Laboratory 2: 2D Strain Measurement – Instructions for Report
October 22/23 2008 Due: Thursday 6th November 2007
BIOEN 5201 – Introduction to Biomechanics
Instructor: Jeff Weiss
TA: Scott Sibole

Each student must turn in a separate laboratory report representing his or her own work. The report should be prepared using MSWord or an equivalent word processor. The department has asked me to include grading of the grammar and style of your written report as part of the means of evaluation, so please proof your report, rewrite the initial draft as necessary and check for spelling and other grammatical errors before submission. The report should contain the following sections:

Title/Name:
Your report must include the following information in the upper-left corner of the first page:

BIOEN 5201 - Laboratory 2, Fall 2006: 2D Strain Measurement
<YOUR NAME HERE>
<DATE HERE>

Objective: (1 paragraph)
State the purpose of the lab measurements and analysis. Motivate the need for the measurements. State your perception of the intended educational goals of the laboratory in terms of learning new measurement and analysis techniques. This section should be one paragraph.

Methods: (No longer than 2 pages)

a) Describe the methods and step-by step procedure to perform the measurements, i.e.
   • Pre-test Measurements
   • DMAS Calibration, importance of 2D calibration
   • Material Test Procedure (how you loaded/strained the sample)
   • Use of DMAS system to track marker coordinates

b) Provide a high-level overview of the program that you write (MATLAB suggested) to analyze the data. Please do your own work.
   • Describe any subroutines and reference them by name
   • Explicitly write (in direct notation) the equations that are used in your MATLAB program to obtain the strains and other results.
   • Make this section concise (i.e. don’t just re-hash your code).

Sections a) and b) should be no longer than two pages, combined.

Note – Your code should be well commented! Please limit your comments to the first 72 columns so they don’t run off the edge of the page.
Results/Discussion (3 pages including 2 pages for plots):

Plot 1: Green-Lagrange Strains as function of time: Assuming that the test configuration corresponded to finite simple shear, plot the $E_{11}$ and $E_{12}$ components of the Green-Lagrange strain tensor based on the actuator displacement as a function of test time for the final cycle of testing. Include both curves on the same plot if you can.

Plot 2: Stress-strain curve: Plot the average 1st Piola-Kirchoff shear stress component $P_{12}$ (this is the current force over the reference cross-sectional area, the “engineering stress” in Pascals) as a function of Green-Lagrange shear strain $E_{12}$ determined based on actuator displacement for the final cycle of testing (from neutral to peak). Explain shape of response.

Strain tensor from marker coordinates: Determine the components of the Green-Lagrange strain tensor within the region defined by the markers, assuming that the strain is homogenous within that region, using the equation:

$$ds^2 - dS^2 = 2E_{MN}dX_M dX_N \iff ds^2 - dS^2 = 2dX \cdot E \cdot dX$$

Assume that the out-of-plane shear strains ($E_{13}, E_{23}$) are zero. You have four markers, so you can construct six different “$dX$” vectors. This will yield six equations for the three unknown strains ($E_{11}, E_{22}, E_{12}$). You can determine these unknowns for every time that you have marker data during the test by solving the normal equations. It is highly recommended that Matlab is used for this analysis.

Plots 3-5: Generate three additional plots using the data from the above analysis

- $E_{11}$ (marker) and $E_{11}$ (actuator) versus test time
- $E_{22}$ (marker) and $E_{22}$ (actuator) versus test time
- $E_{12}$ (marker) and $E_{12}$ (actuator) versus test time

Provide a detailed explanation for any differences between the strains determined from the marker coordinates versus those determined from the actuator displacement.

Plot 6: Assuming incompressibility, calculate and plot the out-of-plane normal strain $E_{33}$ based on the values for the in-plane strain components determined from the marker data as a function of test time.

Turn in the 6 plots described above (2 pages max)

Interpret your results. Are they what you expected? Why or why not?
The verbal description of your results and interpretation section should be <1 page.
Also include in discussion:
- Limitations of the experiment
- What effect an inaccurate DMAS calibration could have on your results?
- How the experiment could be improved.
Here is a suggested outline for your Matlab program:

- Read in DMAS and Labview data.
- **Remove every other row from Labview data.** The following code can be used for this purpose, however if you are one of the groups with zeros on every other line, make sure this is removing the zeros and not your real data.

```matlab
%remove every other line from Labview data
c=0;
for i=1:length(Labview)
    test=(-1)^i;
    if test>0
        c=c+1;
        Labview_temp(c,:)=Labview(i,:);
    end
end
```

- Create a loop to solve for strains from actuator displacement data and stresses from load cell / dimension data.
- Establish \( dX^1, dX^2, dX^3, dX^4, dX^5, dX^6 \) vectors from coords at start of test (these never change)
- Calculate \( dS^1, dS^2, dS^3, dS^4, dS^5, dS^6 \) (these never change)
- Loop over data for each time point
  - Calculate \( ds^1, ds^2, ds^3, ds^4, ds^5, ds^6 \)
  - Set up \( Ax=b \) equations
    - \( A \) will have dimensions 6x3, \( b \) will have dimensions 6x1
  - Solve equations for unknown vector \( x \), containing \( E_{11}, E_{22} \) and \( E_{12} \)
- Make Plots

**NOTES:**
- Labview data has four columns. Column 1 is the clamp displacement (mm), column 2 is the force (N), column 3 is the time and column 4 is the cycle number.
- Labview data either has a zero displacement every other line or a repeated time measurement on every other line (depending on which station you were at). Be sure to remove every other line!
- Labview data and DMAS data might not be aligned temporally—be sure to align them. The easiest way to do this is to plot both data sets in excel and then find the start and end points for a single cycle, then save a single cycle for each data set to new files for use in Matlab.
- Dmas frequency is 30 hz.

**Appendix:**

Include the source code for your analysis program as an appendix to the report.
Troubleshooting Tips:

- If you did not get a good calibration, your marker strains will not agree well with your clamp strains. To check if you marker calibration is good, examine the distance between the markers at t=0. The markers should form a square of sides~4mm.
- The camera calibration was a right handed coordinate system, so the shear angle was negative. If your marker and clamp strains are inverted, then you forget to take this into account.
- For all groups, the curves for the Ex and Exy strain should have the same general shape as the clamp strains, but will be smaller in magnitude. If your clamp and marker strains do not look similar, something is wrong.