

**IPST SURFACE PATTERN IMAGE VELOCIMETER
DOCUMENTATION AND SOFTWARE MANUAL**

Project F005

Report 2

to the

MEMBER COMPANIES OF THE INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

April 2000

INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

Atlanta, Georgia

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A Progress Report

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By

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April 2000

1.0 Introduction

The forming jet velocity profile has a significant impact on the physical properties of finished paper. It is believed that slight variations in the velocity profile can strongly affect fiber orientation, forming table streaks and other properties. Typically, in order to achieve a desired jet-to-wire ratio, the forming jet velocity is controlled using feedback from a pressure transducer in the headbox and the jet velocity is calculated using Bernoulli's streamline equation. However, with high levels of turbulence in the headbox, the total head at the point of the pressure measurement includes a non-negligible velocity head that varies with the flow rate. Thus the equation for the total head of a free jet at a nozzle must include a term accounting for the significant head losses resulting from the turbulent flow through the nozzle. These losses vary for differing headbox designs, flow rates and slice openings and the head-loss equations must be determined empirically. In practice it is difficult to obtain jet velocity measurements with accuracy better than two percent.

To better characterize the impact of forming hydrodynamics on the physical properties of a sheet accurate measurements of the jet velocity profile are required. Laser Doppler Velocimetry (LDV) is a useful technique for taking these measurements but it is limited in that it can only produce data for one location at a time and it cannot be used to analyze fiber suspension and other opaque flows. Similarly, other methods exist that use point correlation to measure the surface velocity at a given point.

In order to obtain the surface velocity profile of a section of the forming jet a Surface Pattern Image Velocimeter (SPIV) has been developed based on the cross-correlation of sequential images similar to Particle Image Velocimetry (PIV) techniques.

The PIV technique is a particularly powerful method for velocity field measurements. However, this method is limited to transparent fluids with well defined seed particles. The fiber suspension in the headbox and the forming section is not transparent and therefore can not be measured using PIV methods. SPIV takes advantage of the non-uniform flow patterns on the surface of the forming jet by recording the position of distinct flow patterns using a high-speed digital camera and using the cross-correlation between a sequential pair of images to determine the jet velocity profile.

2.0 The Surface Pattern Image Velocimetry Technique

The SPIV technique is based on the comparison of a pair of sequential images and the tracking of recognizable nonuniform patterns between the two images. This is illustrated in figure 1 below.

