Laser Ultrasonic Web Stiffness Sensor

Final Report

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Project Objective

The objective is to provide a sensor that uses non-contact, laser ultrasonics to measure the stiffness of paper during the manufacturing process. This will allow the manufacturer to adjust the production process in real time, increase filler content, modify fiber refining and as result produce a quality product using less energy. The tasks include optimization of ultrasound generation on moving paper, construction of a prototype for use on the paper machine, installation of the prototype sensor (LUSS Laser Ultrasonic Stiffness Sensor) and demonstration of the sensor's ability to save energy and increase productivity. The sensor operates by moving back and forth across the paper web, at pre-selected locations firing a laser at the sheet, measuring the out-of-plane velocity of the sheet then using that measurement to calculate sheet stiffness.

Background

Laser ultrasonic methods have the potential to greatly extend the utility of on-line ultrasonic telemetry. Existing on-line ultrasonic techniques using contact transducers function only on board grades. Laser ultrasonic methods could perform at higher speeds without causing damage to lightweight papers. Laser ultrasonic methods are able to determine the bending stiffness of the paper. Bending stiffness is a property that is currently measured off-line on paper that determines end-product rigidity and is of great importance in a wide variety of paper grades. Laser ultrasonics could also provide single-sensor in-plane and out-of-plane characterization and give the first on-line gauge of stiffness orientation.

The current project combined efforts of four organizations; two with complementary experiences in paper physics and laser ultrasonics, Boise Paper which provided the paper machine for the trial of the prototype sensor and ABB which assisted with the integration of the into the paper machine control system. IPST at GeorgiaTech contributed paper physics expertise and close relations with the paper industry as well as laser expertise. Lawerence Berkeley National Laboratory (LNBL) is expert in the art of laser acoustic wave generation. They have also demonstrated laser ultrasonic capabilities by constructing unique laboratory ultrasonic systems for use on paper. Boise Paper made available the #4 Paper Machine at the St Helens, OR mill. ABB provided web stabilization technology, sensor design advice, software and assistance with installation of the LUSS.

This project was intended as a continuation of previous work in which an earlier prototype had been tested on a Boise Paper machine in Jackson, AL. The intent of the project reported on here was to (1) demonstrate unattended operation and (2) document energy savings produced by process optimizations made possible by the sensor.

Funding

This project was originally funded through the Department of Energy (DE-FC07-97ID13578). The DOE project was continued in a no cost extension status through Jun3 30, 2008. In 2006 additional funding was obtained form the Northwest Energy Efficiency Alliance. The NEEA funding was directed specifically at the installation and demonstration of the prototype sensor on the Boise paper machine. The original funding from NEEA was provided to both LBNL and

Georgia Tech-IPST. Some additional funding was provided to Georgia Tech-IPST to complete the project.

Jackson AL, vs St Helens, OR Trial

An earlier trial of a laser ultrasonincs stiffness sensor was run on the Boise Paper mill in Jackson, AL. This trial showed reasonable results, with on line measurements corresponding to laboratory measurements of samples taken from the paper machine.

The Jackson trial and the St Helens trial were run under different operational requirements. In the Jackson study, the system was always run while being actively monitored by either IPST or LBNL personnel. In the St Helens trial, it was a requirement of the trial that the system run without on-site or real time monitoring. Due to this requirement, most of the hardware used in the Jackson study had to be replaced with more robust hardware. In addition, the operational requirement also necessitated that most of the software be rewritten. The only software retained was that used to convert the measured sheet response into a stiffness measurement. As a result of these changes the data signals were obtained at a slower rate than in Jackson. The actual data signals obtained were of good quality.

Preparation for St Helens Trial

1. The Sensor used in the St Helens trial used robust industrial quality actuators and guide rail for moving the sensor back and forth across the web. Integration of these hardware pieces into the sensor enclosure required a redesign of both the exterior and interior of the enclosure. The new hardware also required new industrial quality electrical interfaces and a new computer interface.

The equipment was then sent to the Boise Paper mill in St Helens, OR. For unattended operation the entire system needed to integrated into the paper machine control system in a manner which would provide for Fail-Safe operation of the system as well as operation in manner that would not interfere with normal machine operations. Achieving this goal required that the sensor system also interface with the existing ABB scanner system (used for basis weight, caliper and moisture measurements). The entire LUSS system incorporated a number of parts

2. Sensor package with generation laser fiber optics, with associated actuators, and interferometer
3. Generation laser and laser launch (not contained in the sensor package due to space and power limitations)
4. Guide rail for moving the sensor package, with a dedicated controller
5. Data acquisition and control hardware
6. Dedicated LUSS Computer
7. Data acquisition and control software
8. ABB software and electrical interfaces
9. Paper machine control system and electrical interfaces
10. Dedicated safety systems

An operating manual for the system is provided in Appendix A of this document.

A number of problems occurred during the integration and preliminary testing of the system. These problems were primarily the result of difficulties integrating communications between the various elements of the systems. The DOE Quarterly reports provide a concise summary of the problems encountered and the actions taken to correct the problems. The status sections of all the DOE Quarterly reports are provided in Appendix B

Boise #4 Test Results

Test Summary

The LUSS was run on the #4 PM for about two weeks in January 2008. During this time, when running, the LUSS calculated sheet stiffness in real time at the center of the sheet (ABB position 250) and near the tending side of the sheet (ABB position 500). This data was recorded on the LUSS computer. Also recorded on the LUSS computer were the raw data used to calculate the sheet stiffness. Samples were collected from rolls made while the LUSS was running. These samples were sent to IPST and the stiffness was measured in the laboratory using a L&W Bending Resistance tester and TAPPI method T556. There were eleven cases in which the samples could be correlated with LUSS data. Data could not be correlated with all cases because some of the sample were either not labeled or were incompletely labeled.

The LUSS system uses a calibration file to calculate the bending stiffness. The file is used in the calculation of sheet stiffness based on the velocity of the sheet out of plane vibrations. This calibration file should be optimized for the particular grade being measured if accurate bending stiffness values are to be obtained. During the time period when the LUSS was run on the #4 PM calibration files were used that were based on previous testing, but were not necessarily optimized for the grade being run. However, since the raw data was saved, post processing of the data could be performed using an optimized or verified calibration file.

Data Analysis Method

For the eleven cases in which physical samples could be correlated with LUSS data, there were potentially three different sets of data to be analyzed. The first set was obtained from the laboratory testing of the physical samples. The second set was data obtained by post processing the raw data with either the original calibration file or a new verified calibration file. The third and final set of data was the bending stiffnesses calculated in real time by the LUSS. Recovering real time data is extremely time consuming, therefore only a selected subset of the eleven cases were examined.

For all three sets of data, the average bending stiffness and standard deviation of the bending stiffness were calculated for ABB locations 250 and 500. The data was statistically evaluated to determine if there was a difference between the stiffnesses at the two locations. This effectively provides an indication of the resolution of the particular measurement technique.

The laboratory measurements show a low standard deviation and a statistically significant difference between the stiffness at the two locations in all eleven case when considering CD stiffness and a statistically significant difference for seven of the eleven cases when considering MD stiffness. Overall, the CD measurements showed a larger magnitude difference between the two locations than did the MD measurements. The stiffness values obtained by post processing the LUSS data showed a different trend, the CD values showed a lower magnitude difference between the two locations and in several cases the difference was in the opposite direction as compared to the laboratory measurements, e.g. there were several cases in which the laboratory measurements showed a higher stiffness value at the 250 location as compared to the 500 location, but the values from the post processed data showed the opposite – a higher value for the 500 location as compared to the 250 location. In addition, post processed data had more cases in which the differences were not statistically significant. The real time LUSS measurements showed the least correspondence to the laboratory data and in general did not correlate with the post processed data.

Discussion of Results

Testing Procedures

During the on-line testing of the LUSS, the system was programmed to first go to the center of the sheet (ABB location 250) and measure the CD and MD stiffness. This required that the system fire the laser 16 times with the interferometer measurement point located 5 mm from the laser impact point (near point). For a CD measurement the separation was in the CD direction and for an MD measurement the separation was in the MD direction. The laser was then moved so that the laser impact point and interferometer measurement point were separated by 10 mm (far point) and the laser was fired 16 more times. The interferometer signals for each set of firings were then averaged to create a near and far pair. This pair of signals was then used to calculate the stiffness value. Prior testing at the mill had shown that 16 signals was the minimum number of signals required for consistent results.

After collected data for CD and MD stiffness, the LUSS was moved to the tending side of the machine (ABB location 500) and the process was repeated. The LUSS moved back and forth between the two locations for about 2 hours. The exact time varied, as occasionally not all the laser firings would result in a valid interferometer signal, i.e., the magnitude was too low. In the case of invalid signals, the process was continued until a full set of signals were obtained. During each LUSS run approximately 80 separate stiffness measurements were made, 40 MD and 40 CD measurements.

The LUSS stopped producing valid signals after about a week and a half. The software appeared to be operating correctly and all of the systems used to position the LUSS and the laser appeared to be operating correctly. The laser was set at the correct power setting as well. The conclusion is that the laser signal did not pass through the fiber optic cable. The laser produces a laser pulse which is passed through a lens that focuses the laser on the tip of the fiber optic cable. If the laser power is too high or if it is not exactly focused on the center of the fiber optic, the fiber optic cable can be melted. It is assumed that this is what happened. Laser power can be reduced but this will reduce the signal quality requiring an increased number of signal pairs to be averaged in order to make reliable measurements. The ultimate resolution is a redesign of the laser launch to provide a more robust setup and longer lifetime, or computer hardware and software modifications to increase the data acquisition rate from ~1 Hz to at least ~5 Hz, which will allow averaging of more samples and a lower laser pulse energy to be used.

Full width CD strips were cut from one of the rolls made each time the LUSS was run. The strips were cut three layers deep. These strips were then sent to IPST. Not all of the strips were labeled with dates and times. There were eleven strips which could be correlated with LUSS runs in which 'good' data was produced by the LUSS. Therefore, there are eleven CD and eleven MD potential comparisons between laboratory data and LUSS data. Each of the CD strips was laid out and two CD and two MD samples were cut from ABB locations 250 and 500 in each layer. The result is that there were six CD and six MD samples at each location. These samples were then tested using an L&W Bending Resistance tester and TAPPI method 556. For each sample type the device was set up so that the sample was bent 15^o. The testing method produces a bending stiffness value in standard bending stiffness units. Other methods do not produce a similar measurement and must be converted to standard bending stiffness. Each sample was tested twice; the samples were rotated 180^o between measurements. The testing method was verified by testing stainless steel and bronze shim stock; in these cases the test data can be compared with theoretical values. As a result there were 12 stiffness measurements for both the CD and MD directions at both locations.

All of the data from the LUSS was downloaded from the LUSS using a remote connection to the computer. There are two methods by which the data can be reviewed. In the first method, the raw data is run through a separate program and the stiffness for each near and far signal pair is calculated. This program (called pce file viewer) allows different calibration files to be used and is typically employed to develop an optimized or verified calibration file. During the LUSS runs there were several calibrations files used, these files were created based on previous testing of similar grades. Grade codes had been incorporated into the information supplied to the LUSS computer so that when possible an appropriate calibration file could be used. The pce file viewer was used both with the calibration file employed by the LUSS during the actual on line measurements and was used to create a new optimized calibration file or to verify that the original file was an optimized file. There were 6 CD cases and 8 MD cases in which either a new, verified calibration file was created that resulted in a reasonable correspondence with the laboratory date or the original calibration file provided a reasonable correlation. In the remaining cases, the original calibration file did not provide an adequate correlation with the laboratory data. New calibration files were not developed because of the time required and because the other files were sufficient for comparison with the laboratory data.

It was also possible to view the results of the stiffness calculations made by the LUSS computer during the LUSS runs. The program on the LUSS computer is similar to the pce file viewer program and given identical data and the same calibration file should produce the same stiffness values. Viewing the real time LUSS data is time consuming because the data for each individual near and far pair must be viewed separately. This data was reviewed for 6 CD cases and 4 MD cases. It was found that the LUSS real time data did not correspond with the pce file viewer data. The pce file viewer data did correspond, in general with the laboratory data, which indicates there is a problem with the LUSS software.

Data Analysis

Each set of MD and CD measurements were subjected to a similar analysis. First the average and standard deviation of the measurements at each location (ABB 250 and 500) were calculated. Since an objective of this work is to determine the possible utility of the LUSS measurement, i.e., can it be used to measure relatively small differences in stiffness, the difference between individual ABB 250 and ABB 500 measurements was then calculated in order to treat the data as a paired comparison. The average, standard deviation and standard error of these differences were then found. The data was then subjected to a single tailed Student T Test in which it was assumed that the true difference in stiffness between the two locations was zero. The result is a significance test for that assumption – how likely is it that the measured difference would occur due to random variations if the true difference were zero. If the level of significance is low, then it shows that there is a low likelihood that the measured difference would have occurred by chance. If the level of significance is high, then there is a high likelihood that there is no statistically significant difference between the measurements at the two locations. One can then examine the results and possibly determine how small a difference between the measurement locations can be and still represent a statistically significant difference.

Data

A summary of the data for all cases is given in the Appendix C to this report. Also, provided in the appendix are bar graphs of the stiffness data for each of the eleven cases. Each bar graph contains the data for MD and CD measurements for all three measurement methods (laboratory, pce file viewer and LUSS real time) at both the ABB 250 and 500 locations. Error bars are given which are equivalent to one standard deviation.

Table 1 provides a summary of the data for cases in which the pce file viewer data showed an apparent correspondence to the laboratory measurements. The upper half of the table shows the CD cases (6 cases) and the lower half shows the MD cases (8 cases). In some of these cases there is an offset between the laboratory and pce file viewer data, however the results were considered so as to gain a better understanding of the variation produced by each method. The LUSS real-time results are included for comparison. The information included for each measurement techniques includes

1. The average measurement at the ABB 250 location (ABB 250 stiff)
2. The standard error for the stiffness measurement at the ABB 250 location (ABB 250 std error). Minimum, maximum and average over all the cases are provided at the bottom of the column.
3. The results of the single sided Student T significance test for the assumption of zero difference between the stiffness measurements at the ABB 250 and ABB 500 locations (T Signific.) A low percent indicates a low likelihood that the measured difference was due to random variations.
4. The average difference between the stiffness measurements at the ABB 250 and ABB 500 locations (avg diff). Minimum, maximum and averages are over the cases in which the difference was considered significant are provided at the bottom of the column.
5. The ratio of the average difference in stiffness measurements to the average ABB 250 stiffness measurement (avg diff/avg 250). This is given as a percentage. Minimum, maximum and averages are over the cases in which the difference was considered significant are provided at the bottom of the column.
6. An indication of whether or not the difference in stiffness between the two locations is considered significant (Sig Diff) indicated by Yes (Y) or No (N)
7. An indication of whether the ABB 250 location measurement was larger than the ABB 500 location measurement (250 – 500 > 0) indicated by Yes (Y) or No (N). This is left

blank if the difference between the two measurements was considered to not be significant.

In the table, cases where the difference between the ABB 250 and ABB 500 location measurements were considered to not be significant are shaded light blue. Cases in which the ABB location 250 measurement was less than the ABB 500 location measurement are indicated with blue font.

Several aspects of the table are worth noting.

1. The standard errors for the laboratory measurements are slight greater than one half of the standard error for the pce file viewer in the CD cases and less than one half of the standard error for the pce file viewer in the MD cases. The laboratory measurements are the average of 12 data points. The other two measurements are the average of 30 to 47 data points depending on the case. Case 9 is an exception, only 15 data points were available. This indicates that there is more variability in the measurements obtained from the LUSS data than in the laboratory measurements.
2. The measurements do not follow the same trends when comparing the laboratory measurements to the pce file viewer measurements
    a. For the laboratory measurements, the MD measurements have a smaller 'avg diff' than the CD measurements. The opposite is true for the pce file viewer measurements. This is also demonstrated in the 'avg diff/avg 250' values and in the overall average of the 'avg diff' values.
    b. For the laboratory measurements, the MD measurements show a greater number of cases where the difference between the ABB 250 and ABB 500 measurements was considered to not be significant. The opposite is true for the pce file viewer measurements.
    c. There are two cases (CD case 4 and MD case 12) where the laboratory measurements and the pce file viewer measurements show opposite trends with regard to whether the ABB 250 location measurements is larger than the ABB 500 location measurement.
    d. There are two CD cases (case 3, 13) where the laboratory measurement indicates that the difference between the ABB 250 and ABB 500 location measurement is considered to be significant but is not significant in the pce file viewer case.
    e. There are four MD cases (case 1, 2, 4, 7) where the pce file viewer measurement indicates that the difference between the ABB 250 and ABB 500 location measurement is considered to be significant but is not significant in the laboratory case.
3. The LUSS Real Time measurements were all made using the original calibration file. There is little correspondence between the LUSS Real Time measurements and the pce file viewer measurements.

The data indicate that the current calibration files used with the current configuration of the LUSS can produce bending stiffness measurements, but these measurements have more variability and are less accurate than the laboratory measurements. Variations in bending stiffness across the width of the web cannot be reliably identified with the current set up. The signal quality produced by the current set up was good, therefore the most probable way to decrease variability and increase accuracy is to average a greater number of signal pairs for each measurement. This will require more time or changing the computer hardware/software to allow for a higher data rate.

The reason for the lack of correspondence between the pce file viewer data and the LUSS Real time data is assumed to be a software problem. Given the same signal pairs and the same calibration file, both methods should produce the same bending stiffness values. While the LUSS user interface was written specifically for the Boise St. Helens installation, the portion of the software on the LUSS computer that performs the required calculations was written prior to this portion of the project and the programmer is not longer employed by IPST/Ga Tech. Unfortunately, the code is not well documented.

Conclusions

The LUSS has the following current issues

1. The laser launch needs to be repaired, long term durability requires a redesign or the use of lower laser power settings and a higher data acquisition rate.
2. The LUSS system can produce consistent bending stiffness measurements when using the post processed data.
3. The variability of the measurements produced by the LUSS system is greater than in the laboratory measurements. The variability is large enough that distinguishing changes in stiffness across the CD width of the web is questionable.
4. Obtaining higher quality measurements which can be used to reliably distinguish variations in bending stiffness across the width of the web will require a higher data acquisition rate which can reasonably only be attained by updating the computer hardware and software.
5. Due to a software problem, the stiffness values produced in real time by the LUSS are not correct. The time required to identify and fix the problem is unknown

Installation of the LUSS system took considerably more resources than were anticipated. Since the installation a considerable amount of time has been spent on obtaining and analyzing the data presented in this report and on attempting to diagnose some of the problems identified. In reaching this point in the project the monies from DOE and NEEA have been exhausted. In addition I have expended some discretionary money to which I have access.

Resolving the above issues will require at least another six months and several trips to Boise St. Helens. There is currently no funding for such an effort. The current available funding will allow for dismantling of the system and a return of the laser equipment to LBNL. If funding were to become available it is unlikely that the personnel who worked on the project over the past year (Paul Ridgway and David Huggins) will be available to devote the required effort. Alternative personnel would have to be found.

