INSTRUCTION MANUAL

DMA Software

Dynamic Muscle Analysis

November 8, 2002, Revision 3

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1.0 General Description

The DMA program was designed to analyze the data files from the muscle control program (DMC). The program also has the facility to read in delimited text files generated by other programs. The program is divided up into several analysis modules that together allow a wide range of data to be characterized and evaluated.

The following is a short list of the capabilities of the DMA software:
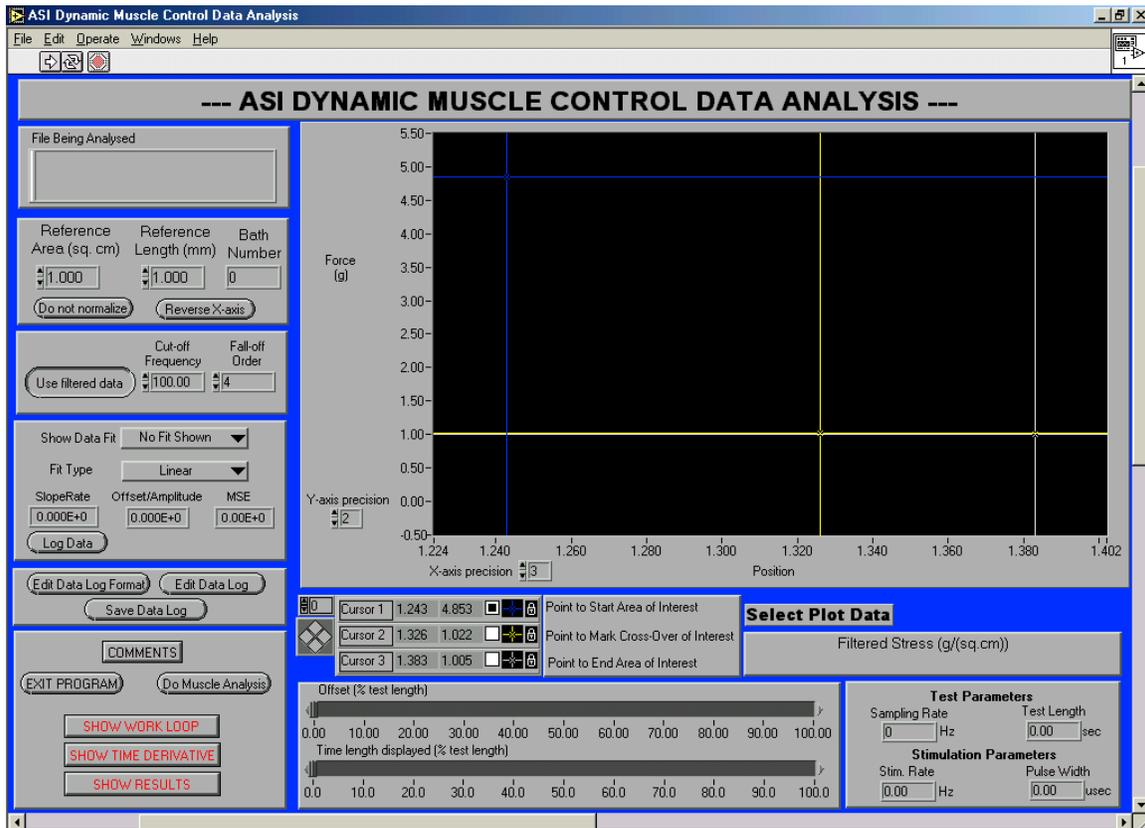
1. Digital filtering of the data with user defined cut-off and fall-off order.
2. Normalization of data by user defined factors.
3. Simultaneous display of three measured quantities.
4. Linear and exponential fitting to user defined segments of the data.
5. Custom user defined setup of evaluated data output files.
6. Phase plot capability with custom analysis tools such as loop integration.
7. Time derivative analysis including numerical and segmented linear regression analysis of the time derivatives calculated.
8. Calculation of all basic muscle statistics from basic muscle tests such as twitch, work loop, force-velocity (a.o.) protocols.

2.0 DMA Main Screen Description

The DMA main screen is shown in Figure 1 before the program is started. To start the program the white arrow at the top is pressed using a left mouse click. Exiting the program is accomplished either by pressing the red button in the top tool bar or by pressing the 'Exit Program' button on the left bottom of the main screen. To the left below the title bar is an indicator showing the user the name of the data file currently loaded and being analyzed.

Below the data file indicator are the input boxes for the reference values of the quantities to be analyzed. In the analysis of DMC experimental data files, these input boxes represent, for example, reference area and reference length to normalize the force and length outputs of the DMC to stress and strain respectively. Whether or not the displayed data is normalized by these factors or not is determined by the state of the 'Normalize' button. Next to the 'Normalize' button is the control to display the x-axis in reverse increasing from right to left instead of left to right.

The digital time filtering options are located below the Normalize and Reverse Axis controls. A toggle control on the left allows the user to select whether or not the filtered data is to be used for data analysis. Beside the toggle filter control, the user inputs for filter cut-off frequency and filter fall-off order are located. Digital filtering of data can be very helpful in smoothing measurement noise, but can also skew actual experimental results. It is recommended that users always compare the filtered data to the unfiltered data to ensure that the filter is not contaminating experimental results. The program sets the filter cut-off frequency at one third of the sampling frequency. The default fall-off order is 4. The higher this number, the sharper the filter drop-off becomes beyond the cut-off frequency. However, very high order filters can skew large gradients present in the data. It is recommended that users not set the fall-off order above 8.

Figure 1 Main Screen of DMA program

Below the controls for digital filtering of the data are user inputs to control the display and type of data fit shown. The top input controls whether or not and over what domain the data fit is calculated and displayed. The next input down controls the type of fit calculated and displayed (linear or exponential). Indicated below these inputs are the characteristics of the calculated fit, including the slope or rate (depending on the type of fit), the offset or amplitude and the quality of the calculated fit represented by the mean squared error (MSE). The 'Log Data' button below the characteristics of the calculated fit is used to initiate the registering of user selected information for later saving in a summary data log file. (See Section 0)

The data log editing and format controls are located below the log data control. These buttons allow the user to call up windows that determine the format of the summary data output file (Edit Data Log Format), edit the data in the data log (Edit Data Log) and save the data currently contained in the data log to a delimited spreadsheet compatible ASCII output file (Save Data Log). (See Section 0)

Below the data log controls the user will find the button that controls the display of the comments entered for a given DMC output data file. Upon pressing the button the program will display a pop-up window showing the entered comments, if any. Recall that at the very least

the comments contain the time and date of collection of the experimental data. Pressing the 'EXIT PROGRAM' button will terminate the program. The 'Do Muscle Analysis' button will initiate the calculation of basic muscle metrics for the current location of the cursors as discussed below in Section 0.

The 'SHOW WORK-LOOP' button allows the user to call up the phase plot of the two measured quantities. In the case of a DMC data file such a plot will correspond to a plot of position versus force and allow the user to perform work loop type analysis. The functionality of the controls available in that window are discussed in Section 0.