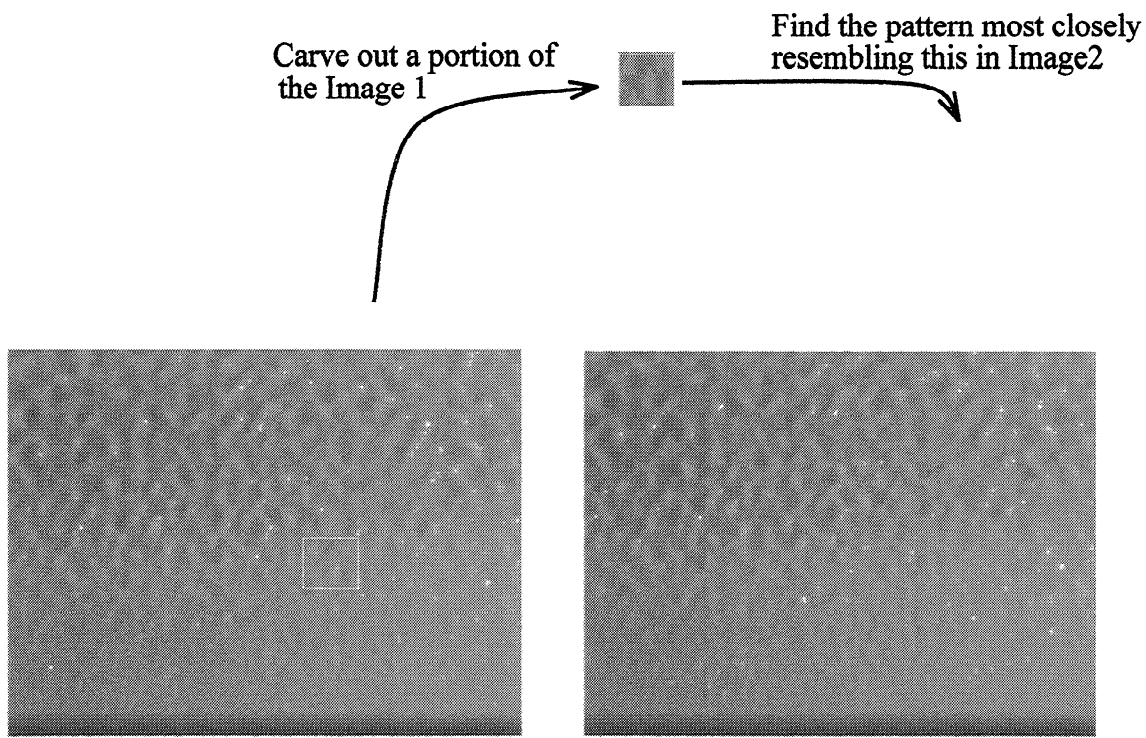


Figure 1 – Illustration of the basis of SPIV

2.1 The Cross-correlation Method

The cross-correlation method is used to compare two patterns. The formula to obtain the cross-correlation value is given in Equation 1 below. The displacement during a time interval is determined by searching Image 2 for the highest cross-correlation value for each point in image 1.

$$D(i, j) = \frac{\sum_{n=1}^N \sum_{m=1}^M \{v(m, n) - \mu_v\} \{u(m + i, n + j) - \mu_u\}}{\sqrt{\sum_{n=1}^N \sum_{m=1}^M \{v(m, n) - \mu_v\}^2} \sqrt{\sum_{n=1}^N \sum_{m=1}^M \{u(m + i, n + j) - \mu_u\}^2}} \quad -p \leq i, j \leq p \quad (\text{Eq. 1})$$

$D(i, j)$: Cross-correlation value

$v(m, n)$: value of gray scale of Image 1 (0~255)

$u(m, n)$: value of gray scale of Image 2 (0~255)

μ_v, μ_u : Mean value of $v(m, n), u(m, n)$ inside of the inspection box

M, N : Size of inspection box

2.2 Estimation of the Displacement at the Sub-pixel Level

This method has a limit in resolution since the calculated displacement is always expressed in whole pixels. In order to obtain more accurate velocity measurements the resolution of the image must be increased or some filter must be added to the scheme of the calculation. The SPIV method overcomes this limitation, and realizes sub-pixel resolution in velocity measurement, by fitting the three points adjacent to the peak of the correlation distribution function with a Gaussian profile. This method is used to reduce the digitization error that occurs whenever a continuous field is projected onto a discrete domain. This is illustrated in Figure 2 below.

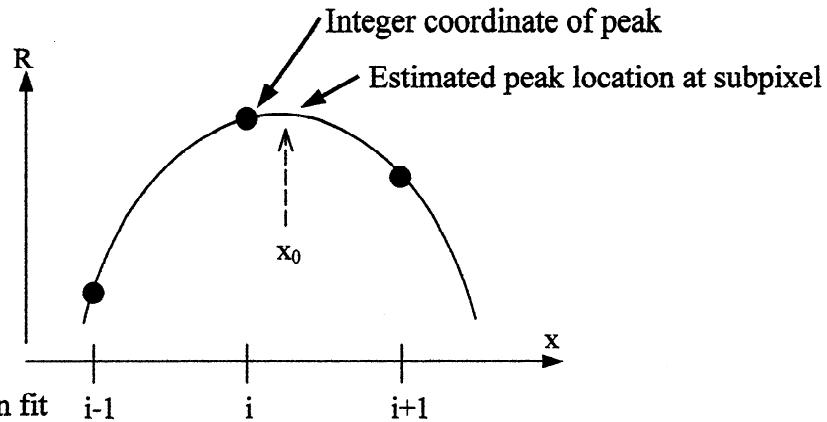


Figure 2 – Gaussian fit

The Gaussian equations are represented by:

$$f(x) = C \exp \left[\frac{-(x_0 - x)^2}{k} \right]$$

$$x_0 = i + \frac{\ln R_{(i-1,j)} - \ln R_{(i+1,j)}}{2 \ln R_{(i-1,j)} - 4 \ln R_{(i,j)} - 2 \ln R_{(i+1,j)}} \quad y_0 = j + \frac{\ln R_{(i,j-1)} - \ln R_{(i,j+1)}}{2 \ln R_{(i,j-1)} - 4 \ln R_{(i,j)} - 2 \ln R_{(i,j+1)}} \quad (\text{Eq. 2})$$

(i, j) : integer coordinate of peak

$R_{(i,j)}$: cross correlation value at (i, j)

The use of this Gaussian filter greatly improves the accuracy of the SPIV technique. The range of the error is reduced by two thirds and the standard deviation of the error is reduced by approximately four fifths. This increases the effective resolution of this technique by a factor of four or five over the resolution of the basic technique.