Table 1 Cases with Verified Calibration Files

			Laboratory Measurement							Post Process - pce file viewer								LUSS Real Time						
	Grade	Case	ABB 250 Stiff	ABB 250 std error	T Signific.	avg diff	avg dif/avg 250	Sig Diff	250 - 500 >0	Calibration File	ABB 250 Stiff	ABB 250 std error	T Signific.	avg diff	avg dif/avg 250	Sig Diff	250 - 500 >0	ABB 250 Stiff	ABB 250 std error	T Signific.	avg diff	avg dif/avg 250	Sig Diff	250 - 500 >0
	34.5# FB	2	0.099	0.0020	0.108%	0.017	16.9%	Y	Y	Verified - new	0.071	0.0023	7.543%	0.004	5.1%	Y	Y	0.087	0.0026	49.119%	0.000	-0.2%	N	
	34.6# FB 92	3	0.101	0.0025	0.002%	0.025	24.5%	Y	Y	Verified - new	0.067	0.0023	35.068%	0.001	1.5%	N		0.082	0.0037	16.159%	-0.009	-11.3%	N	
CD	34.5# FB	4	0.095	0.0023	0.141%	0.010	10.5%	Y	Y	Verified - new	0.070	0.0018	1.017%	-0.005	-7.2%	Y	Y	0.080	0.0029	3.695%	-0.012	-15.6%	Y	N
	34.6# FB92	5	0.095	0.0024	0.749%	0.014	14.3%	Y	Y	Verified - new	0.071	0.0027	6.365%	0.006	9.2%	Y	Y	0.098	0.0085	30.818%	-0.004	-4.2%	N	
	44.9 Poly Base	13	0.201	0.0049	0.012%	-0.033	-16.2%	Y	N	Verified - org	0.315	0.0155	21.780%	0.018	5.7%	N								
	45.5# SOW2	9	0.250	0.0043	0.000%	0.054	21.7%	Y	Y	Verified - orig	0.242	0.0058	4.681%	-0.015	-6.1%	Y	N	0.243	0.0061	13.417%	0.024	10.0%	N	
	min			*0.0020*		*0.010*	*10.5%*					*0.0018*		*0.001*	*5.1%*				*0.0026*					
	max			*0.0049*		*0.054*	*24.5%*					*0.0155*		*0.018*	*9.2%*				*0.0085*					
	Average			*0.0031*		*0.025*	*17.4%*					*0.0051*		*0.007*	*6.9%*				*0.0047*		*-0.012*	*-15.6%*		
	34.5# FB	1	0.232	0.0044	46.783%	0.000	0.2%	N		Verified - orig	0.304	0.0099	0.002%	0.054	17.7%	Y	Y							
	34.5# FB	2	0.231	0.0043	23.286%	0.005	2.2%	N		Verified - orig	0.279	0.0095	0.538%	0.037	13.4%	Y	Y	0.094	0.0058	4.263%	-0.021	-22.1%	Y	N
	34.6# FB 92	3	0.243	0.0055	0.890%	0.018	7.6%	Y	Y	Verified - orig	0.285	0.0137	0.139%	0.050	17.6%	Y	Y	0.103	0.0078	2.107%	-0.032	-30.9%	Y	N
MD	34.5# FB	4	0.237	0.0044	16.695%	0.007	3.0%	N		Verified - orig	0.288	0.0088	0.050%	0.041	14.4%	Y	Y							
	34.6# FB92	5	0.235	0.0041	2.400%	0.015	6.3%	Y	Y	Verified - orig	0.285	0.0067	0.184%	0.036	12.7%	Y	Y							
	34.5# FB	7	0.237	0.0031	10.630%	0.006	2.4%	N		Verified - orig	0.314	0.0113	0.004%	0.074	23.7%	Y	Y							
	34# FB 92	8	0.233	0.0037	6.071%	0.011	4.8%	Y	Y	Verified - orig	0.335	0.0114	0.529%	0.042	12.7%	Y	Y							
	45.5# SOW2	9	0.596	0.0075	0.096%	0.030	5.1%	Y	Y	Verified - new	0.454	0.0314	16.025%	-0.050	-11.0%	N		0.251	0.0187	21.001%	0.022	8.8%	N	
	min			*0.0031*		*0.011*	*4.8%*					*0.0067*		*0.036*	*11.0%*				*0.0078*		*0.021*	*22.1%*		
	max			*0.0075*		*0.030*	*7.6%*					*0.0314*		*0.074*	*23.7%*				*0.0187*		*0.032*	*30.9%*		
	Average			*0.0047*		*0.019*	*5.9%*					*0.0139*		*0.048*	*16.0%*				*0.0132*		*0.026*	*26.5%*		

Appendix A – Laser Ultrasonic Stiffness Sensor Manual

System Overview
The Laser Ultrasonic Stiffness Sensor (LUSS) is a non-contact system that measures MD and CD sheet bending stiffness. The measurement is made by firing a generation laser at the sheet. This causes an out of plane vibration in the sheet. The speed of the vibration is measured using a detection laser (interferometer). The sheet stiffness is found by firing the generation laser from two different points (near and far) relative to the detection laser. The speed measurements made by the detection laser for the two cases are then compared and the stiffness calculated based on how the two measurements differ.

The LUSS is normally controlled an ABB control panel display. The ABB system is used to tell the LUSS at whether it should take data at a single point or in scanning mode and whether to take measurements for MD or CD stiffness. The ABB system provides the LUSS with basis weight, ash content, caliper (correlated with the LUSS CD position) and a grade code. This information is used in the calculation of stiffness. LUSS sends to the ABB system the calculated stiffness and CD position for which the stiffness was calculated.

The LUSS has two modes of control (1) Local (2) Remote. In “Local” mode the system is run from the LUSS computer and cannot be controlled from the ABB system panel. This mode is used for set-up and trouble shooting. In “Remote” mode the system can be commanded from the ABB system panel. In this mode the operator can command ‘single point’ or ‘scanning’ operation. In Single Point mode a CD position is selected, the sensor package moves to that position and collects data continuously without further CD movement. In Scanning operation the sensor package moves back and forth across the web. It pauses approximately every six inches and collects stiffness data, then moves to the next location. In either Single Point of Scanning mode the operator can specify that either MD or CD stiffness data be taken.

The LUSS system only operates when the ABB sensor head is on sheet. This is because a valid basis weight is required to calculate accurately stiffness. The system will go off sheet during a sheet break or if the ABB system stops operating. The ABB system will command the LUSS to go off sheet if the LUSS computer stops operating. The LUSS will also be commanded to go off sheet if the On Sheet/Off Sheet on the outside of the control cabinet is moved to the Off Sheet Position.

System Components
The Laser Ultrasonic Stiffness Sensor (LUSS) system consists of:

1. ABB System Interface
    a. Modified 1190 Process Display Menu with button for LUSS Process Overview panel
    b. LUSS Process Overview panel – used to command the LUSS
    c. LUSS S800 I/O interface panel – Trouble shooting panel, no controls or user I/O
    d. LUSS Stiffness data panel – Display panel, historical trends
2. A guide rail and guide rail carriage for moving the Sensor Package back and forth across the web
3. A Sensor Package mounted on the guide rail carriage which contains
    a. Generation laser to create an out of plane vibration in the paper
    b. MD and CD linear motion stages to move the generation laser

c. Detection laser (interferometer) to measure the sheet vibration
d. A small DC motor, with a mirror on the end of the shaft, for tracking a single point on the sheet – it reflects the detection laser light
e. Vortex cooler for keeping the enclosure cool
f. Thermocouple for measuring the sensor package interior temperature and controlling the vortex cooler
g. Air cooled IR sensor for measuring the sheet temperature
h. Pneumatic Bernoulli plate for stabilizing the sheet beneath the generation laser

4. Instrument cabinet which contains
    a. LUSS computer for controlling the lasers, collecting data and communicating with the ABB system
    b. Generation laser power supply, controller, fiber optics
    c. Detection laser combined power supply and controller
    d. Signal conditioner for Interferometer output
    e. Data acquisition boards and relays
    f. Guide rail controller
    g. Manual flow control for air supply to the sensor package

LUSS Operation
Initial startup of the LUSS from a powered off configuration is performed at the LUSS Instrument Cabinet. This cabinet is located on the drive side of the machine and is in-line with the framework supporting the sheet marker and the sensor package guide rail. In general, the system is left in a powered up configuration. If the system is powered down the following procedure is used to power up the system.

Startup
1. Turn On-Sheet/Off-Sheet switch, located on the exterior of the instrument cabinet door, cabinet to "On-Sheet" position. The switch is shown in *Figure 1*. Note-the only active switches/lights on the exterior of the door are those labeled in the figure.
2. ~~In less than 40 seconds, the sensor will move on-sheet and stop.~~
3. Pull red power button, shown in *Figure 1*.
4. Open the instrument cabinet door using a screw driver, the laser control panel is mounted on the inside of the door.
5. On the laser control unit, shown in *Figure 2*:
    a. Turn the control knob to "start"
    b. Press and hold "start" button for at least 3 seconds
    c. Check that the "laser on" light is lit
    d. Turn control knob to "remote".
    e. The trigger knob is not active when Remote is selected
    f. Move the power level switch to "High"
6. Close cabinet door
7. Initiate control of the system using the ABB system control panel in the dry end control.

If the system is not to be used for an extended period of time, several days, it can be shut down. This will remove power from all systems within in the sensor package, from the guide rail and from the components inside the Instrument Cabinet. The following procedure is used.

Shutdown

1. Turn On-Sheet/Off-Sheet switch, located on the exterior of the instrument cabinet door, to the "Off-Sheet" position.
2. Wait (about 30 seconds) until sensor has moved off-sheet into sensor enclosure.
3. Open the cabinet door, press "stop" button on laser control unit.
4. Close the cabinet door.
5. Press the red power button, located on the exterior of the instrument cabinet door.

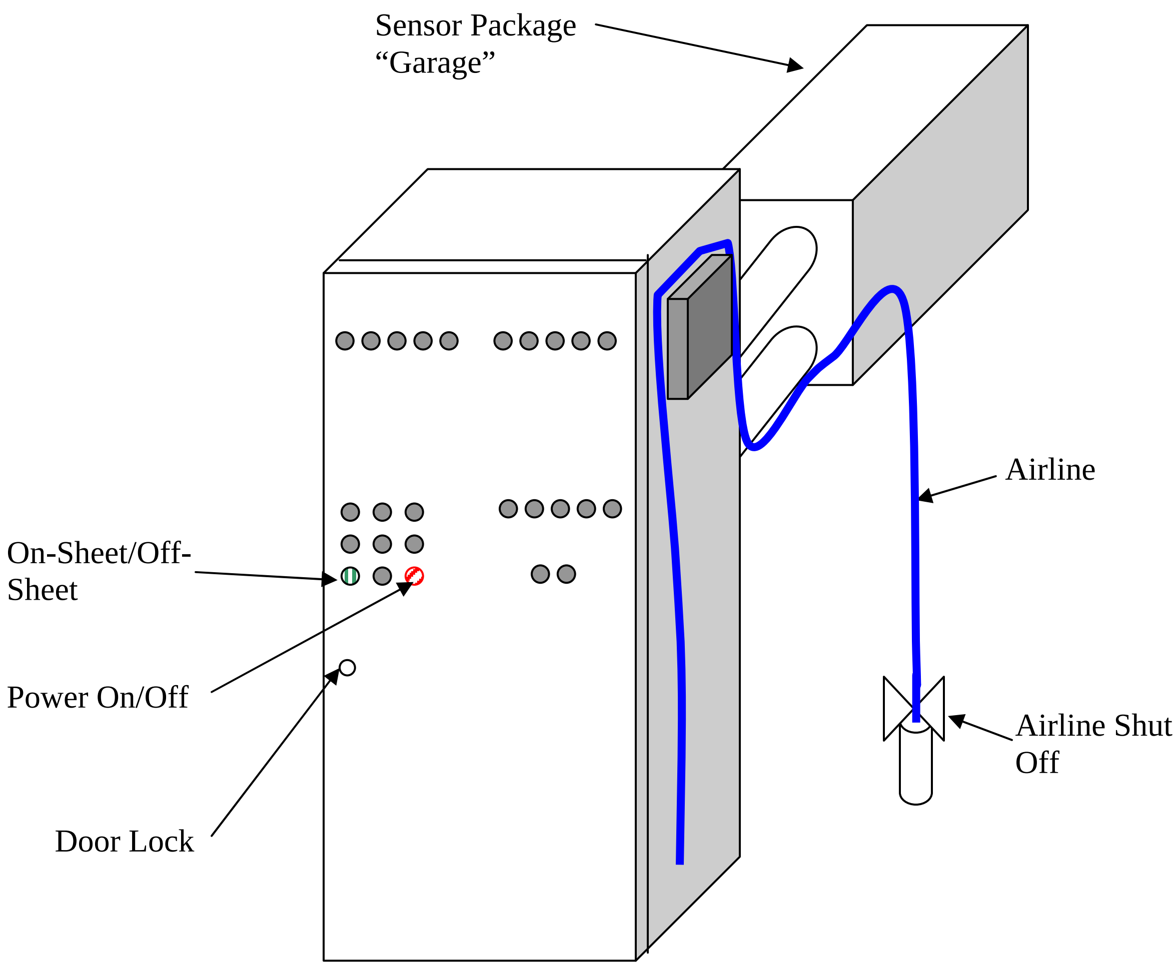

Figure 1. Exterior Instrument Cabinet

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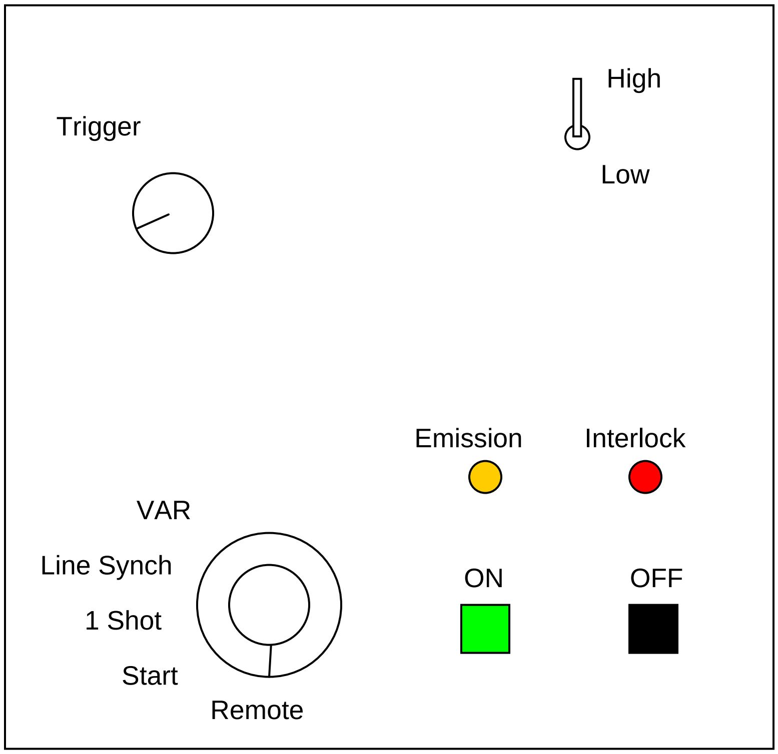


Figure 2. Schematic of laser control panel

LUSS Safety Hazards

The primary safety hazard with the LUSS is the beam emitted from the generation laser. This is a Class IV laser operating at 1064 nm.

There is a hole in the bottom of the sensor package that is approximately 1 inch in diameter. The laser beam is fired through this hole. While the sensor package is on sheet this hole is covered by the sheet. If the sheet breaks or when the sensor package is off sheet the hole is not covered allowing the laser beam exit the sensor package. The generation laser beam is invisible but may damage the eye if viewed directly from less than 6 feet away. When the sensor package has fully moved off sheet a shutter in the control cabinet will block the laser beam and stop it from reaching the sensor package. (The beam is transmitted by a fiber optic cable from the instrument cabinet to the sensor package.)

The red light on top of the sensor indicates when the excitation laser is firing. Do not approach the sensor when this light is illuminated. There are warning labels on the outside of the sensor package which indicate the type of laser and where the beam is emitted.

The detection laser beam which exits the same hole is visible (red) and is low power, safe to be viewed at any distance, with the same caution as appropriate for a laser pointer.

ABB Panel/Operator Control of LUSS Operation

The control and display panels associated with the LUSS are accessed through the ABB 1190 Process Display Menu. The 1190 Menu can be selected from any display via the Menu button just below the cyan diamond at the top of the screen. This area, fixed display, is made available on each display in the system.

On the 1190 Process Display Menu the button for the LUSS Process Overview is the bottom button in the 4th column, as shown in *Figure 3*. (Note - The buttons text appears normal on the actual Operators Stations display). This will be the normal place for an Operator to select the LUSS Process Overview.

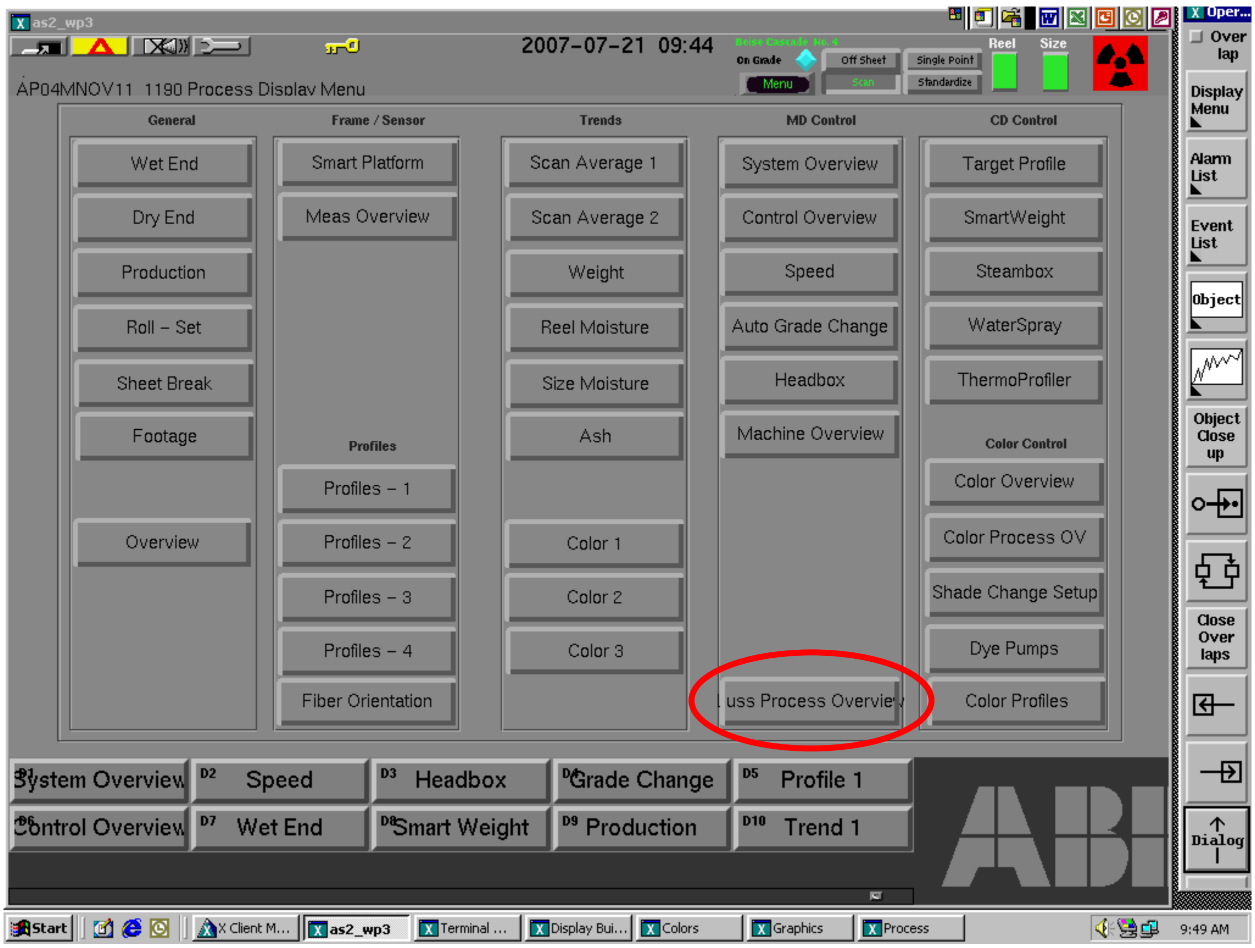


Figure 3. 1190 Process Display Menu

The display used to control the LUSS is shown in *Figure 4*. This is the panel used to select operating mode (Single Point or Scanning), to select MD or CD stiffness measurement, to tell the LUSS to go off sheet as well as to access a troubleshooting panel and a data display panel. This panel allows control of the LUSS when it is in “Remote”, if the LUSS is in “Local” mode the panel is inactive. In “Local” mode the LUSS is controlled through the instrument cabinet located on the drive side of the machine.