Similar to the 'SHOW WORK-LOOP' button, the 'SHOW TIME DERIVATIVE' button allows the user to call up a window showing the time derivatives of the measured quantities for the currently selected cursor locations. The analysis options available for the time derivative window are discussed in Section 0.

The 'SHOW RESULTS' button causes a dialog window to pop up that displays all the basic muscle metrics calculated when the 'Do Muscle Analysis' button was pressed. Pressing this button without first pressing the 'Do Muscle Analysis' button will result in the program first executing the muscle analysis and then calling the window to display the results. Calculated muscle metrics are discussed in Section 0.

The data loaded from the selected file is shown in the large graph below the title bar. The y-axis of the plot defaults to automatically scale with the limits of the loaded data. Left clicking in the plot will allow the user to deselect the auto-scale option and subsequently enter the desired y-axis limits by left clicking on the axis labels at the ends of the y-axis. The x-axis limits can be manipulated by using the slide controls below the cursor and data display controls. The slide controls respectively control the lower x limit (as a percentage of total test length) and the total percentage of the test length displayed. The two slides can thus be used to zoom in on any desired part of the collected data.

To the right below the graph is the control for what data is displayed. In the case where a DMC output data file is loaded the options include the simultaneous display of filtered and unfiltered position or force as well as the simultaneous display of force and position outputs. Separate display of force or position is also possible. For the case where the absolute magnitudes of force and position vary greatly, it is recommended that one or both outputs be appropriately normalized using the normalize control discussed above. For the case where the stimulation signal was also collected, it can be displayed together with force and position.

To the left below the graph are the controls for the location and display of the cursors that determine the data sections of interest. The cursors allow the user to mark the overall domain of interest and also to separate the domain of interest into two sections. The order of the cursors should follow the cursor number, i.e. Cursor 1 (blue) should mark the start of the area of interest, Cursor 2 (yellow) should mark the cross-over point between the two sections of data of interest and finally Cursor 3 (white) should mark the end of the area of interest. The index control (furthest to the left on the cursor control) should not be changed by the user.

Below the index control is the active cursor control pad. The active cursor is determined by the location of the black square next to the cross hair color of the active cursor. Activate a cursor by left clicking in the white box next to the cross hair of the cursor to be activated. Once activated the cursor location can be manipulated using the cursor control pad. The cursors have been locked to the data on the display so that the up-down and left-right controls on the pad are not independent. Clicking on the pad controls will move the cursor along the plot in the desired direction. Left clicking on the cross hair in the graph and dragging the cursor to the desired location can also move the cursors. The control pad is used mostly to precisely adjust the location of the cursor. In the case where the cross hairs are not shown on the display, the user can bring the cursor to the center of the display by left clicking on the desired cursor's cross-hair and selecting bring to center as shown in Figure 2. The same method can be used to change the color of the cursors and how they are displayed.
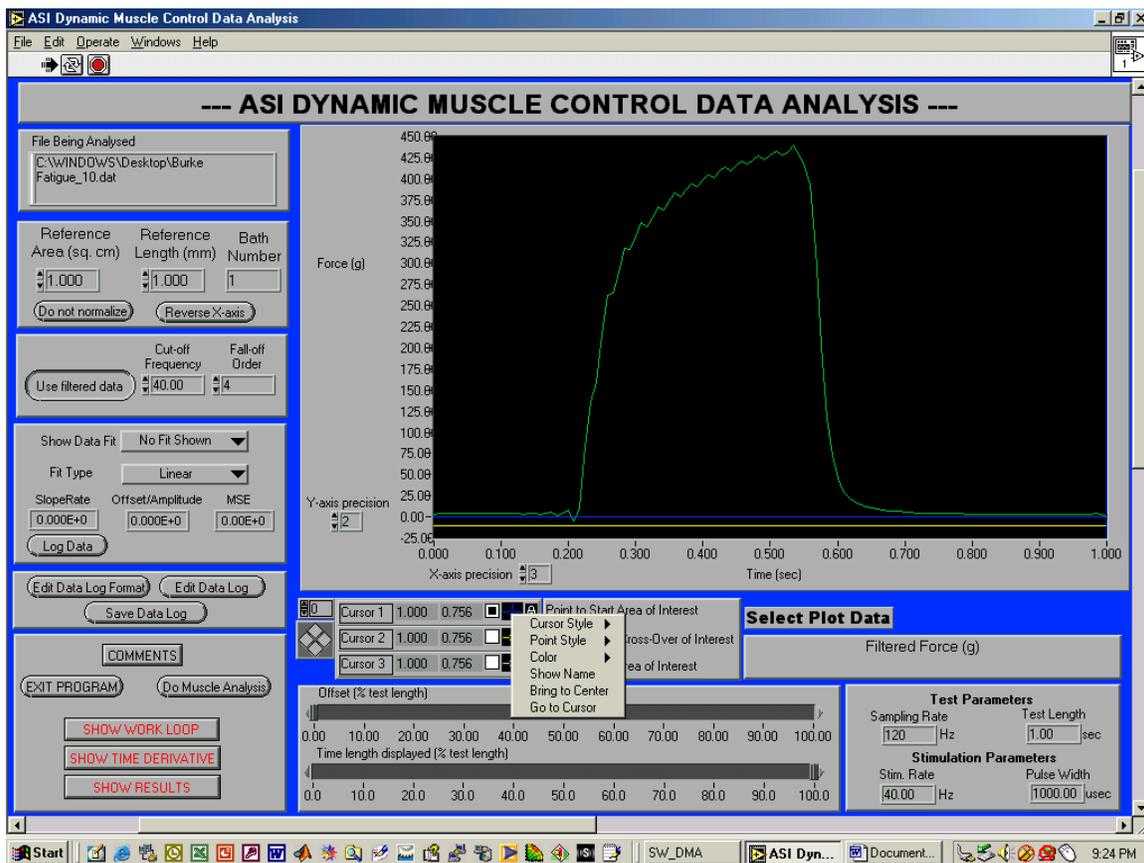

Figure 2. Cursor display control

Finally, to the right of the graph display slide controls are the indicators showing relevant test parameters for the given data set. These parameters are loaded from the DMC output data file or can be entered manually for data files loaded through the ASCII data file

dialog window. Displaying these test parameters in the main window help the user in, for example, selecting appropriate values for the cut-off frequency of the digital filter.