2.3 The Elimination of Questionable Data

The results of these calculations often contain data points that do not seem correct in relation to their neighbors. These questionable data points are eliminated to insure that the velocity profile varies continuously in space. The value calculated at each point on the image is compared to the average value of its eight neighbors and is discarded if it deviates from this average by more than a specified threshold value.

3.0 The Implementation of SPIV in Software

Software implementing the SPIV method has been developed at IPST to work in conjunction with the Kodak HRC Motion Analysis System. This software has been programmed in LabVIEW using the G programming language and runs on a Windows based notebook computer.

3.1 Hardware Description

The SPIV software runs as a virtual instrument under LabVIEW 5.1 for Windows 95/98. At IPST it is run on a Gateway Solo Pentium III 500 MHz laptop computer with 128 MB of RAM and an Adaptec Ultra SCSI/Slim SCSI PCMCIA card for image transfer.

Images are acquired by a Kodak high-speed digital video camera shooting in eight-bit grayscale, typically at 1,000 frames per second, and transferred to the core memory of a Kodak Ektapro Model 1000HRC Motion Analyzer.

The analyzer is controlled by the program through a serial data link running from the Com1 port on the laptop to the RS-232 compatible serial port on the analyzer's front panel. Images are transferred from the analyzer through a SCSI link to an external Hewlett-Packard 1.3 GB optical disk drive. The second SCSI port on this disk drive is connected to the PCMCIA SCSI card on the laptop. This does create a SCSI interrupt conflict along the SCSI chain but this is easily dealt with by resetting the SCSI device between the write and read cycles.

IPST Surface Pattern Image Velocimetry System

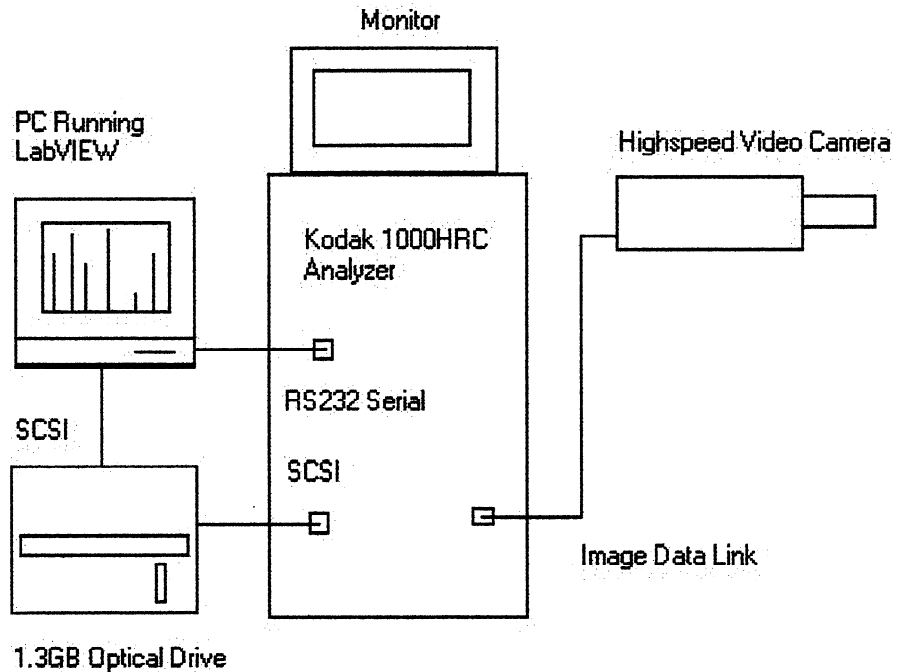


Figure 3 – Hardware Layout for SPIV System

3.2 Launching the Program

To launch the program the operator must double-click on the LabVIEW library icon IPST-SPIV and then select the VI 1-IPSTSPIV from the list. On launching, the VI will display a splash screen for approximately fifteen seconds identifying itself and then will display the already running front panel. Unlike most other LabVIEW VIs this one is designed to run continuously while processing input until LabVIEW is quit.