The 10 D-keys across the bottom of the screen are display links to other related displays. In this case D-keys 5 and 10 have been added. On the panel there is a column labeled **REQUESTS,** below it a re the three possible requests. Next to each is a blue diamond. A filled diamond indicates 'ON' and Empty diamond indicates 'OFF'. Next to the **REQUESTS** column is a column labeled **LUSS STATUS**. A square is to the right of each status indicator; a filled square indicates 'On' and an empty square indicates 'Off'. The functions and operation of the panel are as follows:

1. If LUSS is in Local mode, the Requests (cyan diamonds) will not be functional:
    - 'Put LUSS on Sheet' will be OFF and locked. (Prevented from operating as in 'locked out')
    - 'Put LUSS in Single Point' will be OFF and locked.
    - 'Put LUSS in CD Mode' will be OFF and locked.

2. If LUSS is in Remote mode, the Request diamonds will be functional. When selected ON, the request has 6 sec for a LUSS signal to be received to keep it ON, otherwise it goes OFF.

3. The 'Put LUSS On Sheet' requests the LUSS to go On Sheet.
    - 'Put LUSS On Sheet' diamond when selected ON will request LUSS to go On Sheet. When LUSS is On Sheet, the 'LUSS Off Sheet' status will be OFF.
    - 'Put LUSS On Sheet' diamond when selected OFF will request LUSS to go Off Sheet. When LUSS is Off Sheet, the 'LUSS Off Sheet' status will be ON.

4. When LUSS goes On Sheet the default LUSS operating mode is Scan Mode and the 'Put LUSS in Single Point' diamond is OFF. If the 'Put LUSS in Single Point' request diamond is selected ON then the LUSS goes to Single Point mode.
    - 'Put LUSS in Single Point' diamond when selected ON will request LUSS to go to Single Point. When LUSS is in Single Point, the 'LUSS in Single Pt' status will be ON.
    - 'Put LUSS in Single Point' diamond when selected OFF will request LUSS to go to Scan. When LUSS is in Scan, the 'LUSS in Single Pt' status will be OFF.

5. If ABB Reel Scanner goes Off Sheet (such as during a sheet break) then the LUSS also goes Off Sheet and the 'Put LUSS On Sheet' diamond goes OFF.

6. If LUSS is On Sheet and ABB Reel Scanner goes to Single Point then the 'Put LUSS in Single Point' diamond goes ON and the LUSS goes to Single Point. If ABB Reel Scanner then goes back to Scan, the 'Put LUSS in Single Point' diamond remains ON and LUSS remains in Single Point.

7. The Operator input "Target Location" is used to command the LUSS to the CD position at which Single Point measurements are to be made.

8. The default measurement mode is MD Stiffness. If 'Put LUSS in CD mode' diamond is selected ON then the LUSS goes to CD mode. If the 'Put LUSS in CD mode' diamond is

selected OFF then the LUSS goes to MD mode. The MD or CD mode selection is independent of Scan or Single Point mode.

- 'Put LUSS in CD Mode' diamond when selected ON will request LUSS to go to CD mode. When LUSS is in CD mode, the 'LUSS in CD Mode' status will be ON.
- 'Put LUSS in CD Mode' diamond when selected OFF will request LUSS to go to MD mode. When LUSS is in MD mode, the 'LUSS in CD Mode' status will be OFF.

Figure 4. LUSS Control Panel

9. When the 'Laser Shutter ON' is lit, the laser shutter is open and the laser poses danger if viewed in line of sight.

10. If ABB Reel Scanner goes Off Sheet then the LUSS also goes Off Sheet and the 'Put LUSS On Sheet' diamond goes OFF.

11. If LUSS is in scan then the profile zones reflect the stiffness values where actually scanned. If in single point then just the profile zone where the LUSS scanner position is reading the stiffness is displayed and other profile zones are zeroed.

12. Messages appear in the Status Bar in a priority fashion. Messages are:
    a. LUSS Communications Down
    b. LUSS in LOCAL Mode
    c. LUSS Off Sheet
    d. LUSS in SCAN Mode
    e. LUSS in SINGLE POINT Mode

Watchdog pulses are sent by both ABB to LUSS and by LUSS to ABB. The pulses come from oscillators with a time cycle of 20 sec and a time pulse of 10 sec so each 10 sec the pulse changes from true to false or false to true. If the pulse from LUSS to ABB does not change in 60 sec, then ABB generates a message 'LUSS Communications Down'. If the ABB to LUSS does not see a change in 60 sec then LUSS goes off sheet and closes the Laser Shutter.

Figure 5 shows the same display as *Figure 4*, except it shows a status of 'LUSS in SINGLE POINT mode'. Unlike scan mode where there would be values in all the zones, single point mode will display the profile zone where the LUSS head position is and zero out all other zones. The stiffness value can also be read in the Process Data section.

Figure 5. LUSS Control showing single point mode

Figure 6 shows the I/O Status display. This display is provided to aid in troubleshooting as it represents the S800 I/O units which are the interface between the ABB and LUSS systems. This would not be required by the Operator as there are no controls or commands here, just I/O channel values.

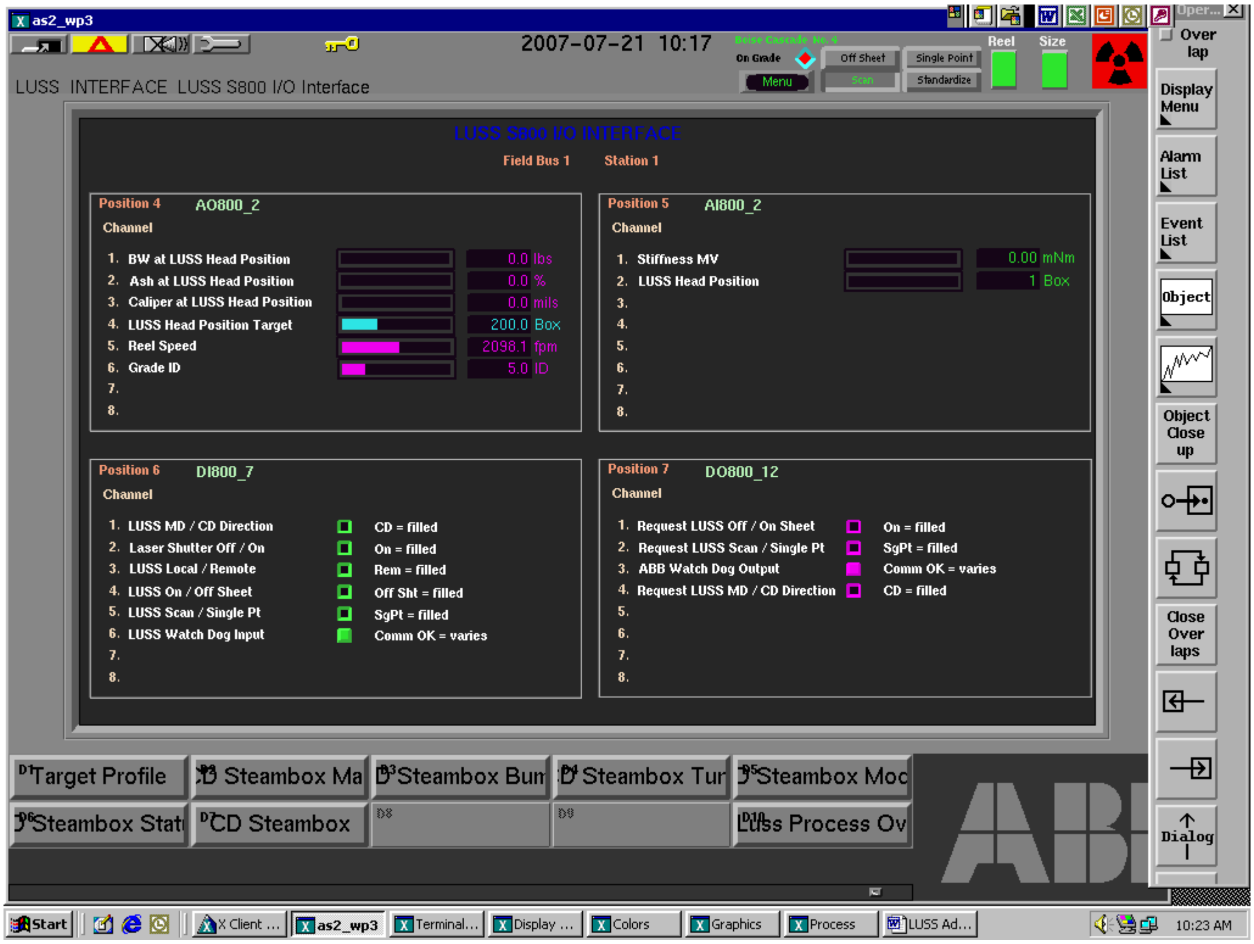


Figure 6. LUSS I/O Status Page

The panel shown in *Figure 7* displays a historic trend of the Stiffness measured values and the LUSS head position. Four more related variables could be trended in relation to these above two values here on this display.

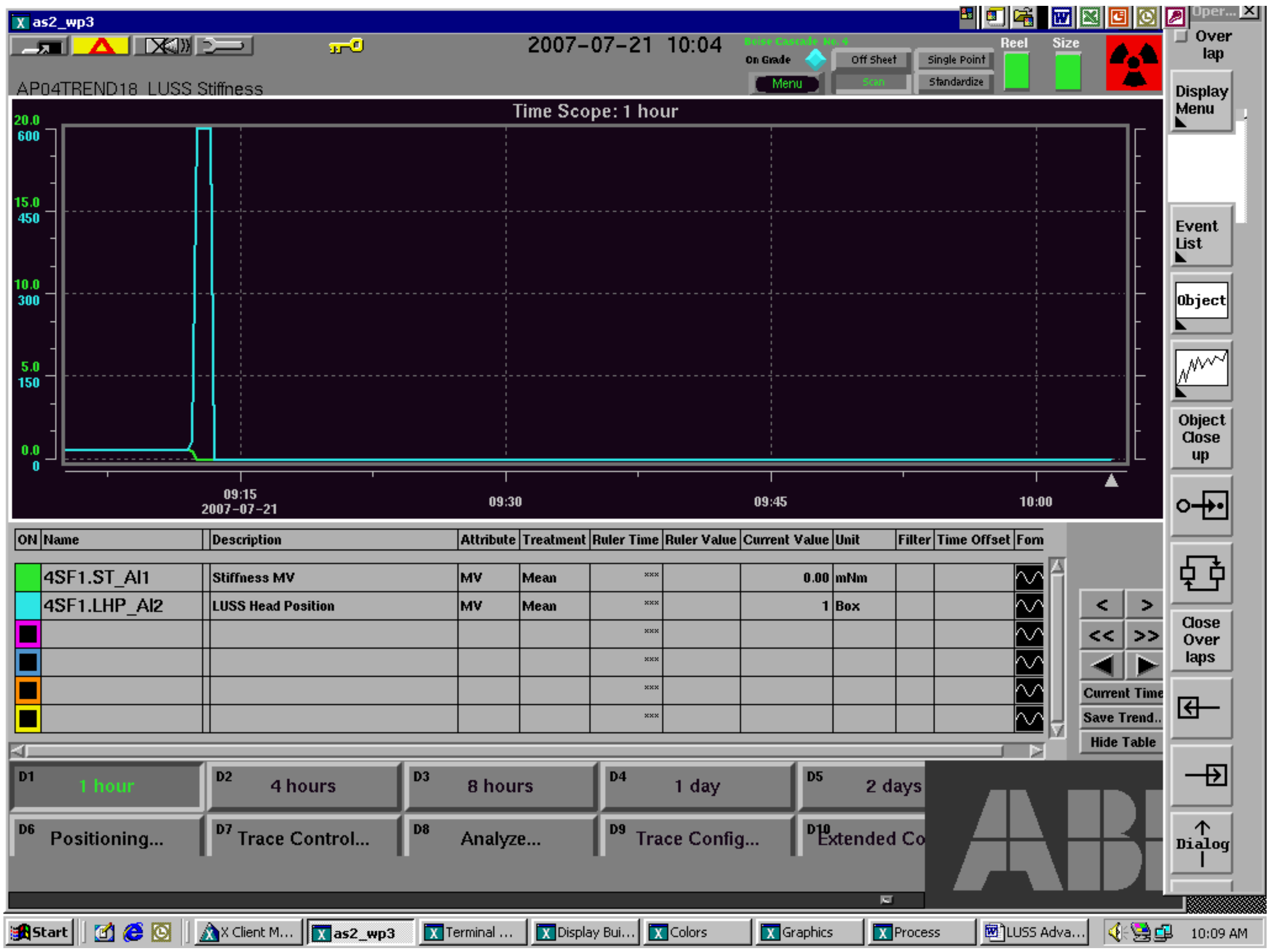


Figure 7. Stiffness Data Display

ABB Grade Code Maintenance

A key factor in accurately calculating stiffness is taking into account the characteristics of the grade being produced. In the calculation of stiffness a curve fitting operation is performed, this operation is simplified if the grade is known. Thus, the grade code is sent to the LUSS. The grade codes currently planned for use are shown in Table 1. There are 150 unique SYST & MISC groups that can be associated with the Product Grade Codes within the ABB system. Presently there are about 300 grade codes each using the same SYST & MISC group #1. For purposes of the LUSS sensor an initial 12 grades will be selected that represent the majority of paper produced. Each of these grades will use a unique SYST & MISC group. They will contain the same information as they presently do with one spare field being used containing a unique number that will be passed to the LUSS system for use in the final measurement value. LUSS Grade ID 1 will represent a default code to denote all other grade codes not of the initial 12. Actually Grade ID 13 has 9 ABB Grade codes assigned to it with the difference being only the actual shade color.

Table 1. ABB – LUSS Grade Codes List

Boise Product Number	ABB Grade Code	Grade Description	LUSS Grade Number *
All numbers not listed below	All codes not listed below	Default for all grades not assigned	1
4410-00-166	4424	55# Val. Safety	2
1150-00-130	8049	54# Smooth Offset	3
4400-94-168	1169	55# Wr. Checkbase	4
1150-00-130	3867	50# Smooth Offset	5
1150-00-130	3868	60# Smooth Offset	6
3210-38-434	3355	55# Tan Kraft	7
1140-00-149	9209	60# Smooth Opaque	8
4010-14-130	3820	51# MOCR	9
0408-91-149	1013	55# RC Pres. Laser	10
1150-09-130	3871	60# Vellum Offset	11
4010-14-130	3836	55# MOCR	12
3010-00-130 for white	3863	55# Wove Env. (Wh & Colors)	13
3010-00-332 canary	6332	"	13
3010-00-373 goldenrod	6372	"	13
3010-00-385 cream	6385	"	13
3010-00-388 ivory	6388	"	13
3010-00-556 green	6556	"	13
3010-00-620 blue	6620	"	13
3010-00-762 pink	6762	"	13
3010-00-818 gray	6818	"	13

* Same as ABB 'SYST & MISC' Group number, (uses index 10)

Appendix a – Instrument Cabinet

All of the hardware required to run the LUSS is contained in the Instrument Cabinet. The exterior of the cabinet is shown in *Figure 1*. When the exterior door is opened an instrument rack which extends from the bottom to the top of the cabinet can be seen. This rack is on a hinge which allows it to swing open in the opposite direction of the exterior door. If the rack is swung open the full interior of the cabinet is accessible. In the interior are located the pneumatic supply manifold and manual controls, the generation laser supply, and on the back wall the opening to the two conduits which carry all the connections to the sensor package.

<u>Pneumatic Controls</u>

The pneumatic manifold and manual flow controls for the

1. Vortex cooling tube
2. Purge air for the Sensor package
3. Purge air for the IR temperature sensor
4. Air for the Bernoulli plate

are located on the floor of the instrument cabinet.

Vortex Cooling

The Vortex cooling tube and Purge air share the same flow control (0 – 50 SCFM). Mounted on the back of the piping associated with flow controller is a solenoid valve which in an un-powered state supplied air to the vortex cooling tube. In powered state it supplies air for sensor package purging. There should be a positive pressure in the sensor package during operation to limit in flow of dust and other foreign material. The flow rate, (nominally 6 SCFM) should not need adjustment. Control of the solenoid is performed using a standard temperature controller mounted on the instrument rack.

Bernoulli Plate

The flow control for the Bernoulli plate is mounted furthest towards the rear of the cabinet. Its flow range is 0-240 SCFH. The purpose of this device is to pull the sheet close to the opening in the bottom of the sensor package, thus insuring that a constant distance is maintained between the end of the generation laser and the sheet. The normal flow rate is 120 SCFH

IR Sensor

The flow control for IR sensor cooling has a flow rate range of 0-50 SCFH, with a nominal flow rate of 10 SCFH. The IR sensor is used to measure the sheet temperature. Temperature has an impact on sheet stiffness.

<u>Generation Laser Power Supply</u>

Also located on the floor of the cabinet is the power supply for the generation laser. The power supply provides power and cooling water to the laser which is mounted on the instrument rack. The cooling water system uses distilled water and is self contained. On the front face of the power supply is a key to which must be in the ON position for the power supply to operate. The key can be left in the on position, as the power supply is energized using the laser control panel which is mounted on the inside of the Instrument Cabinet exterior door. On the rear face of the power supply are the cable going to the laser control panel, the power/water supply to the laser and a B&C connector to the LUSS computer which is used to command the laser to fire.

Instrument Rack

The instrument rack is shown in *Figure 8*. The details of connections between the LUSS and ABB systems are shown in Figures 9 through 15 and in Table 1. The components mounted in the rack are from top to bottom:

1. Polytec OFV 3001 – This is the controller and power supply for the detection laser, it is mounted directly to the rack. The detection laser (Polytec 8000) is mounted in the Sensor Package Garage. This arrangement was necessary because the fiber optic cable from the detection laser to the interferometer (Polytec 7000) mounted in the sensor package is 10 m long. The fiber optic is permanently mounted to the laser and the interferometer and cannot be modified. The output from the controller is the out of plane velocity of the sheet.

2. LUSS Computer – This is a rack mounted PC which is mounted directly to the rack. All of the LUSS software for controlling the Sensor Package, collecting data, calculating stiffness, and communicating with the ABB system resides on this computer. The controlling program is written in LabView. The primary input/output paths from this computer are
    a. RS 232 interface with the motor controllers for the three motion stages inside the Sensor Package. Stages 1 and 2 are linear CD and MD stages for positioning the generation laser. Stage 3 is a DC motor with a mirror mounted on it s shaft to reflect light to and from the interferometer.
    b. National Instruments DAQ Board 6602– dedicated cable
    c. National Instruments DAQ PAD 6259 – USB cable
    d. Generation laser to command laser firing – B&C cable
    e. Detection laser – B&C cable
    f. ITAHCO Amplifier to receive amplified signal – B&C cable

3. ITHACO Amplifier/Filter – This device sits on a shelf and receives the velocity signal from the Interferometer (B&C cable) and amplifies the signal (B&C cable) and sends it to the PC.