3.0 Loading Data Files

When the program is started by left-clicking on the white arrow in the toolbar to the left at the top of the screen, the program offers the user a choice to either reload a data file previously analyzed (choice of the ten last analyzed files) or to load a new data file as shown in Figure 3. When the program is run for the first time, pressing the reload button will of course not display any available data files.
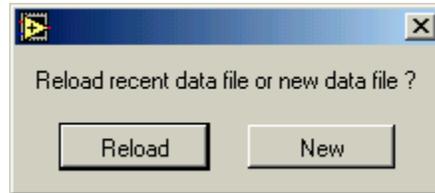

Figure 3. Reload or new data file dialog window

For each subsequent time the program is started however, a window, as shown in Figure 4, will contain the ten most recently loaded data files. Clicking on the radio button next to the desired filename will cause to program to exit from the dialog window and continue with the data loading process using the selected data file.
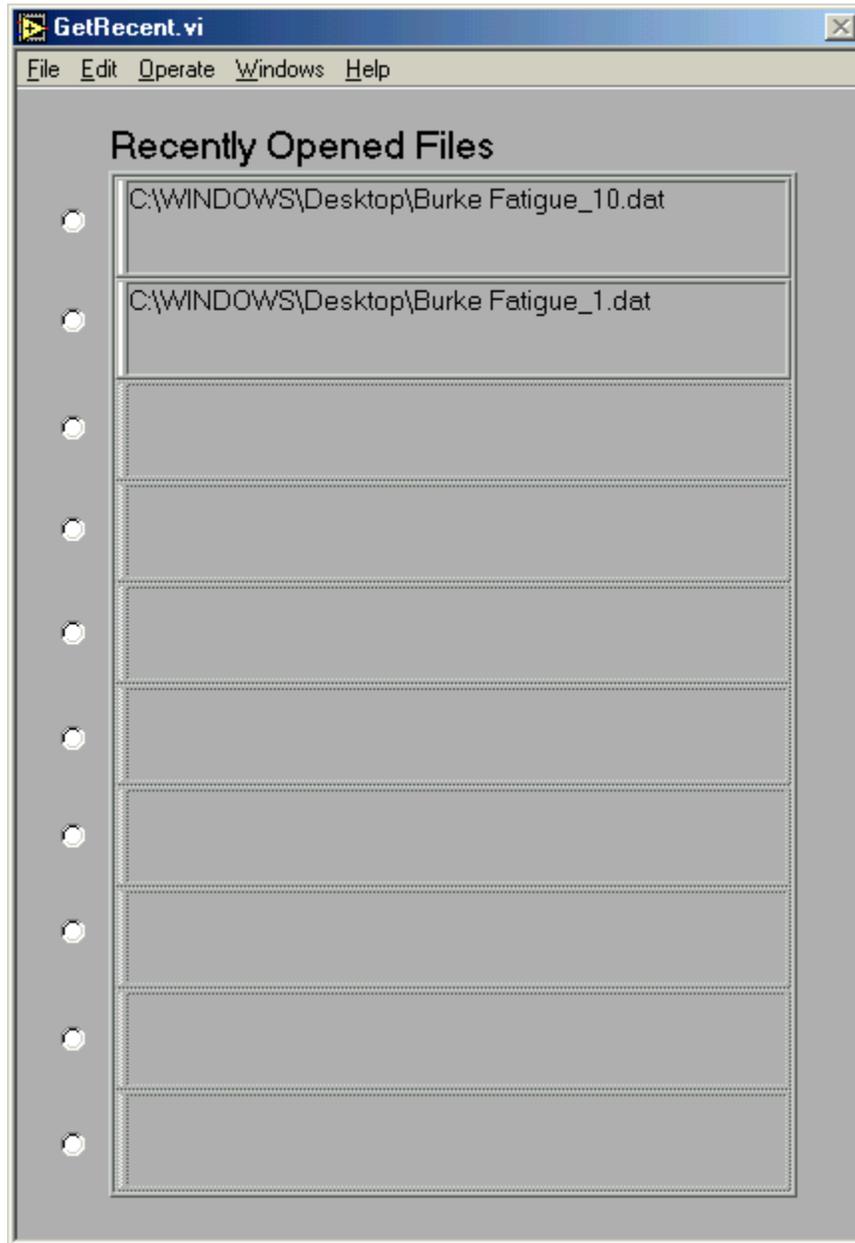
**Figure 4.** Recently opened data files dialog window

Whether or not a new or reloaded data file is analyzed, the dialog window shown in Figure 5 next pops up to determine if the data file stems from the DMC program (LabView) or is an ASCII format data file. The user clicks on the desired file's data type and the data file loading process continues.
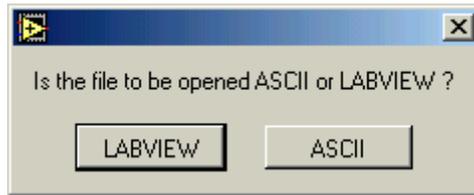
Figure 5. Data file type determination dialog box

If the selected file type has LabView format (from DMC) the program continues with a file dialog window allowing the user to select the file desired for analysis. If a recently opened data file was selected already, the file dialog window does not pop up and the program simply continues by loading the data file contents into memory and returning control to the DMA main screen.

For ASCII data files a special dialog window follows that shown in Figure 5, allowing the user to enter the format of the data file to be loaded. The dialog window is shown in Figure 6.
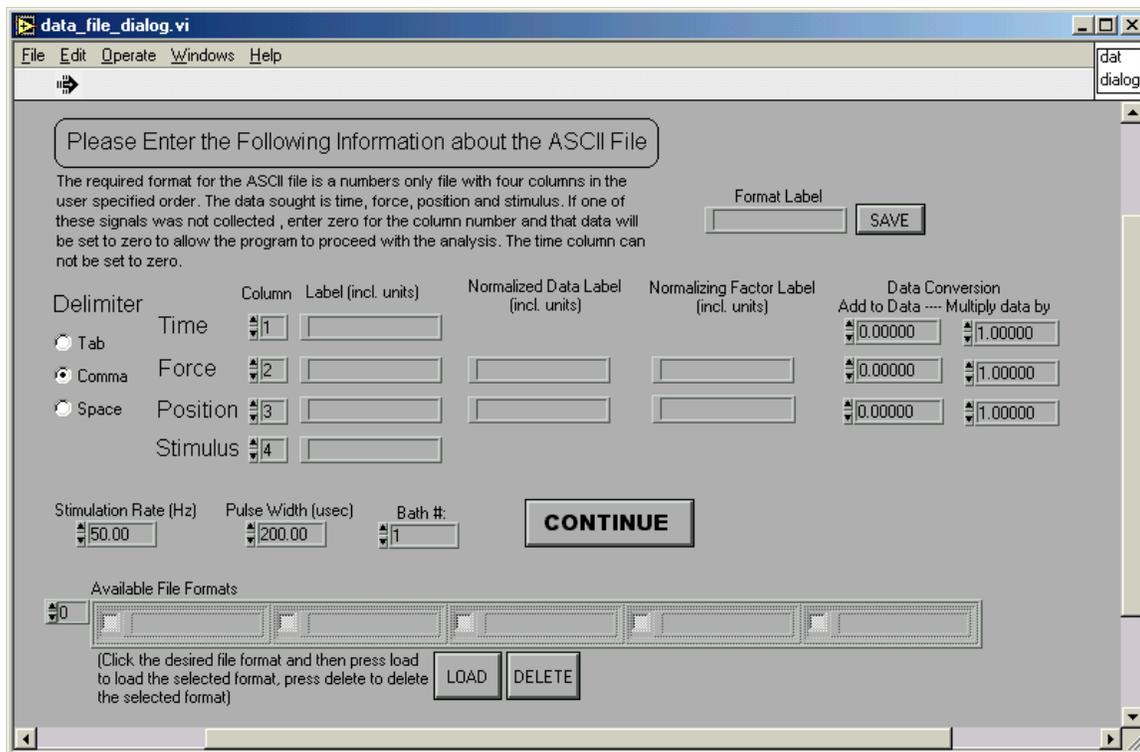
Figure 6. ASCII data file format dialog