3.3 Front Panel Description

The program's front panel, shown in Figure 4, is divided into two major areas; the control cluster and the data display area. The control cluster consists of a number of numeric, Boolean and text string inputs which must be set by the operator.

The top switch (A) activates the data acquisition subroutine and downloads images from the analyzer. Switch (B) starts image processing. The Boolean control (C) toggles the mode between static and time series processing.

The search area control cluster (D) must be set to specify the bounding box and search area for the static analysis. In general, these should be left at the default value. If they are altered the base area size must always be a factor of 16. In (E) flow direction is set with a toggle switch to account for camera orientation and the threshold level for the filtering of bad data points is set in a numeric input box, again it is recommended that this be left at the default of 1 pixel.

In (F) a scale factor for the output may be entered. By default, all velocities are plotted in pixels per second but if the conversion between pixels and some physical length scale is known this value may be entered, along with the proper unit in the pull down menu, and all velocities and distances in the output data will be displayed in the correct units. The camera frame rate may be entered if it differs from the default of 1000 frames per second

The numeric entry box (G) allows the operator to choose the first of the pair of images to be compared in the static analysis. The text entry boxes in (H) allow a path for the acquired images to be set (either for the SCSI drive or images saved on the internal hard drive) as well as the operator's name and the path for saved data files.

The button (I) performs a calculation to give an estimate, in seconds, of the time required to download and process a time series of images based on the number of images and the inspection box size.

The right hand cluster (J) contains parameters for the time series analysis only. The top numeric control sets the number of frames to be processed and must be between two and the total number of frames stored in the analyzer. The next four controls specify the top left corner and the size of the inspection box. Each of these numeric inputs must be a power of 16 and may be selected from the pull down menus. It is recommended that a box be selected near the center of the image (such as 256, 128) and that the box should be 32 pixels on each edge. The box size strongly influences the speed of image processing.

In the data display area (K) a sample of the image series will be displayed. In the static analysis the average velocity in x and y will be displayed above it in the correct units. The SAVE DATA button will save the full vector field data for a static analysis to the harddrive. Areas (L), (M) and (N) are line plots as identified on the screen. The SAVE DATA button will save the data needed to recreate that plot to the hard drive.