4. Strip Mounted Devices
    a. White Relays (IN) Left to Right on Strip. These relays are for signals from the ABB System and Lenze guide rail
        i. MD/CD – Command MD or CD stiffness measurement mode
        ii. Move Lenze– Voltage signal to command guide rail position location
        iii. On Sheet – Command On Sheet/Off Sheet
        iv. SP Scan – command Single Point or Scan Mode for LUSS
        v. Pulse –

b. Red and one Blue Relay (OUT) Left to Right on Strip. These relays are for signals going to the ABB System, Lenze guide rail, National Instruments 6602 interface board and the watchdog timer.
    i. Lenze (blue) – 24 V input signal from Lenze (red), 120 V output to Lenze MD
    ii. Lenze (red) – 0-5 V signal from NI 6602 board to power guide rail, 24 V output
    iii. Shutter (red)– Command shutter open (powered) and closed (unpowered)
    iv. Laser (red) – Command generation laser
    v. Local (red) – Signal Local control of LUSS
    vi. On Sheet (red) – Signal Sensor package is On Sheet/Off Sheet
    vii. SP/Scan (red) – Signal LUSS is in single point or scanning mode
    viii. Pulse (red) -
    ix. On Sheet Command (red) – Command Sensor package On Sheet/Off Sheet
c. 24 V Power Supply
d. Watch Dog Timer – Monitors Watch Dog Signal from ABB

5. National Instrument
    a. National Instruments DAQ Board 6602, see , *Move* done input : dev 3 line 3 **Brown – White Relay Move Done Lenze**

    b. *Figure 9*
    c. National Instruments DAQ PAD 6259 see *Figure 10*

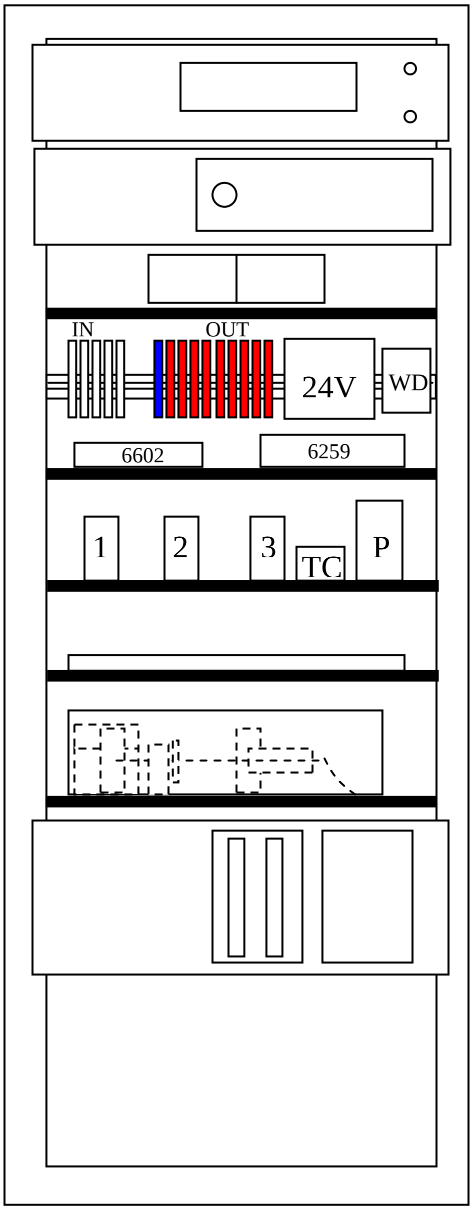
6. VIX Controllers and Power Supply – There are three motion stages (Parker Hannafin VIX) in the Sensor Package; two linear stages for moving the generation laser in the CD-1 and MD-2 direction. The third stage (Mirror-3) is a DC motor which rotates at a rate which is synchronized with the web speed. On the end of the motor shaft, mounted at a 45^{o} angle is a mirror which reflects light to and from the interferometer. Because the rotation is synchronized with the web speed the mirror 'follows' a single point on the web, allowing its out of plane velocity to be measured by the interferometer. The first stage CD-1 is connected to the computer via an RS 232 cable. The other two stages MD-2 and Mirror-3 are daisy chained from the CD- 1. All three stages are powered from the same power supply. There are three large cables which come into the Instrument Cabinet and terminate at these stage controllers
    a. Cable 1 (gray) – stage position and temperature information, CD-1, MD-2, Mirror-3
    b. Cable 2 (gray) – stage limit switch information (only for CD-1 and MD-2)
    c. Cable 3 (green) – power, CD-1, MD-2, Mirror-3, plus IR temperature signals thermocouple signal, 24 V power for the warning light and IR temperature sensor.

Also mounted on this shelf is a temperature controller for the Vortex cooling tube. The controller turns a solenoid on and off based on the sensor package internal temperature (Cable 3 thermocouple signal). The solenoid switches air flow between simple purge air and flow to the vortex cooler .This temperature device is a standalone device which does not interface with the LUSS software.

7. Keyboard and Monitor

8. Generation Laser – The generation laser is mounted on this shelf. In order for the laser beam to reach the Sensor Package the beam must be "funneled" into the fiber optic cable. This requires passing the beam through a lens to focus it and them precisely positioning the focused beam at the center of the fiber optic. If the beam is not positioned precisely a significant amount of beam energy will be lost. This shelf has mounted on it the optical hardware for accomplishing this task; it is therefore constructed from a ½ inch piece of aluminum. The shielding around the optical hardware should not be removed as it insures that the laser light cannot be inadvertently directed into a users eyes. The shutter is located underneath the shielding. The shutter is a rotary solenoid with a metal arm attached to it. When un-powered the metal arm is in the path of the laser blocking it from entering the fiber optic. When powered the arm rotates upward allowing the laser beam to enter the fiber optic cable.

9. Guide Rail – The guide rail (Manufactured by Lenze) is controlled by hardware rack mounted at this location. This hardware included the Lenze controller and electrical connections to the guide rail motor. The controlled has an imbedded control program which is activated by the LUSS PC based Labview program. The LUSS sends an analog signal to the controller to specify the commanded CD location, the controller sends the LUSS PC analog signal state that sensor package position.



1. Polytec OFV 3001
2. PC
3. ITHACO Amplifier/Filter
4. White Relays(IN), Blue and Red Relays(OUT), 24V Power Supply, Watchdog Timer
5. National Instruments DAQ 6602 & 6259
6. VIX Controllers for Stages
   1-CD, 2-MD, 3-Mirror, P-Power Supply
   TC-Temperature controller
7. Keyboard - Monitor
8. Laser and fiber optic launch for generation laser
9. Controller for Guide Rail

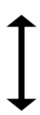
Figure 8. Instrument Rack

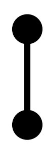
	SIGNAL		SIGNAL		SIGNAL
68	GND				
34	PFI_31 (SOURCE_2)				
67	PFI_30 (GATE_2)	**12**	**PFI_3** **Red – Red Relay MDMode**	1	**+5V** **Red – Red Relay MD** **Green – Mirror Cicuit**
33	GND	**46**	**GND** **Black – White Relay Pulse Gray IN)** **Green – Red Relay Shutter**	35	RG
66	PFI_29 (UP_DOWN_2)	**13**	**PFI_4** **Blue – Red Relay Shutter**	2	PFI_39 (SOURCE_0)
32	**PFI_28 (OUT_2)** **Green – Gen Laser B&C**	**47**	**PFI_5** **Green – Red Relay Local Modes**	36	**GDN** **Black – Red Relay MD** **White – Mirror (Circuit)**
65	**GND** **Black – Gen. Laser B&C**	14	GND	3	**PFI_38 (GATE_0)** **Green - B&C Trigger to Scope** **Green – Mirror Circuit**
31	PFI_27 (SOURCE_3)	**48**	**PFI_6** **Blue – Red Relay Offsheet**	37	RESERVED
64	**PFI_26 (GATE_3)** **Green – Mirror Circuit**	**15**	**PFI_7**	4	RESERVED
30	GND	49	GND	38	RESERVED
63	PFI_25 (UP_DOWN_3)	**16**	**PFI_8 (OUT_7)** **White – White Relay MD/CD**	5	PFI_36 (OUT_0)
29	PFI_24 (OUT_3)	50	GND	39	**GND** **Black – B&C Trigger to Scope**
62	GND	**17**	**PFI_9 (UP_DOWN_7)** **White – Red Relay Pulse**	6	PFI_33 (UP_DOWN_1)
28	PFI_23 (SOURCE_4)	**51**	**PFI_10 (GATE_7)** **Brown – Red Relay SP/Scan**	40	PFI_37 (UP_DOWN_0)
61	PFI_22 (GATE_4)	**18**	**GND** **Black – Red Relay On Sheet (Command)**	7	PFI_35 (SOURCE_1)
27	GND	**52**	**PFI_11 (SOURCE_&\7)** **Red – Red Relay On Sheet (command)**	41	GND
60	PFI_21 (UP_DOWN_4)	19	RG	8	PFI_34 (GATE_1)
26	PFI_20 (OUT_4)	**53**	**PFI_12 (OUT_6)** **Orange – White Relay ON Sheet**	42	GND
59	GND	**20**	**GND** **White – Red Relay Lenze**	9	PFI_32 (OUT_1)
25	PFI_19 (SOURCE_5)	**54**	**PFI_13 (UP_DOWN_6)** **Yellow – Red Relay Lenze**	43	RG
58	PFI_18 (GATE_5)	21	PFI_14 (GATE_6)	10	**PFI_0** **Orange – Red Relay Laser**
24	GND	55	GND	44	**PFI_1** **Green – White Relay ABB singlepoint**
57	PFI_17 (UP_DOWN_5)	22	PFI_15 (SOURCE_6)	11	GND
23	PFI_16 (OUT_5)	56	RG	45	**PFI_2** **Blue – White Relay ABB Pulse**

DIO(n=0…31), Motion Encoder (n=0…7), GATE_n maps to CH_Z_ DIO_n maps to PFI_n, SOURCE_n maps to CH_A_n, UP_DOWN_n maps to CH_B_n, Move done input : dev 3 line 3 **Brown – White Relay Move Done Lenze**

Figure 9. NI DAQ 6602 wiring

Pin	Signal		Signal	Pin	Pin	Signal
33	AI 10		**AI 4** **White-Black - cable 1**	**17**	**1**	**AI 0** **Red – cable 1**
34	AI 24		**AI 12** **White-Black – cable 2**	**18**	**2**	**AI 8** **Orange – cable 1**
35	AI GND		AI GND	19	3	AI GND
36	AI 17		**AI 5** **Red – cable 2**	**20**	**4**	**AI 4** **Green – cable 1**
37	AI 25		**AI 13** **Orange – cable 2**	**21**	**5**	**AI 9** **Blue – cable 1**
38	AI GND		AI GND	22	6	AI GND
39	AI 18		**AI 6** **Green – cable 2**	**23**	**7**	**AI 2** **Black – cable 1**
40	AI 26		**AI 14** **Blue – cable 2**	**24**	**8**	**AI 10** **White – cable 1**
41	AI GND		AI GND	25	9	AI GND
42	AI 19		**AI 7** **Black – cable 2**	**26**	**10**	**AI 3** **Red-Black – cable 1**
43	AI 27		**AI 15** **White – cable 2**	**27**	**11**	**AI 11** **Green-Black –cable 1**
44	AI GND		AI GND	28	12	AI GND
45	AI SENSE 2		APFI 0	29	13	AI SENSE
46	AI GND		AI GND	30	14	AI GND
47	**AO 2** **Red – cable Lenze**		**AO 1** **Red – cable LUSS**	**31**	**15**	**AO 0** **Red-Black – cable 2**
48	**AO GND** **Black – cable Lenze**		**AO GND** **Black – cable LUSS**	**32**	**16**	**AO GND** **Green-Black – cable 2**

 Resistor Jumper

 Capacitor Jumper

Note: Red wires on Pin 47 and Pin 31 are joined together just outside the box
Black wires on Pin 48 and Pin 32 are joined together just outside the box
Forming Black LUSS cable from NI 6259 shown in