The dialog window allows the user to tell the program how to load the data contained in the ASCII data file. The format requirement is that the file contains only numerical data in column format with the columns separated by one of three delimiters: Tab, comma or space. The delimiter of the file is selected by clicking on the radio button next to delimiter used in the

file. The user next assigns the normal time, position, force and stimulus quantities from the DMC to columns in the data file. Entering zero for the column number means that this data column is not contained in the data file and no data will be loaded for that quantity. For each data column the user can enter new labels for the given data column. These labels will be used in the graph control and analysis modules. In other words, the column selected as the position column will not be called position in the DMA program unless that is the label entered in the text box next to the position column. Similarly, the normalized data labels and the normalizing factor data labels can be entered for each of the measured quantities contained in the ASCII data files. The data loaded from the ASCII data files can also be scaled in any desired linear way using the scaling factor controls located furthest right for each row. In this way, the time vector could be scaled from seconds to milliseconds including some offset. It is also possible using these controls to apply a calibration to collected voltages. For example, these controls can translate a sensor's voltage output recorded in the ASCII file to physical units using the sensor's linear calibration characteristics. Stimulation, pulse width and bath numeric controls are provided for the user to enter this information about these test parameters. If these parameters are not relevant to the data to be analyzed, it is possible to simply leave these controls unchanged, as they are not explicitly used in the analysis process.

The ASCII data file format dialog window appears whether or not a new or recently analyzed data file is desired for analysis. To prevent the user from having to re-enter information repeatedly, it is possible to save a given ASCII data file format and then subsequently reload it using simply two mouse-clicks. To save a given ASCII data file format, enter a label for the format in the text box next to the 'SAVE' button on the top right of the dialog window. To save the format click on the 'SAVE' button. The saved format will then appear as an available format in the available file formats list at the bottom of the dialog window. To load a format left-click in the check box to the left of the desired format label and press the 'LOAD' button. Selecting one or several formats and then pressing the 'DELETE' button will result in the removal of these formats from the available file formats. Use the index control on the left of the file format list to access file formats beyond the maximum of five listed in the window at the same time.

The ASCII data file dialog is exited by pressing the 'CONTINUE' button. Upon pressing the 'CONTINUE' button, the program either loads the file selected from the recently opened files list or displays a file dialog for the user to select the ASCII file of interest. Control returns then to the DMA main screen.

4.0 Data Log Output File

The DMA program has the capability to analyze a wide range of data files. Therefore, the summary data ASCII output file generated by the program is not predetermined in terms of format. The user can set up custom so-called data log formats for each type of data file anticipated to be analyzed. The process of setting up the output data log file format is described in this section.

The customize data file format dialog is called from the main DMA window by clicking on the 'Edit Data Log Format' button. The window is shown in Figure 7. The data log is separated into columns that have user defined labels. When saving the data log, the user can decide whether or not to write out the column headings into the output file. The content of each column is selected from all the available data outputs. Each analysis window or module contains a log data button that is used to initiate the transfer of the data from the module into the log. For example, in the main window, the user can choose to log the x or y coordinates of any of the three cursors. To log the coordinates of all the cursors, the user would generate a format containing six columns with each column containing the appropriate cursor coordinate label and then selecting the appropriate information from the drop-down menus. The contents of the drop down windows are discussed in the following paragraphs. Once the data log format has been set, the format can be saved, deleted and loaded analogous to the process described above in Section 0 for saving, loading and deleting ASCII data file formats.
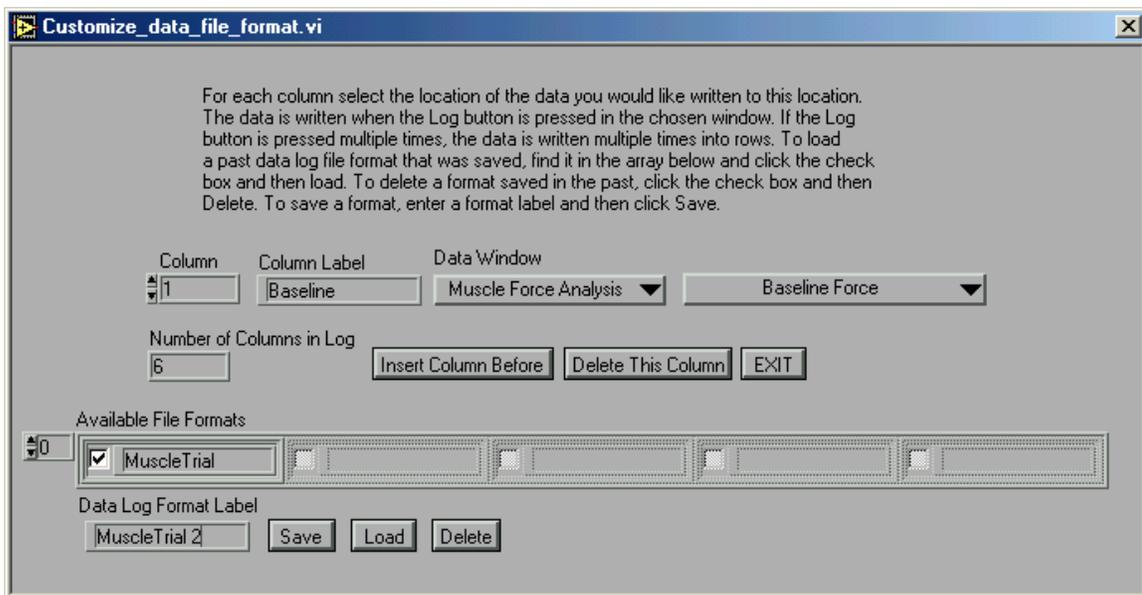
**Figure 7.** Customize data log format window

