPHA))/100)
  forcev =((forcev *4) + (forcev*5))/2
   SINE = Forcev/16
 COSINE = forcev//16
 COSINE = COSINE*100/ 16
 DEBUG   " FORCEV =-",SDEC sine,".", DEC cosine, CR,CR
DEBUG  " ANGLE THETA (BOOM ANGLE)  FROM HORIZONTAL = ", DEC ANGLE,CR,CR

DEBUG  " ANGLE ALPHA (CABLE ANGLE) FROM HORIZONTAL =  ", DEC X,CR
DEBUG CR
RETURN
RETURN
```

APPENDIX B

Appendix C

PARALLAX

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Flexiforce Demo Kit (#28017)
Single Element Pressure Sensor

Tekscan's FlexiForce® sensor measures force between two surfaces. The sensor output exhibits a high degree of linearity, low hysteresis and minimal drift compared to other thin-film force sensors. The Flexiforce single element sensor acts as a resistor in an electrical circuit. When the sensor is unloaded, its resistance is very high. Resistance decreases when force is applied to the sensor. The resistance can be read by connecting an ohmmeter to the outer two pins of the sensor and applying a force to the round tab sensing area at the end of the film.

The resistance of the Flexiforce sensor is proportional to weight. The sensor included in your kit is rated at 1.6 lbs.[1] The purpose of the Parallax example circuit is only to demonstrate the resistive nature of the sensor with a resistor/capacitor discharge time measurement circuit; no correlations to weight are made in these examples.

Packing List

Verify that your Flexiforce Demo Kit has the following components:

* (1) Flexiforce thin-film sensor
* (1) 220 ohm resistor
* (1) 0.1 uF capacitor
* (1) 0.01 uF capacitor

The sample code and circuit uses the Parallax BASIC Stamp 2 module. With a change of directive at the top of each PBASIC program the code may also be used in BASIC Stamp 2SX, 2e, 2p, and 2pe modules. The second sample program uses StampDAQ, an Excel add-on which receives real-time data into an Excel spreadsheet. StampDAQ works with Excel 2000 or higher and can be downloaded for free from www.parallax.com.

---

[1] Based on resistor values in the Tekscan "Flexiforce Sample Drive Circuit" drawing on the manufacturer's web site http://www.tekscan.com. Standard force range of this sensor can be changed to have a full-scale 1 lb – 1,000 lb response by changing driving voltage and feedback resistors and driving voltage in their sample circuit.

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Appendix C

Flexiforce Specifications

Physical Properties	
Thickness	0.005" (0.127 mm)
Length	8.000" (203 mm)
Width	0.55" (14 mm)
Active Sensing Area	0.375" (9.53 mm) diameter
Connector	3 pin post connector

Typical Performance	
Linearity (error)	< ±5% (Line drawn from 0 to 50% load)
Repeatability	< ±2.5% of Full Scale (Conditioned Sensor, 80% of Full Force Applied)
Hysteresis	< 4.5 % of Full Scale (Conditioned Sensor, 80% of Full Force Applied)
Drift	< 3% / logarithmic time (Constant Load - 25 lb.)
Rise Time	< 20 μsec (Impact load - recorded on Oscilloscope)
Operating Temperature	15°F - 140°F (-9°C - 60°C)*

Figure 1: Flexiforce Specifications

The force response of this sensor is approximately 1.6 lbs. using the Flexiforce Sample Drive Circuit on www.tekscan.com. However, the best way to determine the correlation is by placing known weights on the end of the sensor and recording your RCTime values from the sample BASIC Stamp programs.
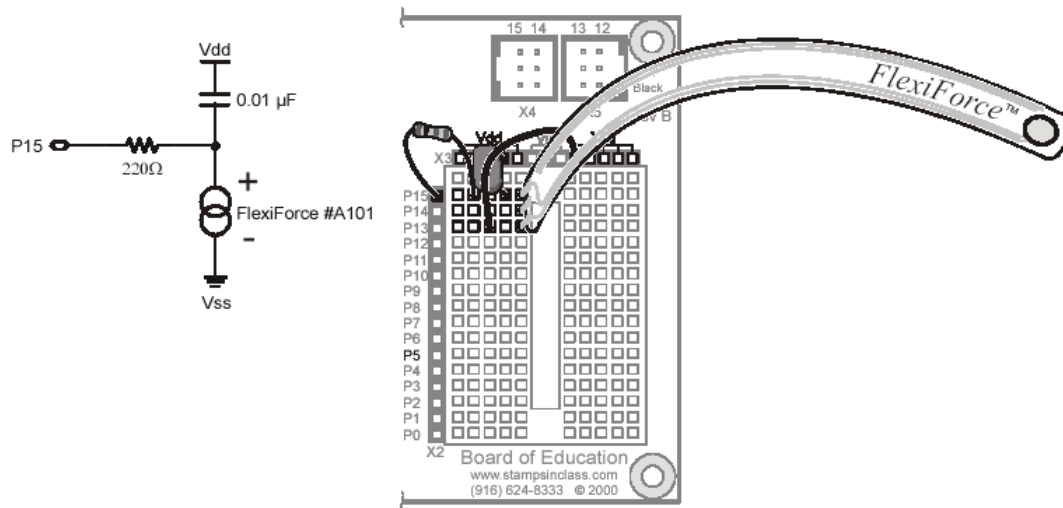
Example Circuit

Figure 2: Example Schematic and Pictorial

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