Figure 10. NI DAQPad 6259 wiring

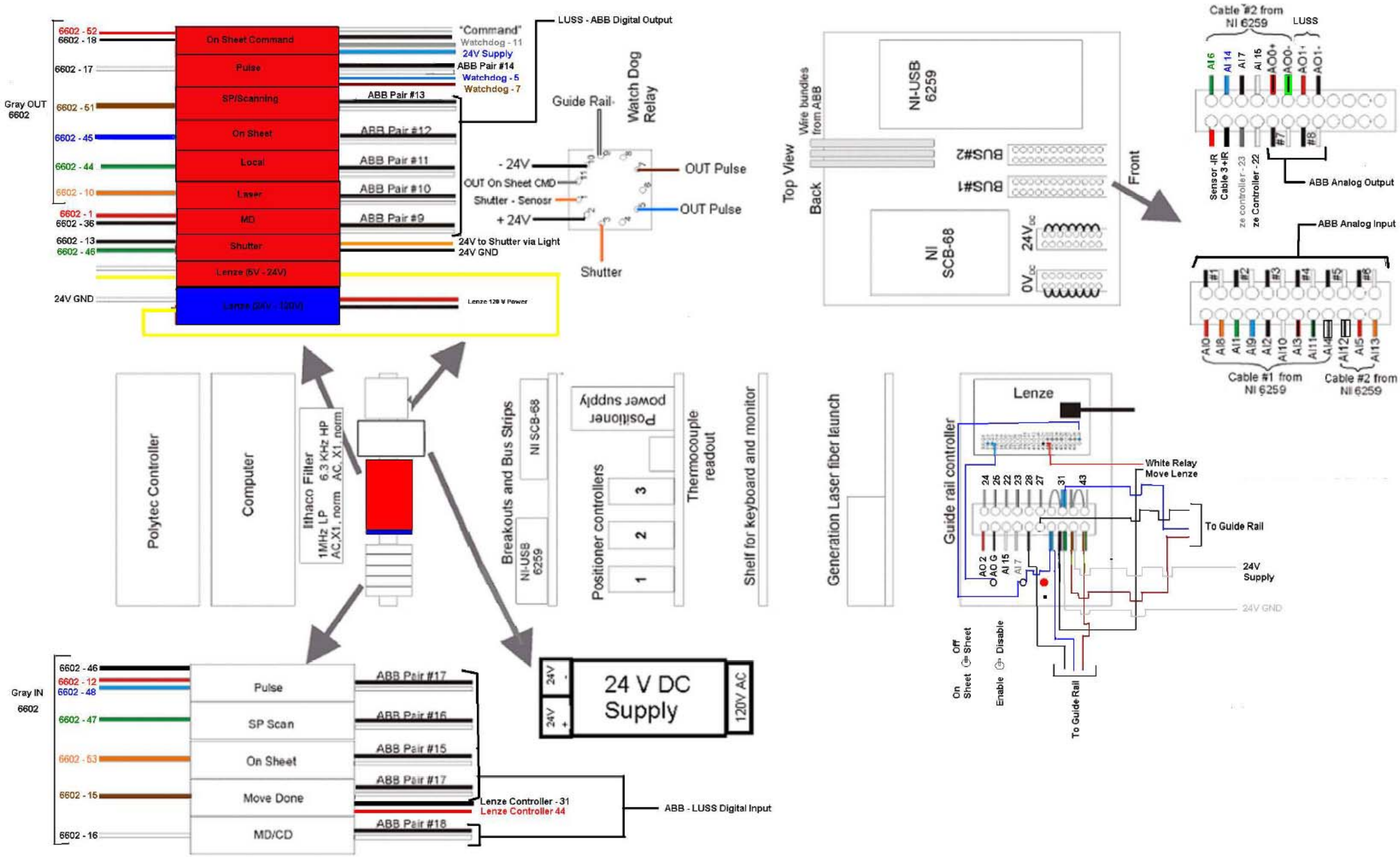


Figure 11a. Instrument Cabinet Wiring

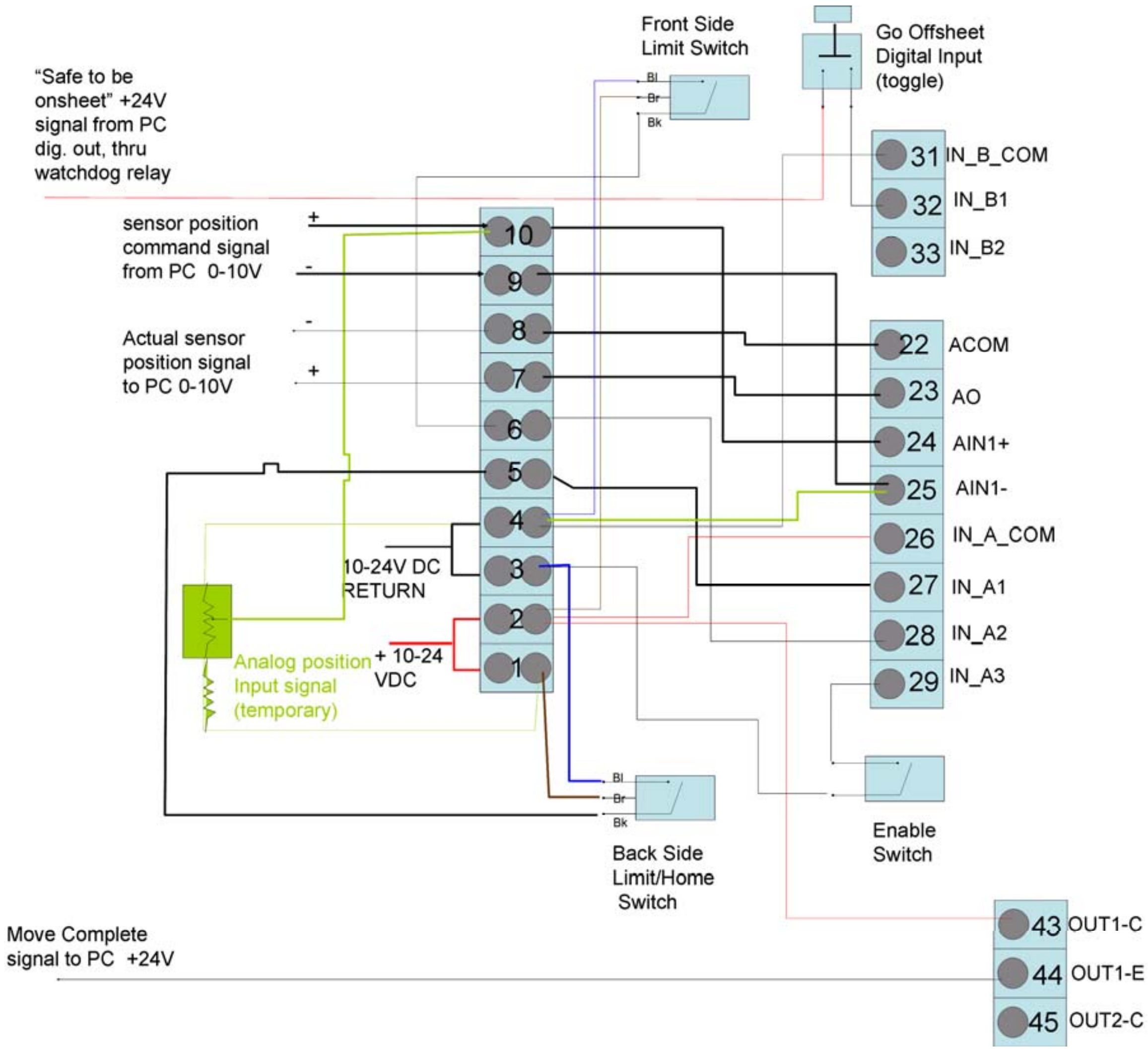


Figure 11b. Details of guide rail wiring

Table 1. ABB Input and Output Signals

I/O *expansion* updated

Discrete I/O list - LUSS / ABB Boise for H4 test 11-28-06 Rev 1

Signal Name	LUSS type	LUSS chan	ABB type	Wire Pair#	ABB channel	Signal range	Scale factor / Logic definition	Update rate	Notes
				Hi Bk, Lo Wh					
Analog from ABB to LUSS									
Basis weight (BW)	AI Diff	AI0+ AI8-	AO SE	1	AO 1	0-10 VDC	0-200 lbs = 0 - 10 V	1 Hz	BW at LUSS head position
Ash content (AS)	AI Diff	AI1+ AI9-	AO SE	2	AO 2	0-10 VDC	0-50% = 0 - 10 V	1 Hz	Ash at LUSS head position
Caliper (CA)	AI Diff	AI2+ AI10-	AO SE	3	AO 3	0-10 VDC	0-10 mils = 0 - 10 V	1 Hz	Caliper at LUSS head position
ABB Head Pos Tgt (HPT)	AI Diff	AI3+ AI11-	AO SE	4	AO 4	0-10 VDC	0 - 600 = 0 - 10 V	1 Hz	ABB box number(1-600). 0 = Offsheet
Reel speed (RS)	AI Diff	AI4+ AI12-	AO SE	5	AO 5	0-10 VDC	0 - 4000 fpm = 0 - 10 V	1 Hz	Current Reel speed
Grade ID (GD)	AI Diff	AI5+ AI 13-	AO SE	6	AO 6	0-10 VDC	0 - 200 = 0 - 10 V	1 Hz	Grade ID, 0 is default
Analog from LUSS to ABB									
Stiffness (ST)	AO SE	AO0	AI Diff	7	AI 1	0-10 VDC	0 - 100 mNm = 0 - 10 V	1 Hz	< 0.1 volt = invalid measurement
LUSS Head Pos (LHP)	AO SE	AO1	AI Diff	8	AI 2	0-10 VDC	0 - 600 = 0 - 10 V	1 Hz	ABB box number(1-600). 0 = Offsheet
Digital from LUSS to ABB									
MD / CD mode (CD)	DO	DIO3	DI	9	DI 1	0 / 24 V	MD = open, CD = closed (2)	1 Hz	Measurement in MD or CD direction
Laser ON (LZ)	DO	DIO4	DI	10	DI 2	0 / 24 V	ON = closed, OFF = open (2)	1 Hz	Laser On indicator
Local / Remote (LR)	DO	DIO5	DI	11	DI 3	0 / 24 V	Rem= closed, Loc = open (2)	1 Hz	Local/Remote indicator
LUSS Off sheet (LOFF) (3)	DO	DIO6	DI	12	DI 4	0 / 24 V	Off= closed, On = open (2)	1 Hz	LUSS Off Sheet indicator
LUSS SP (LSP) (3)	DO	DIO7	DI	13	DI 5	0 / 24 V	SP = closed, Scan = open (2)	1 Hz	LUSS Single Point mode indicator
10s WatchDog (LDOG)	DO	DIO8	DI	14	DI 6	0 / 24 V	1= closed, 0 = open (2)	1 Hz	ABB Communications check
Digital from ABB to LUSS									
On/Off sheet (AON) (1,3)	DI	DIO0	DO	15	DO 1	0 / 24 V	0 V = Off sht, 24 V = On sht	1 Hz	Request LUSS On/Off Sheet
SP/Scan (ASP) (3)	DI	DIO2	DO	16	DO 2	0 / 24 V	0 V = Scan, 24 V = Single pt	1 Hz	Request LUSS SP/Scan
10s WatchDog (ADOG)	DI	DIO3	DO	17	DO 3	0 / 24 V	1= closed, 0 = open (2)	1 Hz	LUSS Communications check

1. Do not send Offsheet during standardize. Offsheet should cause LUSS to unconditionally go Offsheet
2. LUSS provides opto relay DC IN , ABB provides 24 V logic to relay
3. See Truth Table in Logic section for proper interpretation

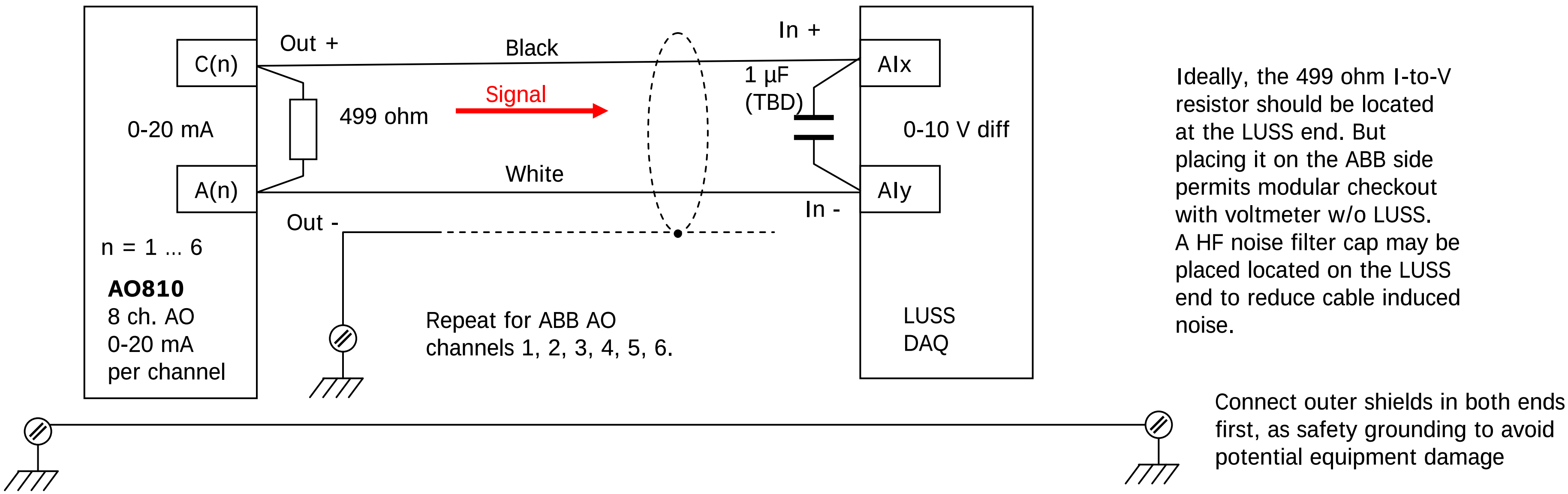


Figure 12. Circuit for Analog from ABB to LUSS

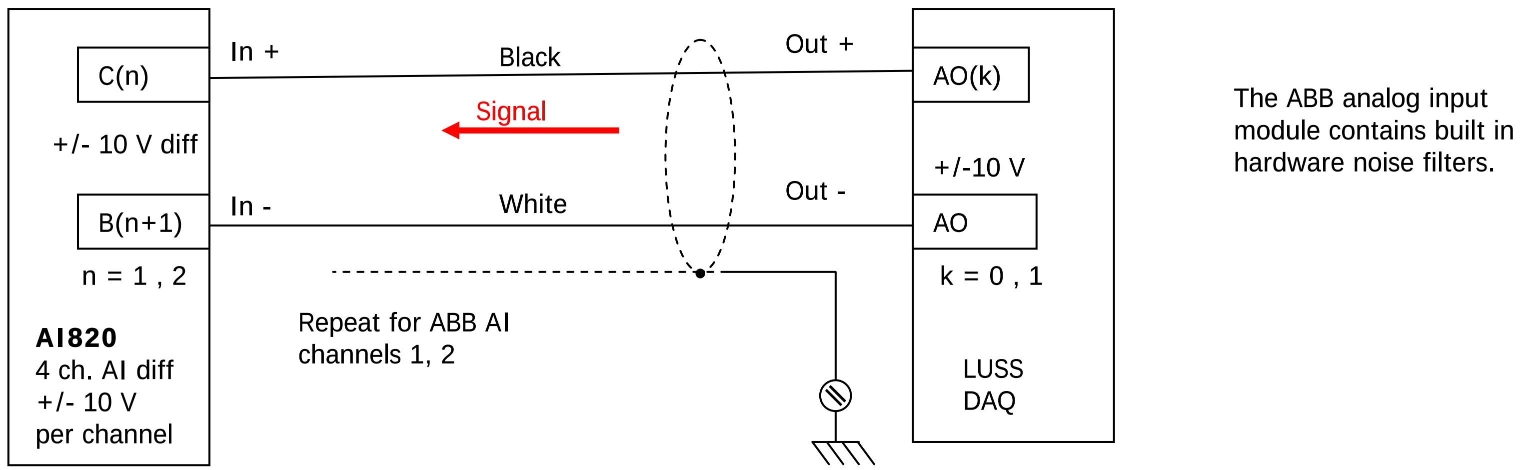


Figure 13. Circuit for Analog from LUSS to ABB

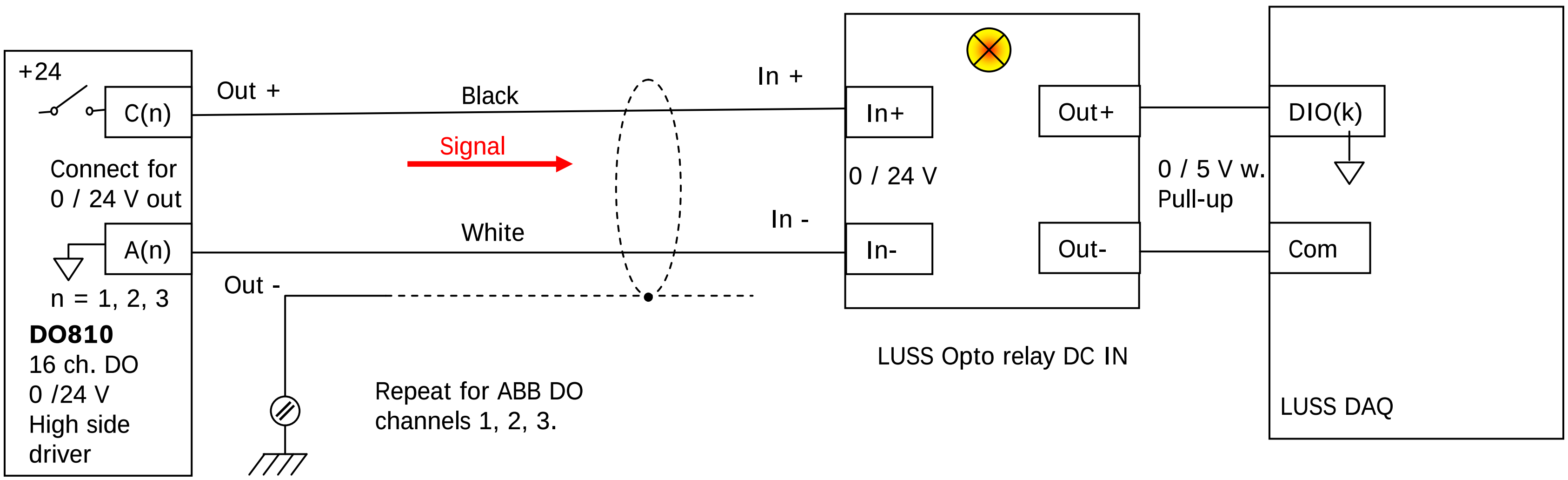


Figure 14. Circuit for Digital from ABB to LUSS

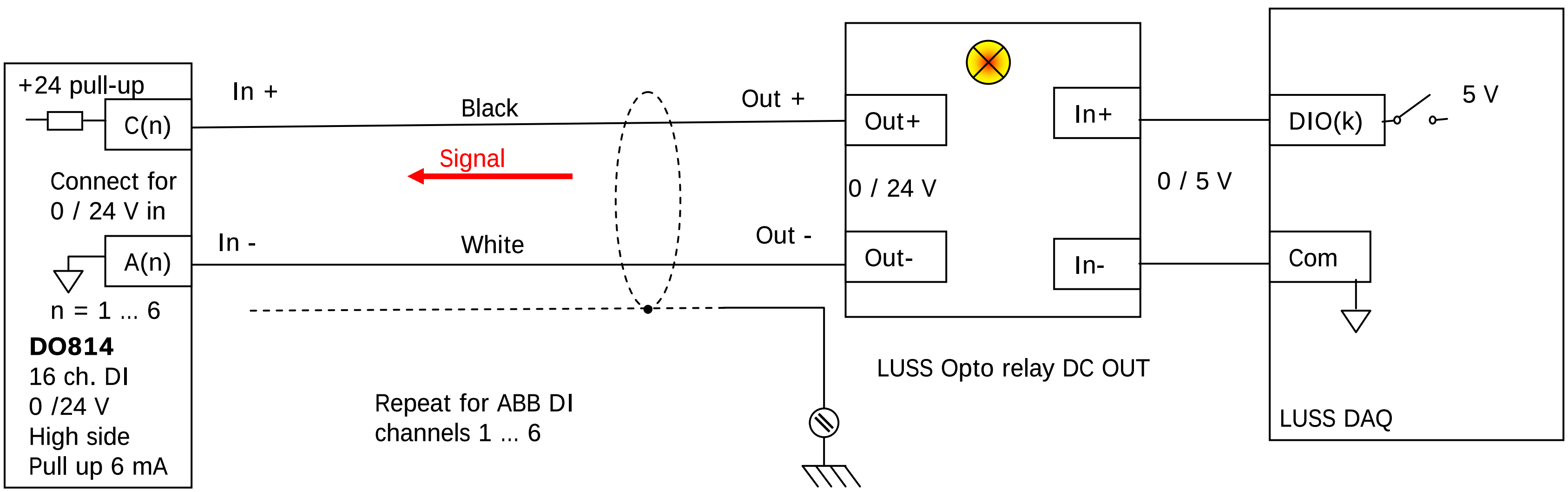


Figure 15. Digital from LUSS to ABB

Appendix b – Sensor Package

The sensor package is shown in Figure 16, the internal wiring and hoses have been omitted for clarity. Three electrical cables, two laser fiber optics cables and four airlines run between the sensor package and the instrument cabinet. The elements contained in the sensor package are:

1. Generation laser emitter, the associated fiber optic cable is a 0.3 in in diameter with a silver metal cover.
2. Holder for generation laser
3. Interferometer (Polytec 7000) emitter and focusing optics, the associated fiber optic cable is 0.5 in. in diameter with a black exterior
4. Support of for interferometer
5. MD linear stage for moving the generation laser emitter in the MD direction
6. CD linear stage for moving the generation laser emitter in the CD direction
7. Mirror motor for spinning the mirror which reflects the interferometer laser
8. Mirror which reflects the interferometer laser
9. Bernoulli plate used to pull the sheet up against the underside of the sensor package
10. An IR temperature sensor (with air purge) for measuring the sheet temperature
11. IR sensor interface
12. Vortex tube cooler used to cool the interior of the sensor package
13. A Thermocouple for measuring the interior temperature of the sensor package (measurement used to control the vortex tube cooler
14. Thermocouple signal transmitter

The the green electrical cable supplies power to the individual motion stages (CD-1, MD-2, Mirror Motor-3) as well as the IR sensor interface, thermocouple transmitter and red “laser On” warning light. The two gray cable, labeled “1” and “2” provide the communication link between the stages and the associated controllers. The communication link allows commands to be sent to the stages and for locations and diagnostic information to be sent to the controllers.

The two fiber optic cables (0.5 in. diameter black cable for the interferometer and 0.3 in. diameter silver cable for the generation laser with red inner core) are delicate. Care should be taken to insure that the cables are not bent around small radii, the inner fiber optic will break if bent too much.

The air lines are discussed at the beginning of Appendix A.

The Bernoulli plate is the blue circular plate on the bottom of the sensor package. The plat circle the hole through which the generation laser fires. It has a number of radial slots around its circumference, air flow though these slots and pulls the paper towards the bottom of the sensor package insuring that the paper is always about the same distance from the end of the generation laser emitter.

The thermocouple is a standard Type K probe thermocouple with 1/8 in. diameter shield.

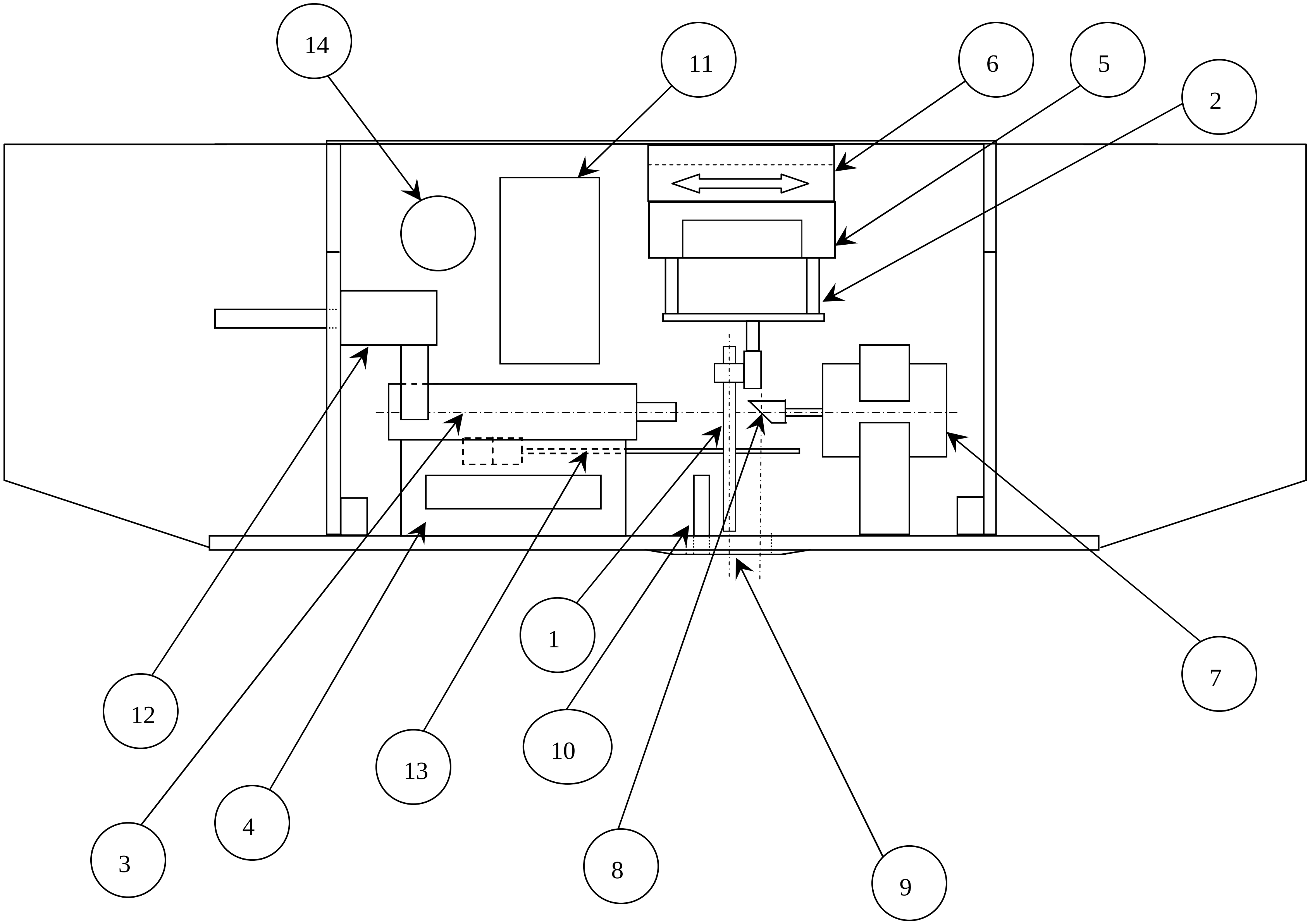


Figure 126. Schematic of Sensor Package Interior

Appendix c – Sensor Package Cable Wiring and Pin Outs

Cables 1 (Gray) and 2 (Gray) provide communication slinks between the motion stages and the associated controllers. Cable 3 (Green) provides power to the stages, thermocouple transmitter, IR sensor interface and the "Laser ON" warning light. The pin outs are shown in Tables 2 through

Table 2. Connector 1 – Wires from stages to Sensor Package connector

Connector 1 Socket

Pin	Parker Color	Signal Name
1	Red	Axis 1 Drive U
2	White	Axis 1 Drive V
3	Black	Axis 1 Drive W
4	Green	Axis 1 Drive Ground
5	Red	Axis 2 Drive U
6	White	Axis 2 Drive V
7	Black	Axis 2 Drive W
8	Green	Axis 2 Drive Ground
9	Red	Axis 3 Drive U
10	White	Axis 3 Drive V
11	Black	Axis 3 Drive W
12	Green	Axis 3 Drive Ground
SHIELD	*Grounded to socket fastener*	

Axis 3's conductors will be covered in braided shield and brought to the socket. The shields of the cables for the linear stages and rotary motor will be attached to each other.