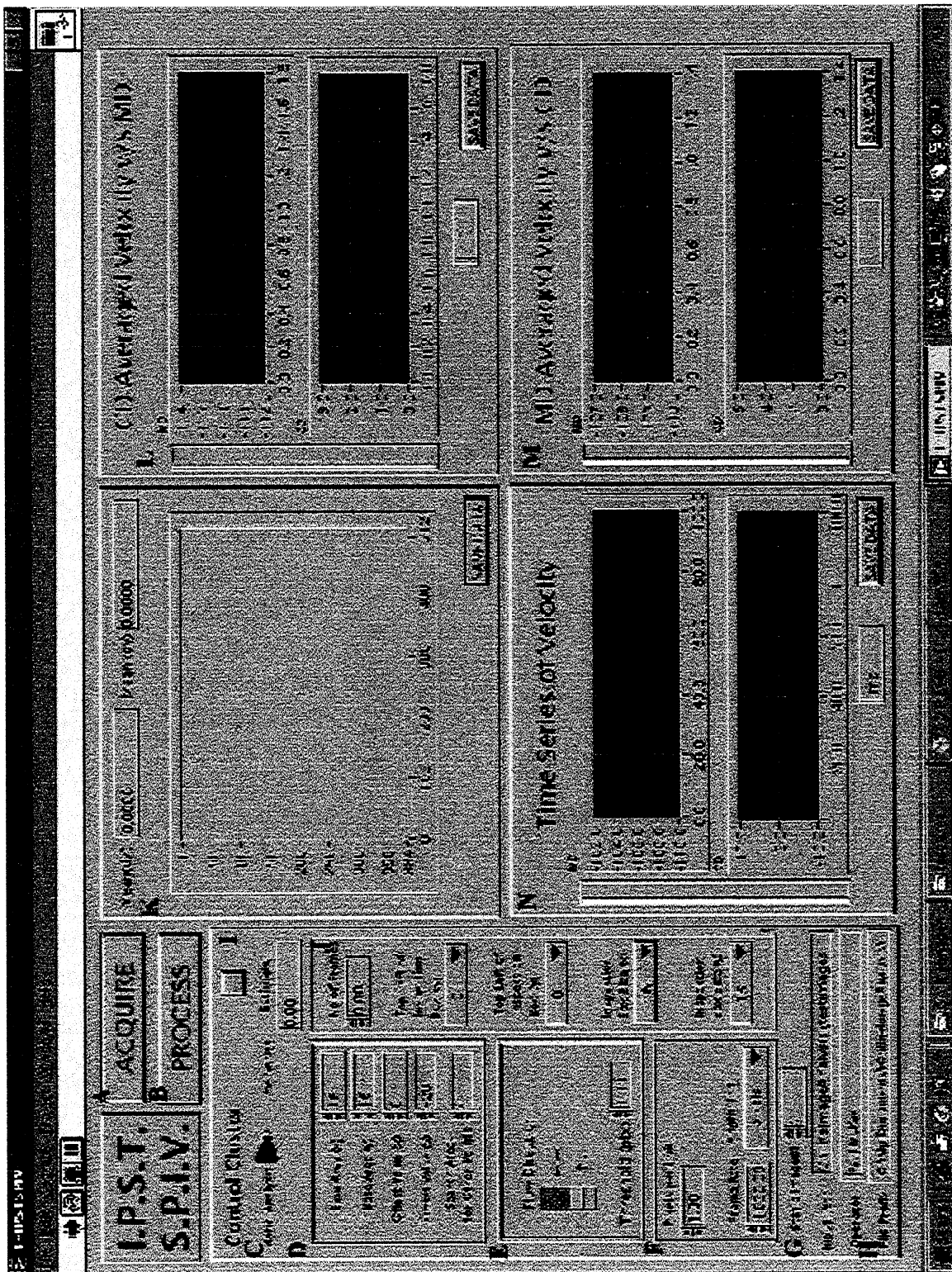


Figure 4 – SPIV Program Front Panel

3.4 Procedure for Static Analysis

To run a static analysis, that is a full vector field analysis of a pair of images representing a single time step, the upper toggle switch must first be set to the static setting. It is recommended that the bounding box parameters should be left at the default but they may be altered so long as they remain a factor of sixteen. Increasing the size will speed analysis but degrade the quality of the calculated results. The flow direction must be set to account for camera orientation. If the length scale is known it may be set otherwise all length data will be plotted in pixels. The frame rate must be set if it differs from the default of 1000 frames per second. The acquisition path defaults to the external optical drive at E:\. By default the program will analyze images 1 and 2 in the series but this may be changed in the image number field. The operator must be sure to hit the return key or click the enter check box after changing each value. Failure to do so will cause LabVIEW to read the field as if it still contained the previous value.

Once all controls are set the Acquire button must be clicked. This will send a series of signals to the analyzer through the serial link to go to and to download to the optical disk drive the images specified. Once this has been completed the system will beep. At this point the SCSI optical drive must be reset to refuse interrupts from the analyzer and accept them from the laptop. This is accomplished by power cycling the device. The system will beep again once enough time has passed for the drive to spin back up.

Following this the Analyze button must be clicked to begin image processing. On the IPST system this should take about 2.5 minutes. While the program is executing a

popup window will appear showing the image pair. If this window does not appear within a few seconds the button should be clicked again. Timing issues can occasionally keep the input from registering if it is clicked at exactly the wrong time.

Once the processing is over, three sets of data will be displayed. The first will be the first image of the pair along with the average velocity in x and y in the units selected. Pressing the SAVE DATA button will save the data necessary to plot the full vector field to a comma delimited (CSV) text file called FullVectorSeriesddmmhhmmss.dat where ddmmhhmmss is a time stamp in the format of day, month, hour, minute and second. In the two windows to the right will be line plots of the velocity averaged along lines of constant CD and plotted against MD and averaged along lines of constant MD and plotted against CD. The axes are arranged as per the axes of the displayed image. The SAVE DATA buttons beneath each pair of plots will save the data needed to reconstruct these plots in CSV text files under the names of CDAveragedddmmhhmmss.dat and MDAveragedddmmhhmmss.dat.