The data window drop down list is shown in Figure 8 and contains the following five options: Main window, time derivative, work loop, muscle force analysis and muscle position analysis. Upon selecting one of these five options the second drop down window that determines the actual data in the column changes. Each of the five selections represents one

analysis module. From each module different data can be extracted and consequently the second drop down menu contents change depending on which of the five analysis modules is selected.
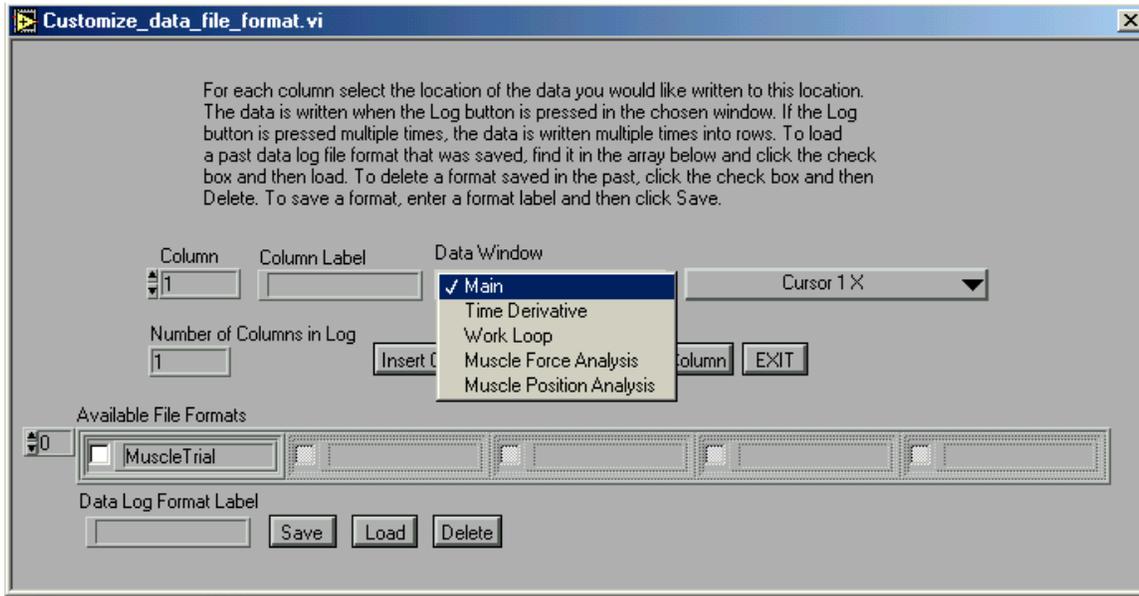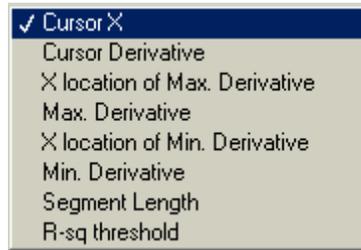

Figure 8. Data window drop-down menu

The main window data log options are shown in Figure 9. The items are self-explanatory and correspond directly to values displayed in the main window of the DMA program. The current value of these items is entered into the data log when the log data button in the main window is pressed. Pressing the log data button multiple times will cause the program to add rows of data and allow the user to log the data under different cursor settings.
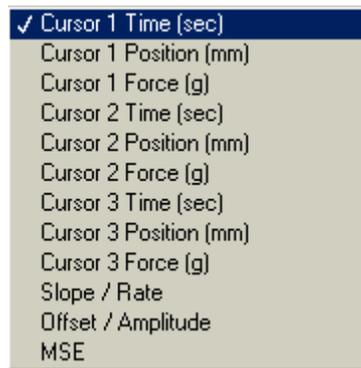

Figure 9. Main window data log drop down menu

The time derivative data window option allows the user to choose among the items shown in Figure 10. These options again correspond to items displayed in the time derivative window and will be explained in that context below in Section 0.


**Figure 10. Time derivative data window drop-down menu options**

Similarly, Figure 11 shows the drop-down menu options for the work loop data window which are discussed below in Section 0. Figure 12 shows the options available from standard muscle force analysis. Figure 13 shows the options available from standard muscle position analysis. Both of these drop-down menus have many options, not all of which are shown in the figures. All the standard force and position muscle analysis options are discussed in Section 0.
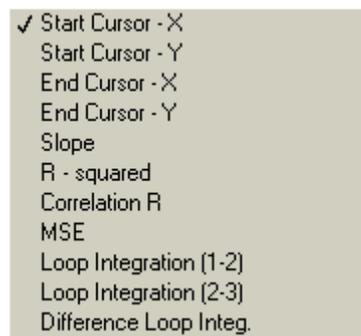
**Figure 11. Work-loop data window drop-down menu options**
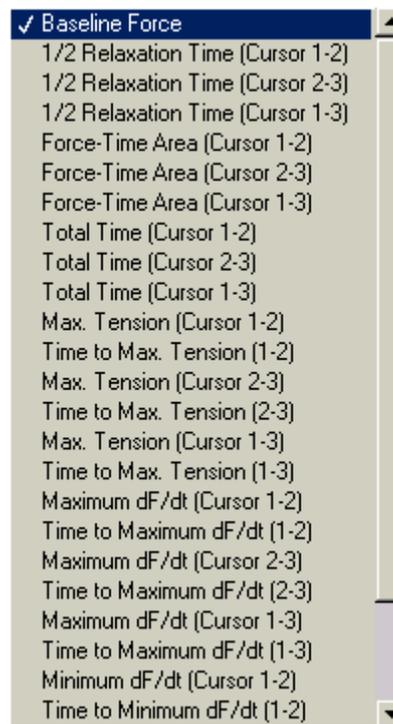
Figure 12. Muscle force analysis data window drop-down menu options
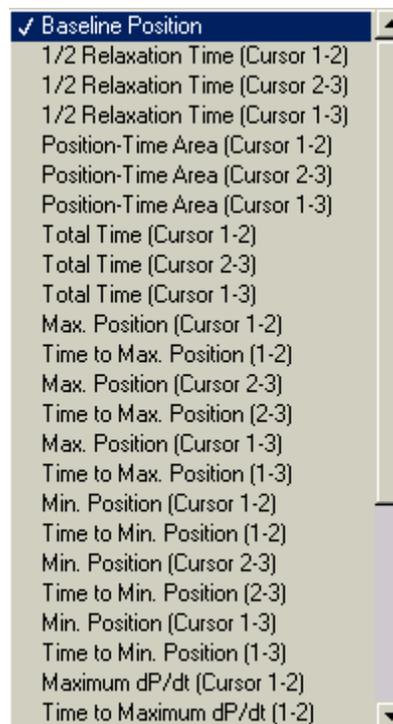
Figure 13. Muscle position analysis data window drop-down menu options

The number of columns currently in the log is indicated by the corresponding control in the dialog window. Using buttons in the window it is possible to insert columns and delete columns as desired. It is important to understand that entering the data log window essentially resets the entire data log and any logged data will likely be lost. The data log can be saved to a spreadsheet compatible file (tab delimited ASCII text file) using the 'Save Data Log' option from the main DMA window.