Table 3. Connector 1 – Wires from Sensor Package to controllers

Connector 1 Plug

Pin	LUSS Color	Signal Name
1	Black 1	Axis 1 Drive U
2	Black 2	Axis 1 Drive V
3	Black 3	Axis 1 Drive W
4	Black 4	Axis 1 Drive Ground
5	Black 5	Axis 2 Drive U
6	Black 6	Axis 2 Drive V
7	Black 7	Axis 2 Drive W
8	Black 8	Axis 2 Drive Ground
9	Black 9	Axis 3 Drive U
10	Black 10	Axis 3 Drive V
11	Black 11	Axis 3 Drive W
12	Yellow/Green	Axis 3 Drive Ground
SHIELD	*Connected to cable clamp*	

Each drives' four conductors will be separated from the VIX end of the bundle and covered with braided shield attached to the shield of Cable 1. Axes 1 & 2 will have the shield of the Parker cable attached to the braided shield added to the LUSS cable. The braid for Axis 3 will be carried to the controller and grounded there.

Connector 1 Socket: 208489-1 (size 22, 16 contact)
Connector 1 Plug: 208488-1 (size 22, 16 contact

Table 3. Connector 2 – Wires from stages to Sensor Package connector

Connector 2 Socket

Pin	Parker Color	Signal Name	VIX Pin	Notes
1	Red	Encoder +5V	5	Shared with Axis 1 & 2
2	Black	Encoder Ground	3	Shared with Axis 1 & 2
3	Orange	Encoder Z	1	Pins 3-13 are Axis 1
4	Brown	Encoder Z-	2	
5	Yellow/Red	Temperature	10	
6	Yellow/Black	Temperature -	6	
7	White	Encoder A	7	
8	Yellow	Encoder A-	8	
9	Green	Encoder B	12	
10	Blue	Encoder B-	11	
11	White/Brown	Hall 1	9	
12	White/Orange	Hall 2	13	
13	White/Violet	Hall 3	14	
14	Orange	Encoder Z	1	Pins 14-24 are Axis 2
15	Brown	Encoder Z-	2	
16	Yellow/Red	Temperature	10	
17	Yellow/Black	Temperature-	6	
18	White	Encoder A	7	
19	Yellow	Encoder A-	8	
20	Green	Encoder B	12	
21	Blue	Encoder B-	11	
22	White/Brown	Hall 1	9	
23	White/Orange	Hall 2	13	
24	White/Violet	Hall 3	14	
SHIELD	*Grounded to socket fastener*			

Red wire from Axis 1&2 will both be terminated at Pin 1.
Black wire from Axis 1&2 will both be terminated at Pin 2.
The shields of the encoder signal cables will be attached to each other and attached to one of the socket's fasteners.

Table 4. Connector 2 – Wires from Sensor Package to Controllers

Connector 2 Plug

Pin	**LUSS Color**	**Signal Name**	**VIX Pin**	**Notes**
1	Red	Encoder +5V	5	Shared with Axis 1 & 2
2	White	Encoder Ground	3	Shared with Axis 1 & 2
3	Red	Encoder Z	1	Pins 3-13 are Axis 1
4	Yellow	Encoder Z-	2	
5	Red	Temperature	10	
6	Green	Temperature-	6	
7	Red	Encoder A	7	
8	Blue	Encoder A-	8	
9	Red	Encoder B	12	
10	Brown	Encoder B-	11	
11	Black	Hall 1	9	
12	Red	Hall 2	13	
13	Black	Hall 3	14	
14	White	Encoder Z	1	Pins 14-24 are Axis 2
15	Black	Encoder Z-	2	
16	Yellow	Temperature	10	
17	Black	Temperature-	6	
18	Green	Encoder A	7	
19	Black	Encoder A-	8	
20	Blue	Encoder B	12	
21	Black	Encoder B-	11	
22	Brown	Hall 1	9	
23	Black	Hall 2	13	
24	Orange	Hall 3	14	
SHIELD	*Connected to cable clamp*			

Red wire from VIX 1&2 will be terminated at socket 1.
Black wire from VIX 1&2 will be terminated at socket 2.
The shields of the encoder signal cables will be attached to each other and connected to the cable clamp.

Connector 2 Socket: 208459-1 (size 28, 24 contact)
Connector 2 Plug: 208457-1 (size 28, 24 contact)

Table 5. Connector 3 – Wires from stages, light, IR sensor, Thermocouple to Sensor package connector

Connector 3 Socket

Pin	Parker/Sensor Color	Signal Name	VIX Pin	Notes
1	Red+White/Blue	Encoder/Hall 5V	5	Pins 1-12 are Axis 3 (Rotary Motor)
2	Black	Encoder Ground	3	
3	Orange	Encoder Z	1	
4	Brown	Encoder Z-	2	
5	White	Encoder A	8	
6	Yellow	Encoder A-	7	
7	Green	Encoder B	12	
8	Blue	Encoder B-	11	
9	White/Brown	Hall 1	9	
10	White/Orange	Hall 2	13	
11	White/Violet	Hall 3	14	14
12	Orange	End of Travel+	6	Axis 1
13	Blue	End of Travel-	7	
14	Green	Home	8	
15	Orange	End of Travel+	6	Axis 2
16	Blue	End of Travel-	7	
17	Green	Home	8	
18	Red (Blue, Purple)	IR Temp	Tyco 1	+24V Input (shared)
19	Black	IR Temp Ground	Tyco 2	
20	Green	IR Out	Tyco 3	
21	White	IR Out-	Tyco 4	
22	Yellow	Omega Out-	Tyco 5	
23	White	Lamp Return	Tyco 6	
24	-	-	-	No Connection
SHIELD	*Grounded to socket fastener*			

Rotary motor encoder wires will be covered by braided shield and brought to the socket. The other signals (pins 18-24) are joined in the LUSS head with Tyco Mate-N-Lok II (770020-1, 770027-1) connectors.

Table 6. Connector 3 – Wires from Sensor Package to Controllers, Breakout strip

Connector 3 Plug

Pin	LUSS Color	Signal Name	VIX Pin	Notes
1	Red	Encoder/Hall 5V	5	Pins 1-12 are Axis 3 (Rotary Motor)
2	White	Encoder Ground	3	
3	Red	Encoder Z	1	Add pigtail
4	Yellow	Encoder Z-	2	Add pigtail
5	Red	Encoder A	8	
6	Green	Encoder A-	7	
7	Red	Encoder B	12	
8	Blue	Encoder B-	11	
9	Red	Hall 1	9	
10	Brown	Hall 2	13	
11	Black	Hall 3	14	
12	Red	End of Travel+	6	Axis 1
13	Black	End of Travel-	7	
14	White	Home	8	
15	Black	End of Travel+	6	Axis 2
16	Yellow	End of Travel-	7	
17	Black	Home	8	
18	Green	IR Temp	-	+24V Input (shared)
19	Black	IR Temp Ground -	-	
20	Blue	IR Out	-	
21	Black	IR Out-	-	
22	Brown	Omega Out-	-	
23	Black	Lamp Return	-	
24	Orange	-	-	No Connection
SHIELD	*Connected to cable clamp*			

The encoder signal wires will be covered by braided shield attached to the LUSS cable shield and terminated in a metal shell D connector. (Amp 748468-1 or equivalent). The limit signals for axes 1 & 2 will be covered in braided shield and terminated in metal shell D connectors (Amp 748634-1 or equivalent). Pins 3 & 4 (Z, Z-) will be brought out in a shielded pigtail for input to the SCB-68. The other signals will be brought out to a terminal strip routed well away from the digital and motor drive signals.

Connector 3 Socket: 208459-1 (size 28, 24 contact)
Connector 3 Plug: 208457-1 (size 28, 24 contact)

Appendix C – DOE Quartely Report Status

Covering Period: January 1, 2006 to March 31, 2006
Date of Report: April 28, 2006
Status:
This quarter we worked mostly towards the commercialization of the sensor and we found a host mill for our alpha plus trial.

In January 2006, we started a limited liability company in charge of commercializing a non-scanning version (across the CD) of the stiffness sensor. The distinction between scanning and non-scanning is of importance here. Indeed the purpose of this company is not to target the same market as ABB whose specialty is process control of the entire web using scanning platforms. Instead, the focus is on a lower price semi-portable sensor that can be moved from a paper machine to another in a paper mill, to troubleshoot stiffness problems and monitor the evolution of stiffness at a single CD position as function of time. Paul Ridgway (with LBNL) and Emmanuel Lafond are the partners of the company, and Gary Baum is a consultant. The name of the company is Vibrant Sensors LLC and a temporary web page has been set up at: http://www.vibrantsensors.com .

After the creation of the company, negotiations took place between Georgia Tech and Vibrant Sensors to license a part of the scanning mirror patent needed to make the stiffness sensor work and authorize use of know-how of the stiffness sensor owned by GT, to Vibrant Sensors. Gary Baum led the negotiations and Emmanuel Lafond assisted him with Paul Ridgway providing feedback. The agreement was signed in late March 2006 and gives exclusive rights to Vibrant Sensors to use the technology, but only for non-scanning applications. There are of course milestones in the agreement detailing the number of sensors sold by a certain date to oblige the company to commercialize sensor units relatively fast or risk losing its exclusive rights. The agreement was carefully crafted so as to keep the door wide open for ABB or any other interested scanner manufacturer, for negotiating with GT a license for a scanning version of the stiffness sensor and commercialize a scanning sensor.

In February 2006, Paul, helped by Gary and Emmanuel sent an application for the R&D 100 awards annual competition regarding the sensor. Since these awards are quite prestigious in the field of technical inventions, we thought it was worth entering our sensor into the competition. Results will be announced in September or October 2006.

Regarding the alpha plus trial, we are still awaiting a decision from the North West Energy Efficiency Alliance about funding or not Paul Ridgway from LBNL to help IPST carry out the alpha plus trial. NWEEA required more information from us (especially regarding the availability of a commercial version of the sensor) and a step by step plan for the implementation of the sensor on a paper machine, which we were glad to supply.

Finally, in late March we received positive confirmation from Boise Paper Co. that Boise would like us to install our stiffness sensor on their paper machine #4 in St. Helens, OR for a long term

alpha plus mill installation with process control. This is an older and narrower paper machine than in Jackson, AL, which is producing copy paper and other light weight paper grades.
At this stage we are waiting and hope for a positive decision from the NWEEA to fund Paul Ridgway in the next quarter.

On the downside, the talks with the Stora Enso and Kappa Board mill engineers and the Dutch Kenniscentrum Papier en Karton, regarding a mill demonstration by Vibrant Sensors on a Stora Enso fine paper machine and a Kappa Board paperboard machine have not progressed as much as we wished. The main issue here appears to be the financing of the trials by the Dutch companies and the Kenniscentrum.
Nevertheless, from what we have heard so far from some U.S. paper manufacturers we think we could build a prototype of the sensor at Vibrant Sensors and demonstrate it after the Boise mill trial, providing we find the right source of funding. This could be the topic of a SBIR. Hence, besides Holland there are other opportunities that could be exploited in 2007 to commercialize the sensor. But we need to focus on the Boise trial for now.

Emmanuel Lafond interviewed two more applicants to replace Ted Jackson who was our electrical engineer at the Jackson, AL mill trial and who left Georgia Tech in 2005. One engineer has been selected and he will start to work part-time at IPST starting on April 4^{th}.

In March we asked the U.S. Dept. of Energy for a no-cost extension until end of June 2007, to carry out the Alpha plus Boise mill trial in a satisfactory manner and to have enough time to write the final report.

Plan for next quarter:

- Obtain answer from NWEEA about Paul Ridgway's proposal
- Continue planning for long-term (Alpha plus) trial at Boise with Boise and ABB
- Redesign sensor hardware for extended Alpha Plus trial in close relationship with Boise and ABB and hopefully Paul Ridgway (depending on NWEEA proposal result)

Covering Period: April 1, 2006 to June 30, 2006
Date of Report: July 31, 2006
Status:
This quarter we obtained a verbal agreement from the NorthWest Energy Alliance to support part of our long term alpha plus trial.

In April 2006 IPST and LBNL had a conference call involving several project managers and sponsors of the NorthWest Energy Efficiency Alliance (NEEA) located in Portland, Oregon regarding the stiffness sensor. What was proposed to NEEA was a 6 month trial of the sensor at the Boise St. Helens, OR mill which would be sufficient to demonstrate significant savings in fibers and energy on the paper machine #4 of the mill.

The schedule of the trial is as follows: about 6 months for the design, construction, and testing of the sensor at IPST and LBNL, and 6 months of running the sensor on the machine in St. Helens. The people working on the project on the LBNL side will be Paul Ridgway with a bit of Rick Russo's time. At IPST at Georgia Tech, Emmanuel Lafond, Gary Baum and David Huggins will be working on this 6 months installation. As we did in the past, we will divide the tasks between IPST and LBNL and work together to assemble and test the sensor. But contrarily to the Jackson, AL mill installation, the sensor will be independent from the ABB head package and will be a single CD position sensor. It will be installed close to the ABB platform, on the dry end of the machine. The CD position however will be changeable by the operator to allow the operator to measure the stiffness in the center, and the edges of the web.

There will be some redesign compared to the Jackson trial sensor to allow easier maintenance, repair and servicing of the sensor while the web and ABB Smart Platform are running. At this stage a sensor independent from the ABB head package is needed so as not to interfere with daily operations of the machine during 6 months. A program of the various tasks was drafted and approved in May-June after modifications following feedback from NEEA. As NEEA and the Dept. of Energy have convergent goals - increasing energy efficiency, and decreasing energy consumption of paper machines per ton of paper produced -, we think this is an exciting opportunity to conclude successfully this DOE project with the support of NEEA.

In April through June, Emmanuel Lafond and David Huggins, the electrical engineer who was hired to replace Ted Jackson, worked on reconnecting the sensor from the Jackson trial to the ABB Smart platform and on understanding and documenting the procedures for the operation of the sensor and of its software. This is very important as the St. Helens sensor will reuse most of the communication software with the ABB platform, from the Jackson sensor.
This quarter David Huggins was working only 20% of the time on the project as we are not yet in the design & build stage for the long term sensor. Early on we discovered that the ABB Smart platform of IPST had some serious issues related to a power outage several months ago. After many long hours and great troubleshooting support and advice from Ake Hellstrom and other ABB personnel, we were able to restore first the basis weight and caliper sensor to full operation, to get the head package to standardize properly, and finally in June, to re-establish communication with the service workstation (computer monitoring ABB's sensor) and with the laser ultrasonics sensor. Once more, ABB's help and dedication proved invaluable to restart this Smart Platform.

At the end of June we still have a few communications issues between the sensor and ABB platform to troubleshoot. These deal with the tapping of information of basis weight and caliper from the Smart platform and we are working on them. Funding from NEEA is expected anytime now, once there is agreement on intellectual property between IPST and LBNL. The kick-off meeting of the NEEA project and DOE long term installation is planned for July 28 at the mill in St. Helens.

Plan for next quarter:

- Finalize and sign NEEA contracts both at IPST and LBNL
- Hold kick-off meeting for long-term (Alpha plus) trial at Boise

- Design and build sensor hardware for extended Alpha Plus trial in close relationship with ABB and Boise

Covering Period: July 1, 2006 to September 30, 2006
Date of Report: November 6, 2006
Status:
At the end of September E. Lafond resigned his position at IPST to pursue other opportunities. He was replaced by T. Patterson, who has previously worked on non laser ultrasonic projects of interest to the paper industry and who has an expertise in paper physics and papermaking. During the month of September E. Lafond spent time familiarizing T. Patterson with the technical and managerial aspects of the projects.

In September the agreement with the NorthWest Energy Alliance to support part of our long term alpha plus trial was formally approved. This was culmination of several months work on the part of E. Lafond and P. Ridgeway.

Throughout August D. Hodges and E. Lafond continued to work on integrating the equipment back into the ABB Smart Platform setup at IPST. This work extended into September, the last element being completed was the reintegration of the sensing laser. After that work was completed the system was tested and it work satisfactorily with a moving web.

In September several discussion were held with P. Ridgeway of LBNL to (1) coordinate the transfer of PI duties and (2) to begin the coordination and planning for the planned six month mill trial. As previously planned the tasks will be divided between IPST and LBNL. Both groups will work together to assemble and test the sensor. The sensor will be mounted in its own package and will traverse the web on its own frame. It will be installed close to the ABB platform, on the dry end of the machine. The sensor control system will receive basis weight, CD position, grade ID and several other pieces of information from the Smart Platform system. The CD position of the laser sensor will be changeable by the operator to allow the operator to measure the stiffness in the center, and the edges of the web.

Two issues have been identified

1. Replacement of the current sensing laser actuation method with a pneumatic system to facilitate faster sensor motion.

2. Power to the generation laser and the possibility of placing the generation laser in the sensor package to avoid power limitations imposed by fiber optic laser pulse transmission.

These will be addressed and resolved in the upcoming quarter. Additional items that will be addressed in the upcoming quarter are:

1. Development of project schedule in cooperation with LBNL, ABB and the mill
2. Definition of items and services to be supplied by the mill.