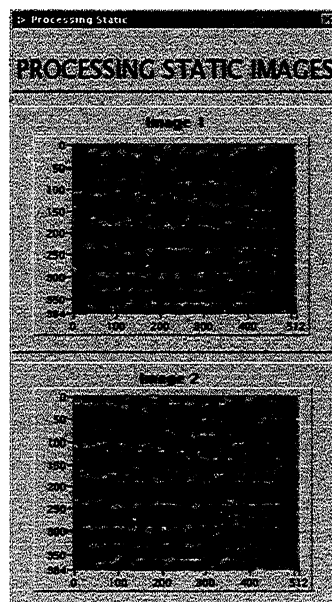


Figure 5 – Static Analysis Progress Window

3.5 Procedure for a Time Series Analysis

To run a time series analysis, that is an analysis of the velocity at the center of a small box across a large number of time steps, the upper toggle switch must first be set to the time series setting. As per static analysis flow direction must be set and unit data may be set. The static bounding box controls have no effect on this analysis. The number of frames to be processed must be set as must the location and size of the sub region to analyze. The calculated velocity will represent an average value within this region. Clicking the Estimate button will generate an estimate, in seconds, of the time required to download and analyze the time series as specified. If this estimate is longer than acceptable, either the number of images or the size of the analysis box must be reduced. Image acquisition is by far the slowest part of the process.

Once all controls are set the Acquire button must be clicked to begin image transfer. This will send a series of signals to the analyzer through the serial link to go to and to download the images selected. Once this is complete the system will beep. At this point the SCSI optical drive must be reset to refuse interrupts from the analyzer and accept them from the laptop. This is accomplished by power cycling the device. The system will beep again once the disk has had time to spin back up. The Analyze button must then be clicked to start the time series analysis. Processing time will vary depending upon the number of images selected and the size of the inspection box.

While the program is executing, a popup window will appear showing the successive images as they are processed as well as the number of the image currently being processed. If this window does not appear within a few seconds the button should

be clicked again. Timing issues can occasionally keep the input from registering if it is clicked at exactly the wrong time.

Once the processing is over, two sets of data will be displayed. The first will be a typical image from the series. No calculated average velocities will be displayed though they may still be visible from any previous static calculation and the SAVE DATA button will not be functional. If this button is pressed it will save to disk the data from the most recent static analysis. Below this will be a pair of line plots showing the variation in time of the average MD and CD velocities in the inspection box. The SAVE DATA button will save a CSV text file with all of the data needed to reproduce this plot under the name TimeSeriesddmmhmmss.dat.

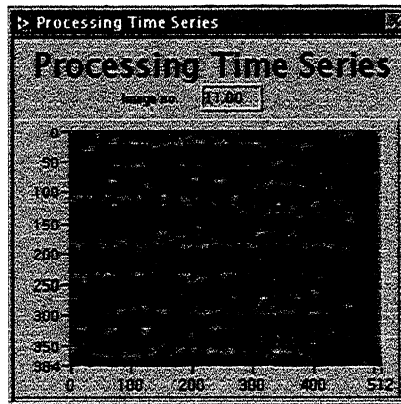


Figure 6 – Time Series Analysis Progress Window

3.6 Analysis of Previously Downloaded Images

The subroutines for acquiring and processing images have been purposely split to allow the operator to use the SPIV software to analyze images previously downloaded to

either the optical disk or the hard drive. The data path, which defaults to E:\, can be changed in the file path control on the VI front panel. By setting this to a directory on the hard drive and bypassing the acquisition step previously downloaded images may be analyzed from the hard drive without the system being connected to the analyzer. This is useful too in that image acquisition is by far the slowest step in time series processing for all but the largest bounding box. Operators may find it useful to set a large number of images to be processed and download them first and then choose to perform analysis on various sub sets of these images without going repeatedly through the acquisition phase. Note that the estimate of time required for the analysis, which includes download time, will be incorrect for this procedure.

Appendices

A1.0 Format of Saved Data Files

The program allows the operator to save the data needed to recreate any of the displayed plots as a set of comma delimited text files. The format for each of these files is shown below.