To exit the format data log window, press the 'EXIT' button. Control returns to the main DMA screen. Once data has been logged using the log data button in the analysis modules, the data log can be reviewed and edited by pressing the 'Edit Data Log' button in the corresponding analysis module window. The dialog window is shown in Figure 14.
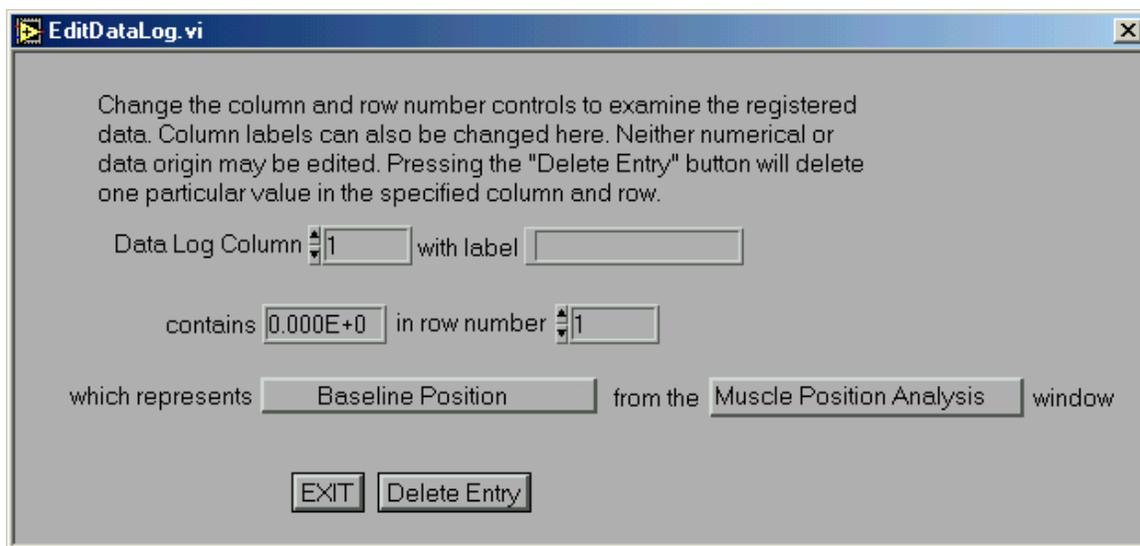

Figure 14. Edit data log window

he window allows the user to browse the data log by column and row number. Only individual row entries can be deleted. Neither the number of columns in the data log nor what the data in the columns represents can be edited. Deleting a row entry in one column will not delete the corresponding row entry in another. The edit data log window can be used to change the column labels. To return to the screen the edit data log was called from, press the 'EXIT' button.

When saving the data log to file the user is first asked to choose whether or not data will be appended to an existing file (Figure 15). The user then chooses the data label which, as a default, is the data file name (Figure 16). The default data label can however be changed to any desired string within the length limits of the input box. The data label is entered in each of the data rows (below the column labels) with the number of the row appended to the string. Finally, the user can decide whether or not the data log file to be saved should contain the column labels (Figure 17). In this way, one large summary data file can be generated containing the results from the analysis of any number of data files. The results from each data

file can still be distinguished due to the row labels entered each time the data log file is appended to.

Figure 15. Append to file dialog
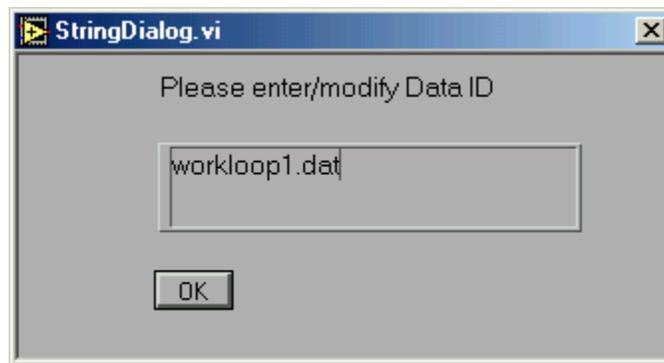
Figure 16. Data ID dialog window

Figure 17. Column headers dialog window

5.0 Work Loop Analysis Window

The work loop analysis window is called from the main DMA window by clicking on the show work loop button. The window is shown in Figure 18 for an example muscle work loop protocol where the muscle is subjected to two consecutive sine wave excursions in position with a single stimulation pulse issued during the second sine wave.
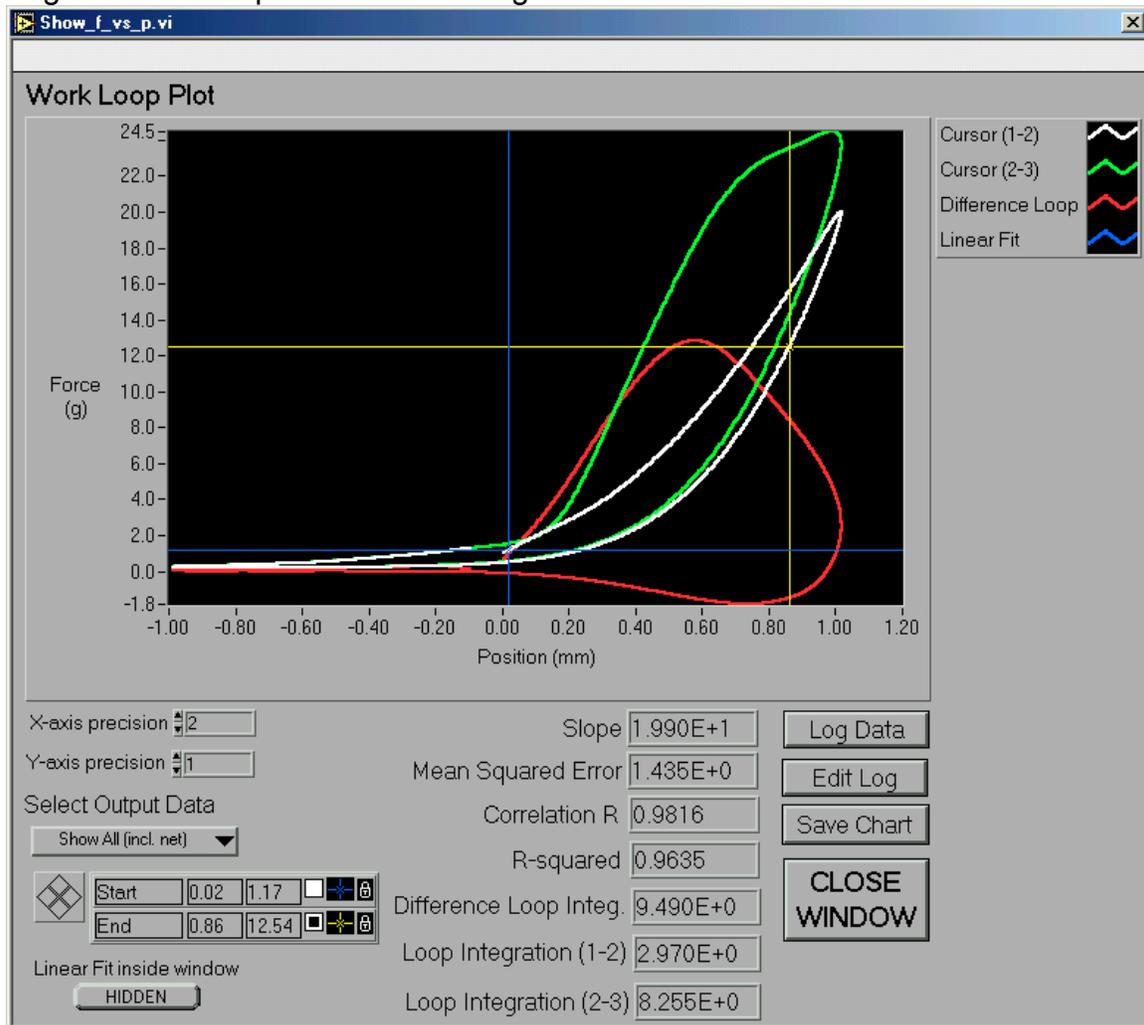
Figure 18. Work-loop analysis window

The window contains a large graph window. The x-axis and y-axis label precision can be controlled using two numeric controls below the x-axis label. To the left of the screen below these controls is the drop-down menu controlling what section of data is displayed. There are five choices. The second and third choices will display the first segment and second segment of data respectively (as determined by the placement of the cursors in the main DMA window discussed above in Section 0). The first choice will subtract the force measured in the first segment from the force measured in the second segment at the same displacement in the sine wave. Thus, the first choice represents a measure of the net work caused by the stimulation

pulse. The last two choices allow for the combined display of the first and second segment or the first and second segments along with the resulting net loop.