3. Design of the frame which will support the laser sensor package (LBNL will complete this task)

Covering Period: October 1, 2006 to December 31, 2006
Date of Report: January 30, 2007
Status:
In the previous quarterly report several items requiring actions were identified. These were

3. Replacement of the current sensing laser actuation method with a pneumatic system to facilitate faster sensor motion.
4. Power to the generation laser and the possibility of placing the generation laser in the sensor package to avoid power limitations imposed by fiber optic laser pulse transmission.
5. Development of project schedule in cooperation with LBNL, ABB and the mill
6. Definition of items and services to be supplied by the mill.
7. Design of the frame which will support the laser sensor package (LBNL will complete this task)

The actions taken were

1. The actuators were not reliable due to limit switches which failed frequently. In addition the upcoming mill trial will require rapid repositioning of the generation laser. The original actuators were relatively slow (50 mm/s). Pneumatic actuators had been identified with actuation speeds of 600 mm/s. However, these actuators required a highly filtered air supply and there was a question as to the long term survivability in a mill environment. Further investigations into suppliers identified a supplier that could provide a linear motor actuator with a speed capability of 1000 mm/s and high positioning accuracy. These actuators were purchased in late December and have been delivered to IPST.
2. Investigation into potential suppliers showed that there were no suppliers capable of providing a generation laser system which could be mounted in the sensor package. The lasers were too large and the cables from the power supply to the laser were too short. The existing laser will be used. There is a small possibility that the existing laser may not have sufficient power to produce a measurable signal in the heaviest papers produced at the Boise St. Helens mill. However, the mill produces a large number of grades and this will no have a significant impact on the project.
3. A project schedule has been developed in cooperation with the Boise St. Helens mill, LBNL, and ABB. Twice weekly teleconferences are held between IPST, LBNL, and ABB to discuss progress. Once a month a teleconference is held between IPST, LBNL, BoisePaper and ABB to review progress and update the schedule.
4. During the teleconferences referenced in Item 3, mill supplied services have been identified and agreed upon.
5. The design for the frame to support the sensor package has been completed.

In the upcoming quarter the following tasks will be completed

1. During a February 1 machine shutdown the sensor frame will be installed at the St. Helens mill. If time permits the actuator system for moving the sensor package on the

frame will be tested. IPST personnel participating in the frame installation are T. Patterson and D. Huggins. P. Ridgeway from LBNL will also participate. This will be the first visit by the IPST personnel to the mill and will provide an orientation opportunity.

2. The new actuators will be installed in the sensor package. This will require a redesign of the mechanical structure and integration of the controller software into the existing control program.
3. The Graphical User interface for the control program needs to be redesigned to allow easy use by mill personnel.
4. A housing for the sensor package will be designed and built. This housing will protect the sensor package when it is off-machine and not in use.
5. Cabinets for the laser electronics and LUSS computer must be fabricated/purchased and the equipment installed.
6. Software for communication between the ABB system and the LUSS computer must be completed and tested.
7. The system is scheduled for installation at the mill during a machine shut down in late March 2007.

Covering Period: January 1, 2007 to March 30, 2007
Date of Report: May 4, 2007
Status:

In the previous quarterly report several items requiring actions were identified. These were

1. During a February 1 machine shutdown the sensor frame will be installed at the St. Helens mill. If time permits the actuator system for moving the sensor package on the frame will be tested. IPST personnel participating in the frame installation are T. Patterson and D. Huggins. P. Ridgeway from LBNL will also participate. This will be the first visit by the IPST personnel to the mill and will provide an orientation opportunity.
2. The new actuators will be installed in the sensor package. This will require a redesign of the mechanical structure and integration of the controller software into the existing control program.
3. The Graphical User interface for the control program needs to be redesigned to allow easy use by mill personnel.
4. A housing for the sensor package will be designed and built. This housing will protect the sensor package when it is off-machine and not in use.
5. Cabinets for the laser electronics and LUSS computer must be fabricated/purchased and the equipment installed.
6. Software for communication between the ABB system and the LUSS computer must be completed and tested.
7. The system is scheduled for installation at the mill during a machine shut down in late March 2007.

The actions taken were

1. The sensor frame was installed at the St. Helen’s mill in February.
2. The new actuators for moving the generation laser have been installed in the sensor package. These actuators are more durable and capable of significantly higher speeds in

comparison to the previously used actuators. This will increase both the utility and reliability of the system.

3. The graphical user interface s been partially redesigned, the remaining work will be completed prior to the end of May 2007.
4. The off sheet housing for the sensor package was designed, built and installed at the mill.
5. The St. Helens mill has provided an unused electrical cabinet for the project and has installed it adjacent to the paper machine.
6. The software for communication between the ABB and LUSS is not yet completed. The communication protocols have been established and programming is in progress.

The system was not installed on the machine

Covering Period: April 1, 2007 to June 30, 2007
Date of Report: August 2, 2007
Status:
In the previous report the following activities were scheduled

1. The system is scheduled for installation at the mill during a machine shut down on May 31, 2007.
2. The Graphical User interface for the control program needs to be redesigned to allow easy use by mill personnel will be completed in May.
3. Software for communication between the ABB system and the LUSS computer must be completed and tested.
4. The complete system will be tested at IPST during May 2007.
5. The system will begin operational testing at the mil following the installation.

During the previous period progress was as follows

1. Lab scale testing at IPST showed that the cabling between the LUSS computer and the LUSS sensor package was susceptible to electromagnetic interference. This interference was of a sufficient magnitude that the data signals could not be interpreted and required that the cables be replaced. As a result the system was not installed in May. A second opportunity to install the system was available during a July 19 shutdown of the paper machine. On July 18, after arriving at the paper mil we were informed that there would not be a shutdown because the previous week other non related problems on the paper machine had caused significant downtime. All installation work that could be accomplished with the paper machine running was performed. This included installing all of the computer and control hardware and software, mounting the LUSS senor package on the guide rail for transporting the package across the paper web, trouble shooting the interface between the LUSS and the paper machine process control system and making stiffness measurements on the moving paper by manually positioning the LUSS over the paper web. A second shut down is scheduled for August 15, 2007. The remaining work will be completed at that time.
2. The graphical user interface was redesigned and approximately 90% of the redesign was implemented. Completion of the remaining portions required that the LUSS be fully installed.
3. The software communication between the LUSS and the ABB system was tested in July at the mill.

4. The complete system was tested at IPST in June 2007.
5. Operational testing will begin following the August 15, 2007 shut down.

Activities for the upcoming quarter are

1. Complete installation of the LUSS during the August 15, 2007 shut down.
2. Write operational manual for mill personnel.
3. Verify accuracy of on-line stiffness measurements over the range of grades produced.
4. Develop new process control strategies based on the on-line LUSS stiffness measurements.

Covering Period: July 1, 2007 to September 30, 2007
Date of Report: October 31, 2007
Status:
In the previous report the following activities were scheduled

1. Complete installation of the LUSS during the August 15, 2007 shut down.
2. Write operational manual for mill personnel.
3. Verify accuracy of on-line stiffness measurements over the range of grades produced.
4. Develop new process control strategies based on the on-line LUSS stiffness measurements.

During the previous period progress was as follows

1. Several problems were encountered during the August 15, 2007 visit to the mill. These centered on triggering of the laser and commanding movement of the guide rail/sensor package on to the moving sheet. A second visit in September was required. During this visit the laser triggering circuitry was replaced with a simpler circuit. The problems with the guide rail were traced to a data acquisition communication problem which was resolved. Two additional problems were encountered (1) the linear actuators used to position the generation laser malfunctioned (2) several parameters were not communicated correctly between the ABB control system and the LUSS system. There was in sufficient time to resolve the problems. A third visit to the mill is currently in progress. The ABB-LUSS communication problem has been resolved. The linear stage problem is being addressed with the help of a manufacturer's representative from the stage manufacturer.
2. An operational manual was written and will be distributed the week of November 5, 2007.
3. Since the system, was not operational, this task will be completed in the current quarter.
4. Since the system, was not operational, this task will be completed in the current quarter and the following quarter...

Activities for the upcoming quarter are

1. Verify accuracy of on-line stiffness measurements over the range of grades produced.
2. Develop new process control strategies based on the on-line LUSS stiffness measurements.
3. Demonstrate the potential economic payback of the system using operational data.

Covering Period: October 1, 2007 to December 31, 2007
Date of Report: January 30, 2008
Status:
In the previous report the following activities were scheduled
1. Verify accuracy of on-line stiffness measurements over the range of grades produced.
2. Develop new process control strategies based on the on-line LUSS stiffness measurements.
3. Demonstrate the potential economic payback of the system using operational data.

During the previous period progress was as follows
1. It had been planned that the system would be operational by the October 1. This was not the case. There had been a visit to the mill in July to install the sensor. Complete installation was not possible because the planned machine shutdown was cancelled. It was attempted to complete the installation during an August trip, however problems were encountered with the linear actuators used to position the generation laser. In September a third trip was made. The actuator problem was solved however integration problems between the control LUSS control system and the controller of the guide rail were encountered. There were also communication issues between the LUSS and the ABB control system. A fourth trip was made at the end of October. During this trip the remaining problems were solved. However, the operation of the LUSS software was not completely verified. .A fifth trip was made at the beginning of January 2008. The LUSS software operation was fully verified and the machine operators were trained on the operation of the system. The system was left in an operational state and the operators were instructed in the procedures for collecting the data needed to calibrate the sensor and to begin collection of base line data for the relationship between operating procedures and stiffness. This data is currently being collected.
2. New process control strategies were not developed because the system was not running.
3. The economic payback was developed because the system was not running.

Activities for the upcoming quarter are
1. Complete collection of calibration data and calibrate the sensor
2. Complete collection of baseline process data
3. Meet with mill personnel to plan LUSS sensor use for development of new process control strategies based on the on-line LUSS stiffness measurements.
4. Demonstrate the potential economic payback of the system using operational data.

Covering Period: January 1, 2008 to March 31, 2008
Date of Report: April 23, 2008
Status:
In the previous report the following activities were scheduled
5. Complete collection of calibration data and calibrate the sensor
6. Complete collection of baseline process data

7. Meet with mill personnel to plan LUSS sensor use for development of new process control strategies based on the on-line LUSS stiffness measurements.
8. Demonstrate the potential economic payback of the system using operational data.

During the previous period progress was as follows

6. A fifth trip was made at the beginning of January 2008. The LUSS software operation was fully verified and the machine operators were trained on the operation of the system. The system was left in an operational state and the operators were instructed in the procedures for collecting the data needed to calibrate the sensor and to begin collection of base line data for the relationship between operating procedures and stiffness.

   The machine operators ran the LUSS from 17 January through 6 February and obtained full CD width samples of paper made while the LUSS was in operation. Two problems occurred. On January 24 the LUSS stopped producing usable data. A number of remote trouble shooting actions were taken and the on site ABB personnel also performed some trouble shooting activities. The laser-fiber optic portion of the system uses a microscope lens to focus, the large diameter laser beam that emerges from the laser, onto the end of the fiber optic that transmits the laser to the sensor package. It is believed that the end of the fiber optic was melted and/or damaged by the laser. The damage is great enough that little or no laser energy is transmitted to the sensor package.

   The samples that were collected were sent to IPST for laboratory stiffness measurements. In examining the samples not all were usable because a number were not labeled. A total of ten samples were labeled and were taken while the LUSS was operating properly. The intent was to use these samples to create calibration files which allow the raw LUSS measurements of the sheet motions to be used to calculate sheet stiffness. While the raw signals appear to be of good quality, there has been some difficulty in developing the appropriate calibration files. The response of the sheet has been distinctly different in the MD and CD directions. Work is continuing to develop the calibration files.
7. New process control strategies were not developed because the system was not running.
8. The economic payback was developed because the system was not running.

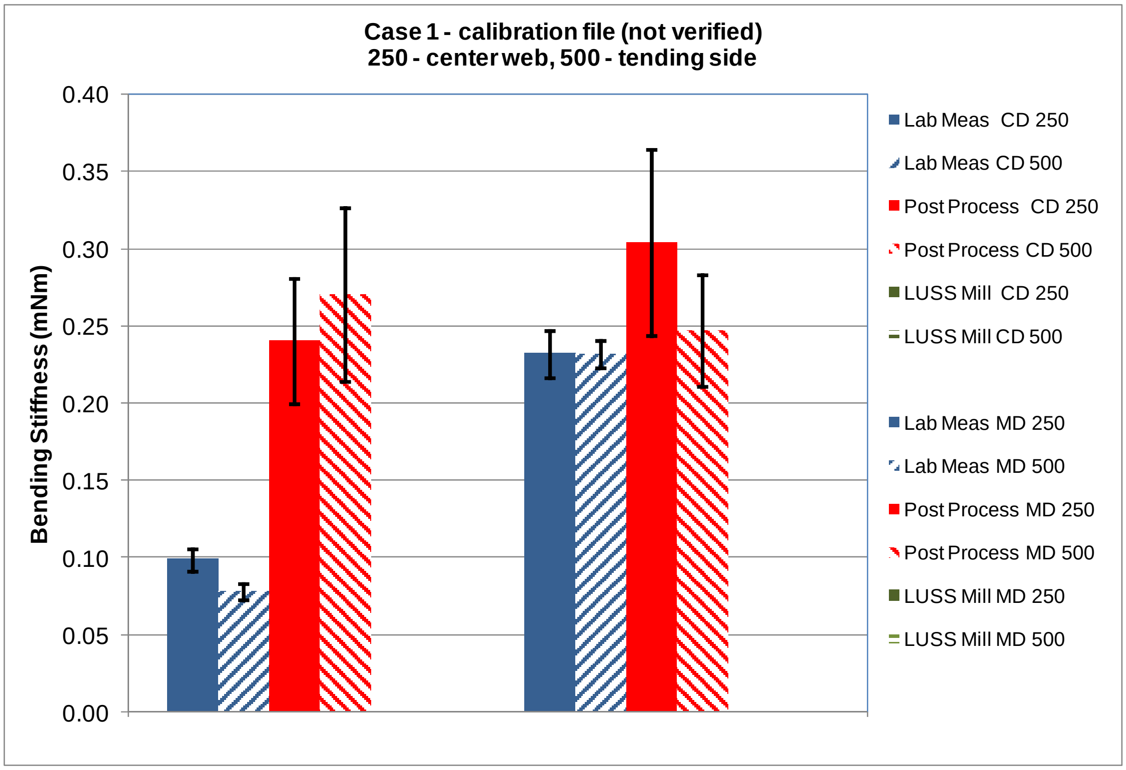
Activities for the upcoming quarter are

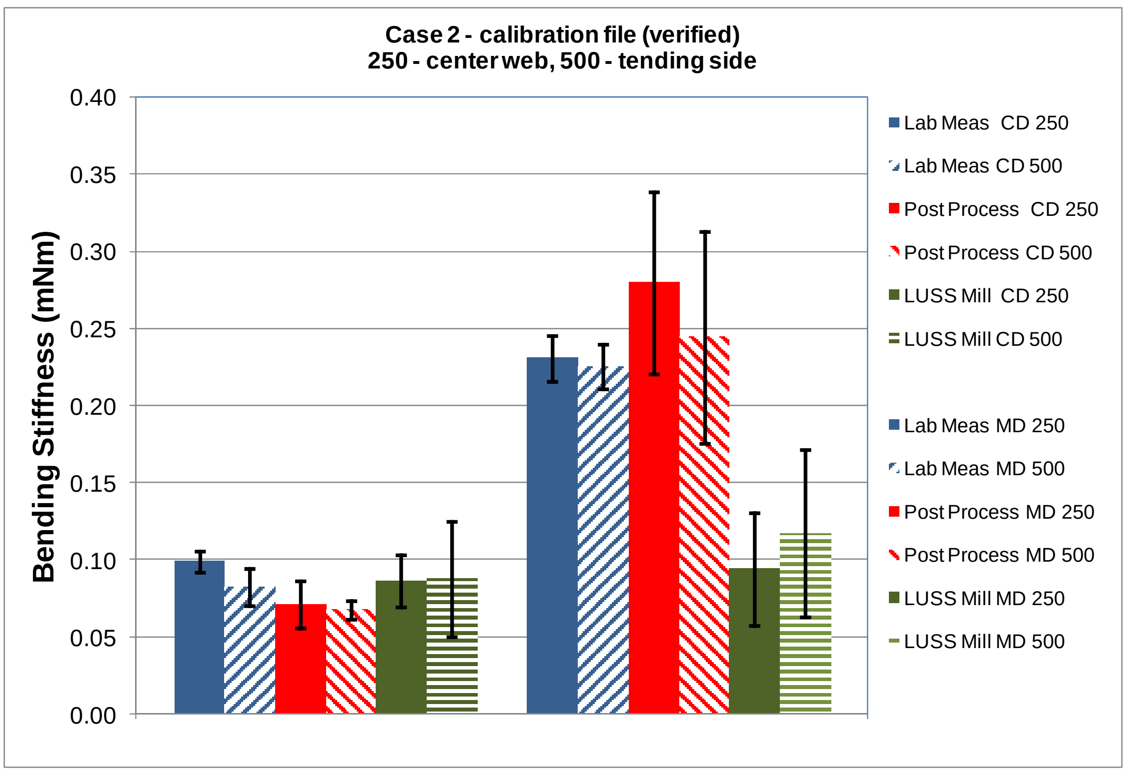
4. Complete development of the calibration files
5. Repair laser-fiber optic
6. Complete collection of baseline process data
7. Meet with mill personnel to plan LUSS sensor use for development of new process control strategies based on the on-line LUSS stiffness measurements.
8. Demonstrate the potential economic payback of the system using operational data.