A1.1 Full Vector Field

The data required to plot the full vector field from the static analysis is saved in a text file named FullVectorFieldddmmhhmmss.dat where ddmmhhmmss is a time stamp of the format day, month, hour, minute, second. For example, if the file were saved at 3:55:17 pm on January 22 the file name would be FullVectorField2201155517.dat.

The format is as below:

date
time
Operator :
x, y, vx, vy

The header contains a date and time stamp as well as the operator's name. The data field contains the x and y location of the point of interest in pixels and the x and y velocity in pixels per second.

A1.2 CD or MD Averaged Velocity

The data required to plot the CD or MD averaged velocity versus MD or CD distance from the static analysis is saved in a text file named

CD(MD)Averagedddmmhhmmss.dat where dddmmhhmmss is a time stamp of the format day, month, hour, minute, second. For example, if the file were for CD averaged velocity and were saved at 3:55:17 pm on January 22 the file name would be CDAverage2201155517.dat.

The format is as below:

date
time
Operator :
Length Unit:
X, v1, v2

The header contains a date and time stamp as well as the operator's name and the length unit. The data field contains the MD location in the appropriate length unit as well as the averaged CD and MD velocities in the appropriate velocity units (length unit per second).

A1.3 Time Series Plot

The data required to plot the time series of velocity from the time series analysis is saved in a text file named TimeSeriesddmmhhmmss.dat where dddmmhhmmss is a time stamp of the format day, month, hour, minute, second. For example, if the file were saved at 3:55:17 pm on January 22 the file name would be TimeSeries2201155517.dat.

The format is as below:

date
time
Operator :
Length Unit:
t, v1, v1

The header contains a date and time stamp as well as the operator's name and the length unit. The data field contains the time in mili-seconds as well as MD and CD velocities in the appropriate velocity units (length unit per second).

A2.0 RS-232 Serial Emulation Issues

The Kodak Ektapro Model 1000HRC analyzer is controlled by the program through the serial port. The port must be initialized to 19,200 baud, no parity, eight data bits and one stop bit with standard XON/XOFF flow control. This is in contrast to Kodak's published port setup data and setting to 9600 baud as specified will not work.

While the Kodak claims that the Ektapro Model 1000HRC has an RS-232 compliant serial port it has been determined that the port does not fully comply with RS-232 standards. Using the utility Portmon by the Sysinternals Group a small deviation from the standard has been detected which is vital if there is any desire to process more than a single command. In a standard RS-232 compliant system the code AA would be transmitted as AA\r/ or as AA\r//. With the Kodak analyzer this will confuse the serial port and while it will accept that command it will refuse all subsequent input. For this system the command must be transmitted as AA\r without the final / or //. Additionally the port will refuse to process at all any commands sent in the format AA\n/ or AA\n// which are common RS-232 compliant methods to send the same command. Even modifying it as per the \r codes to be AA\n with no trailing / or // will not work. This is a minor issue but it is one which is not obvious and which must be borne in mind in reprogramming the serial codes.

Additionally the serial buffer of the analyzer is inadequate to contain the pending commands issued already by the program while the analyzer executes the previous command. This is only an issue during the download cycles so it is necessary to have the program pause for 2.5 seconds after issuing each download command in order to avoid overwhelming the analyzer and requiring it to be rebooted to clear the buffer.

A3.0 SCSI Issues

One area of the operation of the system which is inconvenient and which requires operator intervention is the resetting of the SCSI drive. Since the Kodak analyzer was never designed to be used in an online analysis system it is not provided with a fast and convenient way to transfer image data to another machine. Images may be transferred only while the analyzer is not acquiring new images and then only through a SCSI connection or the optional GPIB connector. Since GPIB is a slow data transfer standard more suited to transferring continuous signals with low bandwidth than discrete packets of high bandwidth data it has been decided to use the SCSI connection in this system.

SCSI, however, was never designed to allow peer to peer data transfer, rather it is a master to slave protocol. Because of this a SCSI buffer must be placed between the two master machines set to act as a slave device to each in turn. The HP optical drive fills this role. However since a SCSI slave device can only accept interrupts from one controller at a time this buffer must be reset between the write and the read sessions. This is accomplished by powercycling the device. This sends the analyzer into a SCSI Error3 state (media not present). The laptop can then issue its own SCSI interrupts and read data

from the drive. When this is through the analyzer can override its SCSI Error 3 state by issuing a SCSI interrupt and regaining control of the device.