The graph allows for the placement of two cursors: the start and end cursors. These cursors determine the domain of calculation of a linear fit to the displayed data. The cursor position in the work loop analysis window is manipulated exactly like the cursor position in the main DMA window. The fit is shown when the toggle control below the cursor control pad is toggled from hidden to shown. The results of the linear least squares fit are shown in display boxes next to the cursor controls. Included with the results from the linear fit is are values for the loop integration, representing the area enclosed by the curves displayed in the graph. The integration is performed using the trapezoidal rule, subtracting the area under the bottom curve from the area under the top curve. The loop integration accuracy is directly proportional to the accuracy of the cursor locations selected in the main DMA window. If there is excessive overlap in the loops or if the loops do not quite close, the calculation accuracy will suffer. Precise location of the cursors in the main DMA window and any window employing cursors is accomplished using the cursor control pad which allows the cursor position to be incremented by one data point.

To the right of the loop integration and linear fit results are the data log controls and the 'Save Chart' button. Pressing the 'Log Data' button will make the program check the data log for any columns requiring data from the work loop analysis window. If such columns are found the appropriate information for that column is taken from the current display values and entered into the last row of the column. Pressing the log data button repeatedly will cause multiple rows of data to be generated in the data log. The proper registration of the desired data in the log can be verified by pressing the 'Edit Data Log' button. The 'Save Chart' button allows the user to save the displayed graph into a spreadsheet compatible ASCII file. The file will contain the first and second data set displayed in the legend. The linear fit is performed for the first curve shown in the legend.

The work loop analysis window can not only be used to investigate muscle work loop data but can also be employed in material fatigue studies as well as a wide variety of dynamics studies that require phase plot analysis. The chart label and data shown in the work loop analysis window are inherited from the main DMA window so that if the data used in the main DMA program is filtered and normalized and has labels A and B then these labels and associated data will be transferred to the work loop analysis window.

To exit the work loop analysis window, the 'CLOSE WINDOW' button is pressed. It is important in navigating all the dialog windows that the controls provided for exiting the windows are used and not the window closing x at the top right of the window.

6.0 The Time Derivative Analysis Window

   The time derivative analysis window is called from the main DMA screen by pressing the 'SHOW TIME DERIVATIVE' button. The time derivative analysis window is shown in Figure 19. Similar to the work loop analysis window, the graph has precision controls for both the x and y axes of the graph. The time derivative window offers only a single cursor for data browsing.
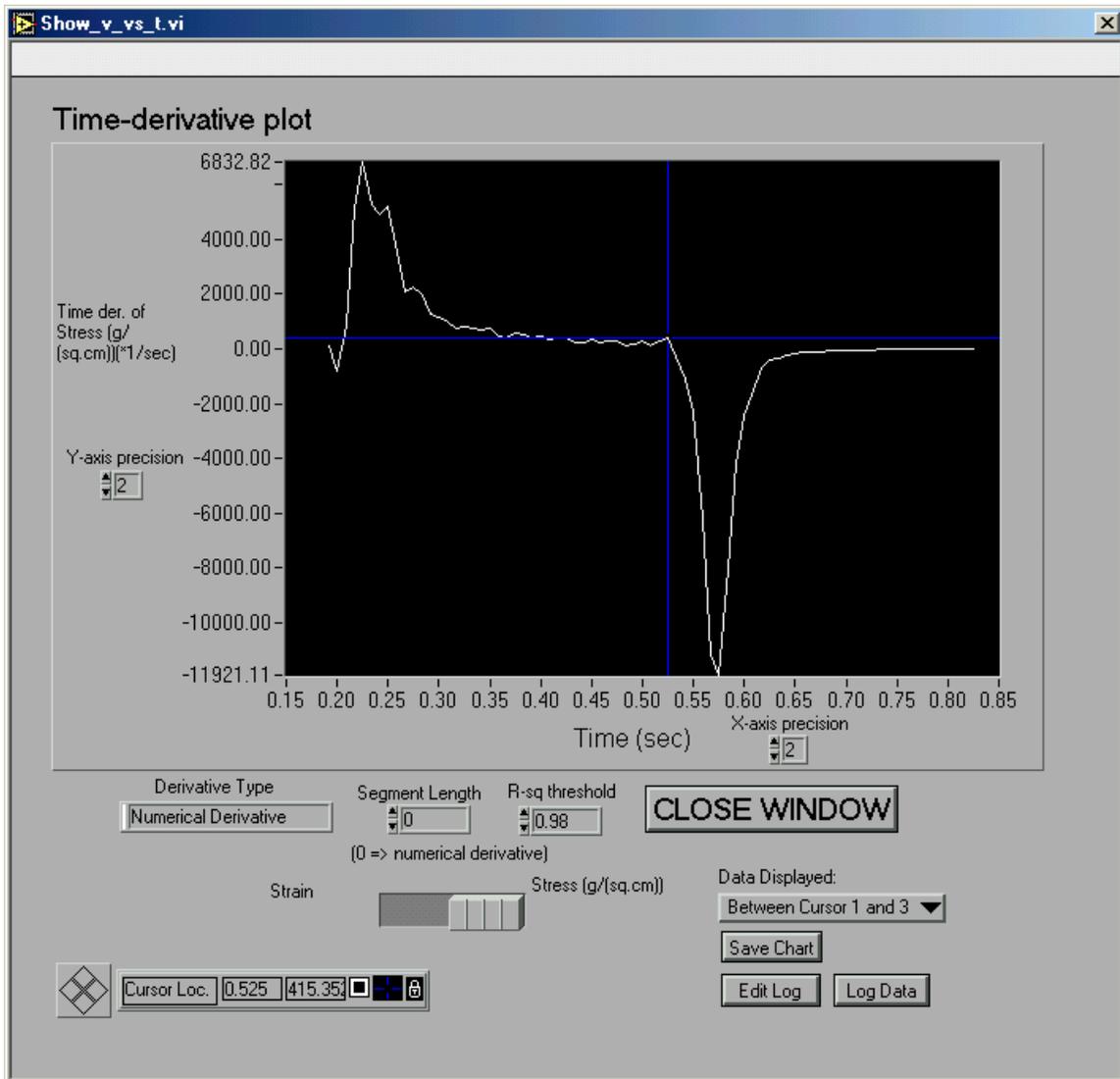
Figure 19. Time derivative analysis window

   The time derivative window displays the numerical time derivative as a default. The numerical derivative is calculated using the 2nd order central difference formula with zero derivative boundary conditions. The segment length control next to the derivative type indicator

controls how the time derivative is calculated. For a segment length of zero, the numerical time derivative as already described is displayed. For a segment length of one, no data is displayed. For segment lengths above one, the time derivative is calculated using a sliding window linear regression analysis. The segment length determines the length of the window. For each window position a linear regression is performed within the window, determining an average value of the time derivative for the data within the window. The time assigned to this average time derivative is the average time of the data within the window. As the window slides a time derivative curve is generated. The time derivative data calculated in this manner is filtered using the R-sq threshold specified in the control located next to the segment length control. The time derivative calculated for a given window position is only added to the data set if the R-sq value of the calculated fit is higher than the threshold value. Setting the segment length above one thus results in an unevenly spaced data set of local time derivatives. In the limit of infinite sampling rate, both methods yield the same results. However, in some applications it is necessary to evaluate the quality of the calculated local time derivative and this can be better controlled using the second method of time derivative calculation. An example where the second method has been used in the past is calcium uptake rate calculations.

Below the segment length controls is the first data display control that switches among the measured quantities subjected to the time derivative determination. In the case of normalized DMC data these measured quantities are stress and strain respectively, as shown in Figure 19. Next to this control is the second data display control which controls what segment of data is displayed, either between cursors one and two, two and three or one and three.

The 'Save Chart' button is located below the second data display control. Pressing the 'Save Chart' button will allow the user to save the data displayed currently in the graph to a spreadsheet compatible ASCII file. The 'Log Data' button will cause the desired information to be extracted from the current display, be it the cursor locations or graph minima and maxima and their locations in time. The 'Edit Data Log' button can be used to verify that the proper information has been registered in the data log.

To exit the time derivative analysis window, left-click on the 'CLOSE WINDOW' button.

7.0 The Muscle Results Window

The muscle results window displays the results of the basic muscle calculations that can be performed on any given experimental data set. Pressing the 'Do Muscle Analysis' button performs the calculations. The muscle results window is opened by clicking on the 'Show Results' button and is shown in Figure 20. The following paragraphs detail the calculations used to arrive at the quantities shown. The quantities are calculated regardless of whether or not the quantity is relevant for a given data set. Each quantity is also calculated for each cursor interval (1 to 2, 2 to 3 and 1 to 3), regardless of whether or not each interval contains data of interest. The data of interest is selected in the data log format as described above.

The half relaxation time measures the amount of time from the displacement or force peak to the time where half of the peak has been reached. The integration of the area under the displacement or force curves is performed by trapezoidal rule for each of the cursor intervals.
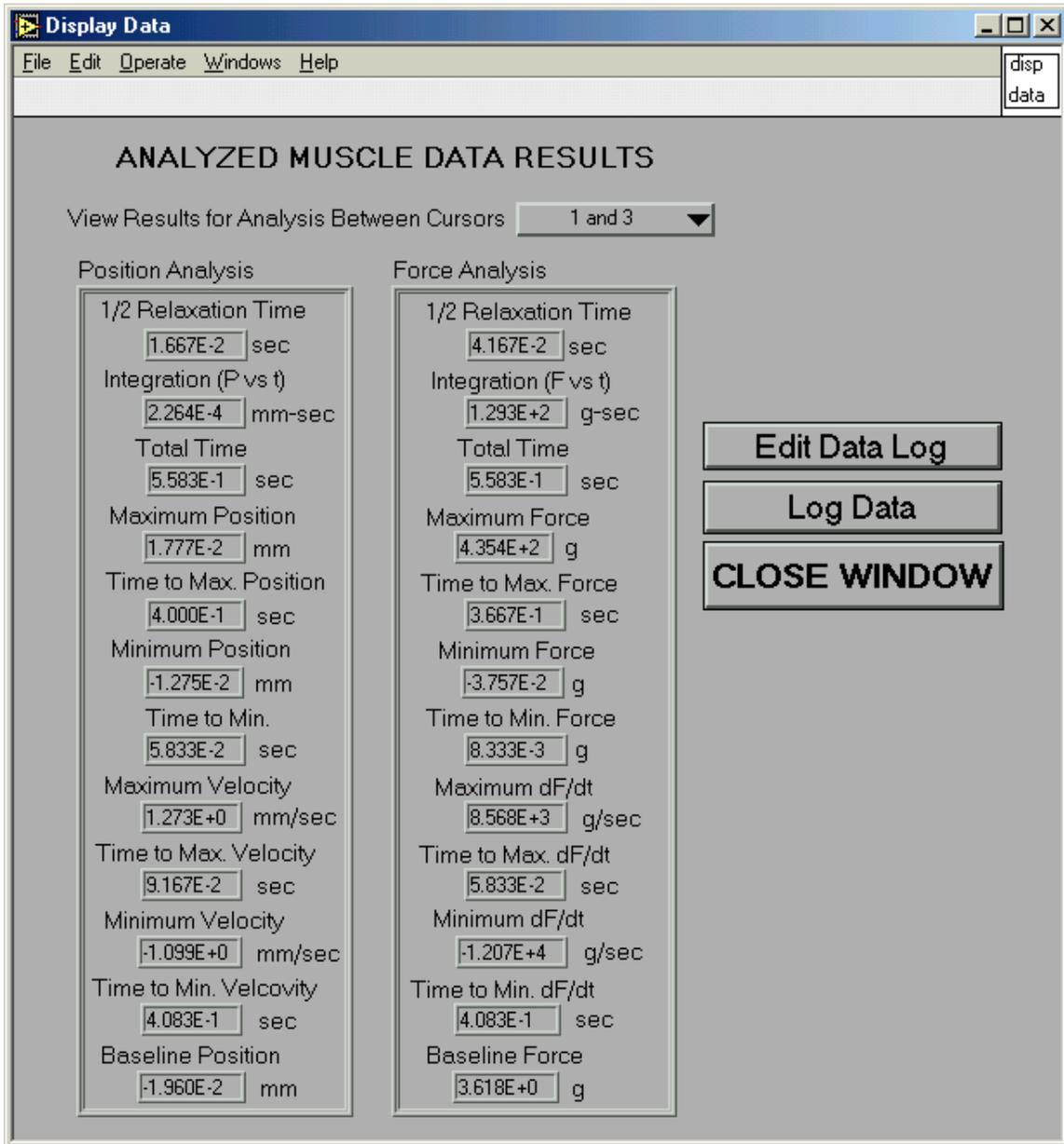
Figure 20. Muscle results window

Total time shows the time difference between the cursors. The maxima of position and force between the cursors are given as well. For position the minimum is also given. For each of the extrema the time of occurrence from the cursor location is also given. Derivatives are calculated by second order central difference. The program also gives the original baseline condition of both displacement and force. All of these pieces of data can be specifically selected for logging in the data file.