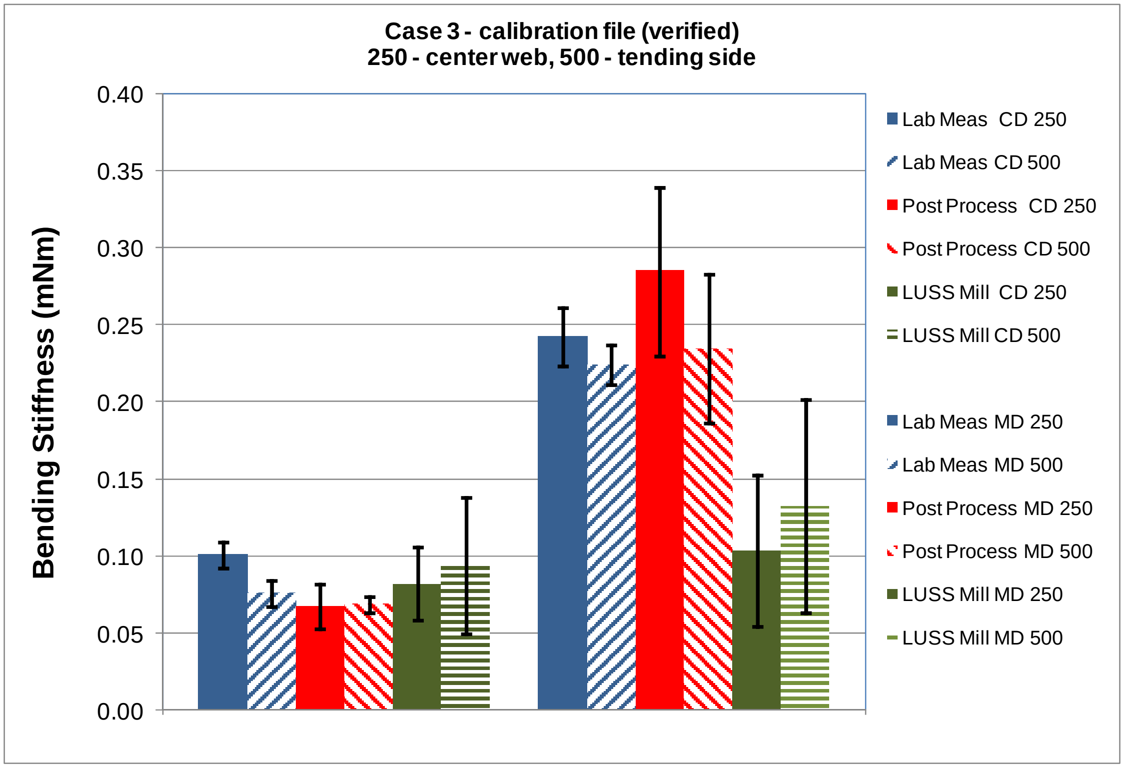
Appendix C - Summary of Boise #4 Paper Machine Test Data

Summary of Data from all Cases

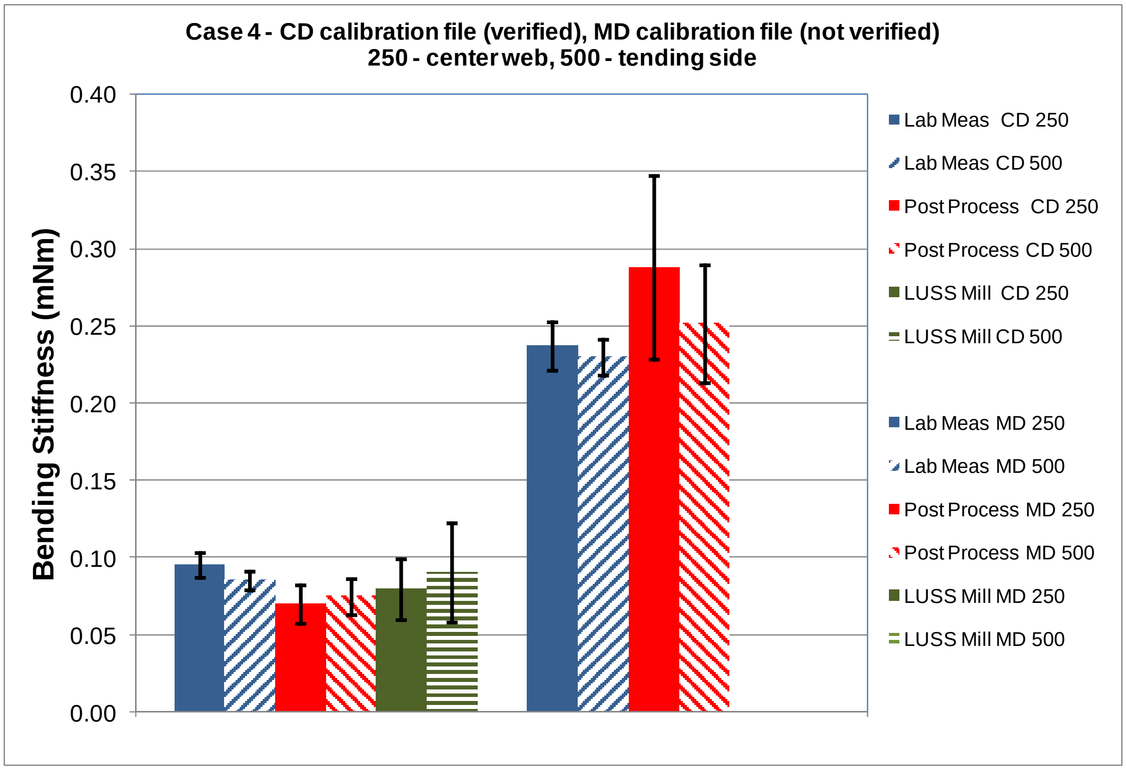
			Laboratory Measurement							Post Process - pce file viewer								LUSS Real Time						
	Grade	Case	ABB 250 Stiff	ABB 250 std error	T Signific.	avg diff	avg dif/avg 250	Sig Diff	250 - 500 >0	Calibration File	ABB 250 Stiff	ABB 250 std error	T Signific.	avg diff	avg dif/avg 250	Sig Diff	250 - 500 >0	ABB 250 Stiff	ABB 250 std error	T Signific.	avg diff	avg dif/avg 250	Sig Diff	250 - 500 >0
CD	34.5# FB	1	0.099	0.0021	0.001%	0.021	21.0%	Y	Y	Not Verified	0.240	0.0066	0.595%	-0.030	-12.6%	Y	N							
	34.5# FB	2	0.099	0.0020	0.108%	0.017	16.9%	Y	Y	Verified - new	0.071	0.0023	7.543%	0.004	5.1%	Y	Y	0.087	0.0026	49.119%	0.000	-0.2%	N	
	34.6# FB 92	3	0.101	0.0025	0.002%	0.025	24.5%	Y	Y	Verified - new	0.067	0.0023	35.068%	0.001	1.5%	N		0.082	0.0037	16.159%	-0.009	-11.3%	N	
	34.5# FB	4	0.095	0.0023	0.141%	0.010	10.5%	Y	Y	Verified - new	0.070	0.0018	1.017%	-0.005	-7.2%	Y	N	0.080	0.0029	3.695%	-0.012	-15.6%	Y	N
	34.6# FB92	5	0.095	0.0024	0.749%	0.014	14.3%	Y	Y	Verified - new	0.071	0.0027	6.365%	0.006	9.2%	Y	Y	0.098	0.0085	30.818%	-0.004	-4.2%	N	
	34.5# FB	6	0.103	0.0015	0.000%	0.024	23.6%	Y	Y	Not Verified	0.239	0.0149	22.084%	-0.017	-7.0%	N								
	34.5# FB	7	0.096	0.0025	0.001%	0.017	17.5%	Y	Y	Not Verified	0.285	0.0101	5.162%	-0.018	-6.1%	Y	N							
	34# FB 92	8	0.101	0.0017	0.066%	0.016	16.2%	Y	Y	Not Verified	0.296	0.0062	2.167%	-0.016	-5.5%	Y	N							
	44.9 Poly Base	13	0.201	0.0049	0.012%	-0.033	-16.2%	Y	N	Verified - org	0.315	0.0155	21.780%	0.018	5.7%	N								
	45.5# SOW2	9	0.250	0.0043	0.000%	0.054	21.7%	Y	Y	Verified - orig	0.242	0.0058	4.681%	-0.015	-6.1%	Y	N	0.243	0.0061	13.417%	0.024	10.0%	N	
	73.34 gsm	12	0.214	0.0037	0.027%	-0.022	-10.1%	Y	N	Not Verified	0.365	0.0314	0.000%	0.196	53.7%	Y	Y	0.158	0.0059	4.053%	-0.014	-8.9%	Y	N
MD	34.5# FB	1	0.232	0.0044	46.783%	0.000	0.2%	N		Verified - orig	0.304	0.0099	0.002%	0.054	17.7%	Y	Y							
	34.5# FB	2	0.231	0.0043	23.286%	0.005	2.2%	N		Verified - orig	0.279	0.0095	0.538%	0.037	13.4%	Y	Y	0.094	0.0058	4.263%	-0.021	-22.1%	Y	N
	34.6# FB 92	3	0.243	0.0055	0.890%	0.018	7.6%	Y	Y	Verified - orig	0.285	0.0137	0.139%	0.050	17.6%	Y	Y	0.103	0.0078	2.107%	-0.032	-30.9%	Y	N
	34.5# FB	4	0.237	0.0044	16.695%	0.007	3.0%	N		Verified - orig	0.288	0.0088	0.050%	0.041	14.4%	Y	Y							
	34.6# FB92	5	0.235	0.0041	2.400%	0.015	6.3%	Y	Y	Verified - orig	0.285	0.0067	0.184%	0.036	12.7%	Y	Y							
	34.5# FB	6	0.246	0.0039	0.204%	0.015	6.2%	Y	Y	Not Verified	0.314	0.0084	0.001%	0.060	19.2%	Y	Y							
	34.5# FB	7	0.237	0.0031	10.630%	0.006	2.4%	N		Verified - orig	0.314	0.0113	0.004%	0.074	23.7%	Y	Y							
	34# FB 92	8	0.233	0.0037	6.071%	0.011	4.8%	Y	Y	Verified - orig	0.335	0.0114	0.529%	0.042	12.7%	Y	Y							
	44.9 Poly Base	13	0.574	0.0123	2.909%	-0.032	-5.5%	Y	N	Not Verified	0.196	0.0115	0.008%	-0.137	-69.9%	Y	N							
	45.5# SOW2	9	0.596	0.0075	0.096%	0.030	5.1%	Y	Y	Verified - new	0.454	0.0314	16.025%	-0.050	-11.0%	N		0.251	0.0187	21.001%	0.022	8.8%	N	
	73.34 gsm	12	0.584	0.0050	3.616%	-0.019	-3.3%	Y	N	Not Verified	0.276	0.0052	0.000%	0.034	12.5%	Y	Y	0.247	0.0074	28.508%	0.004	1.8%	N	


Case 1 - calibration file (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500

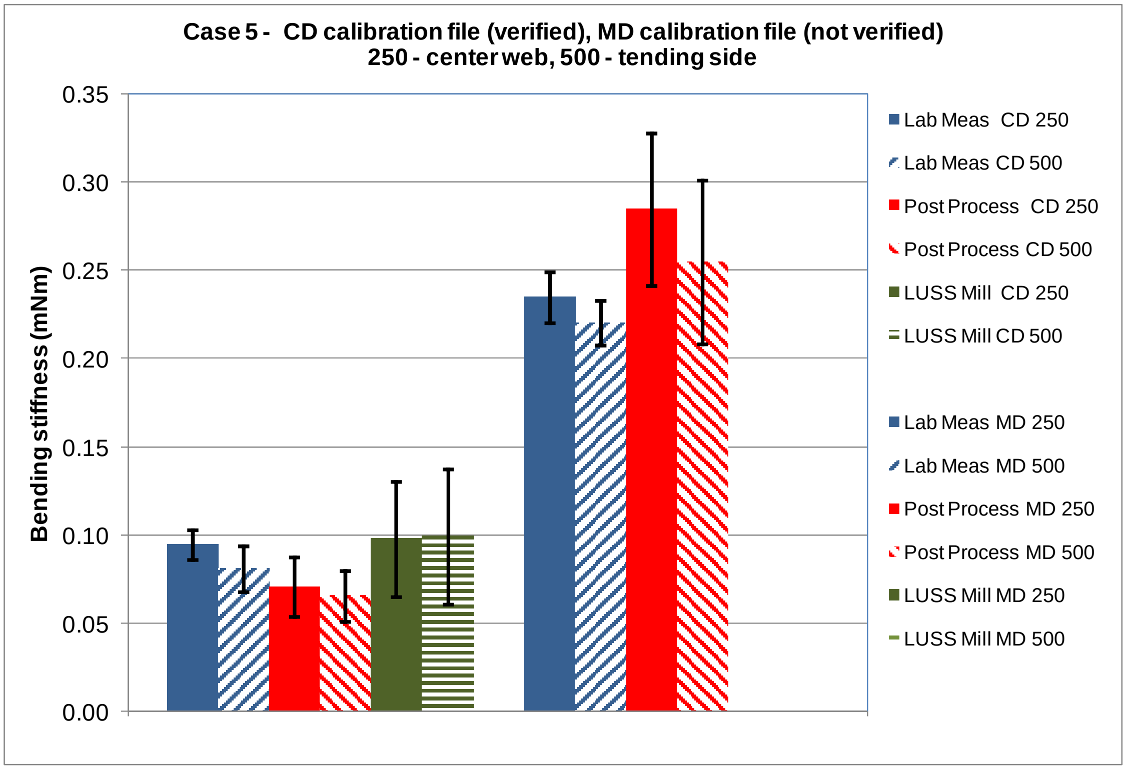

Case 2 - calibration file (verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500

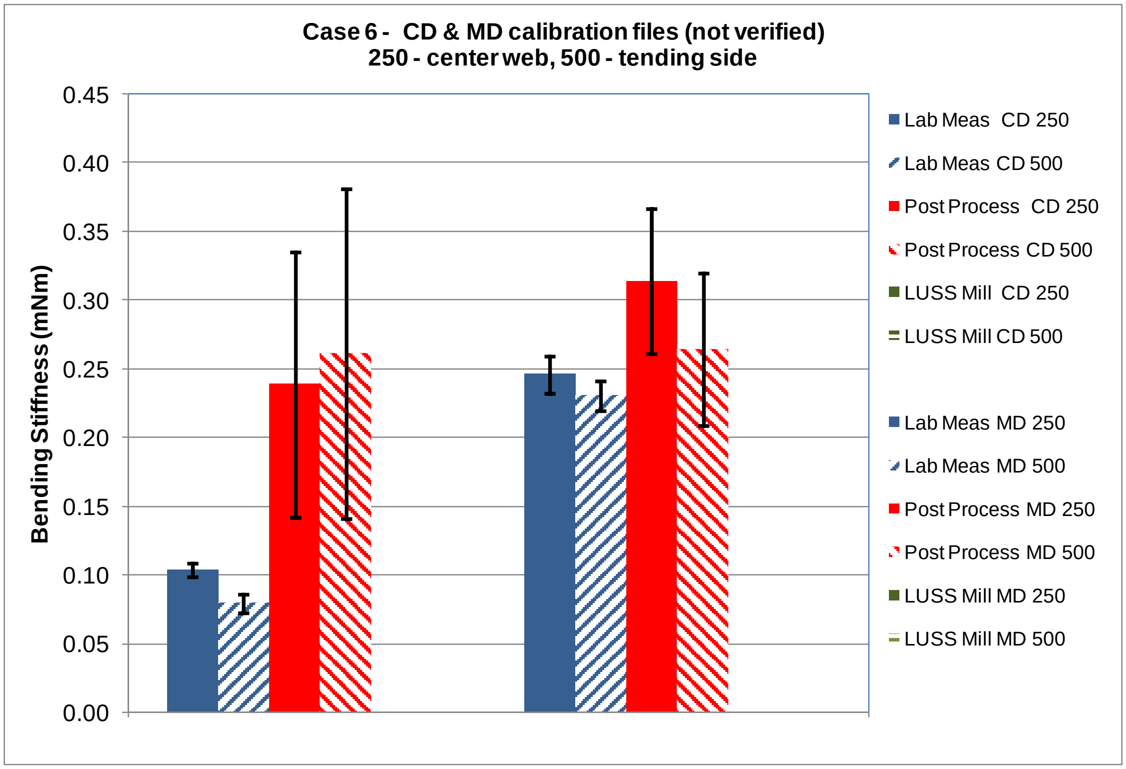


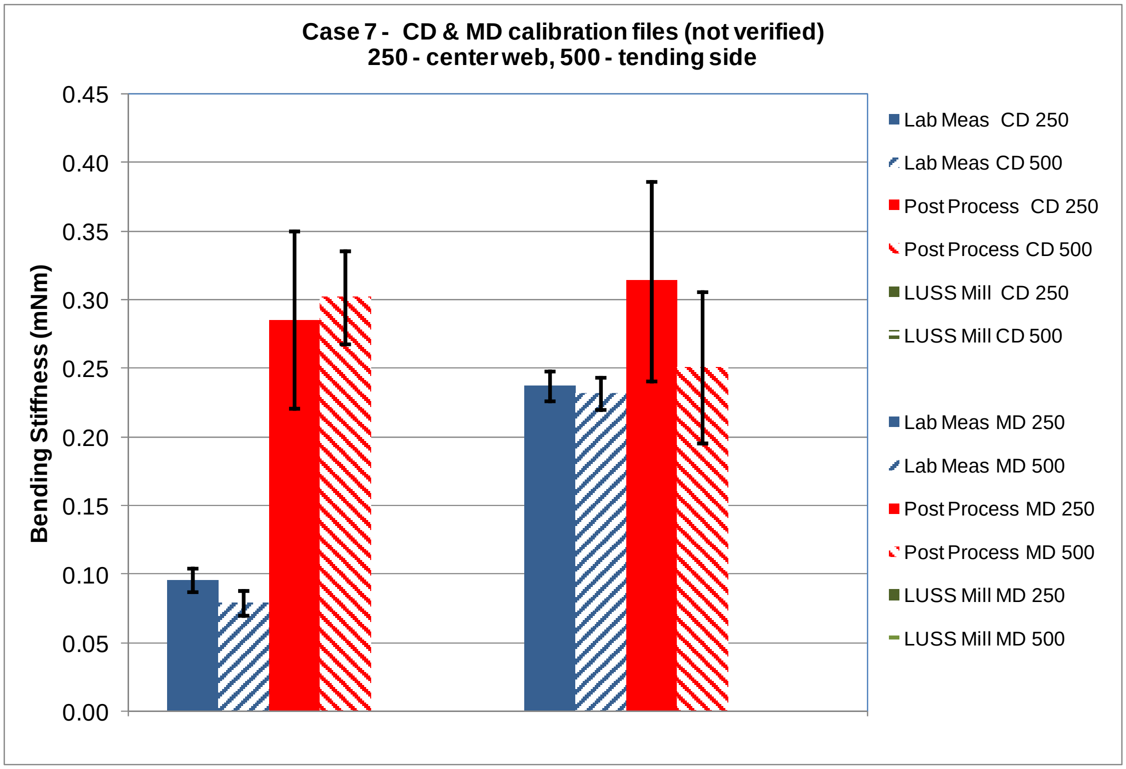
Case 3 - calibration file (verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500

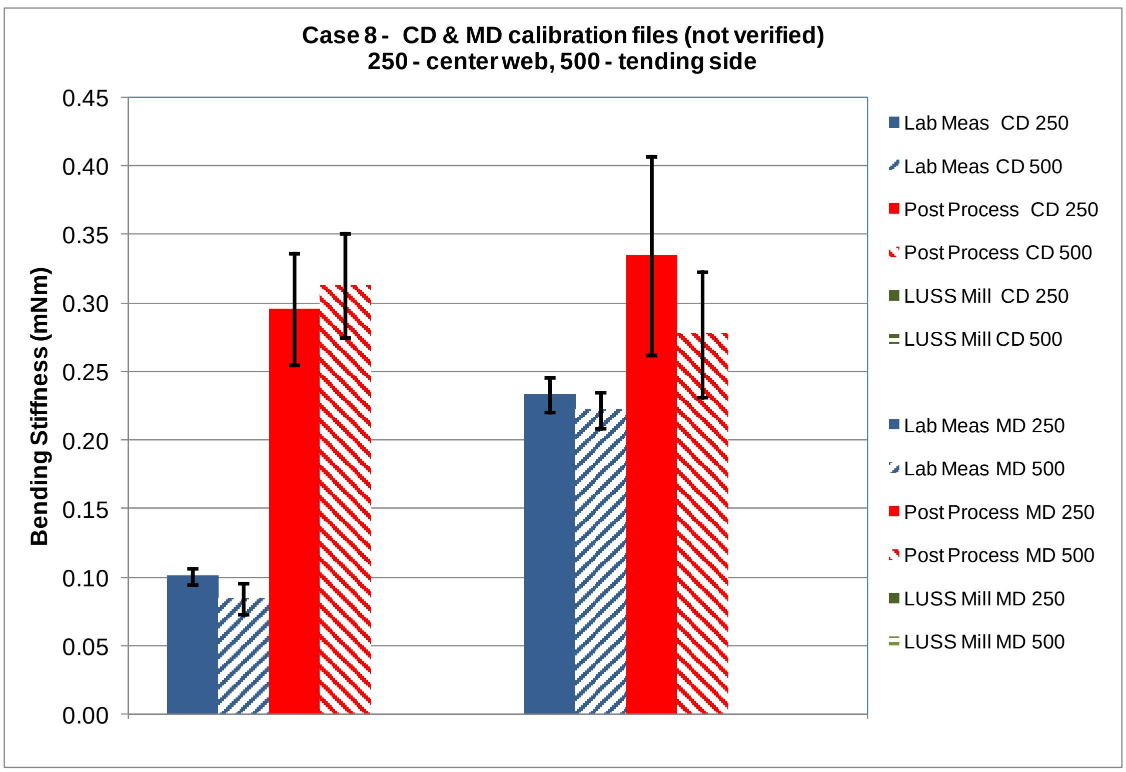


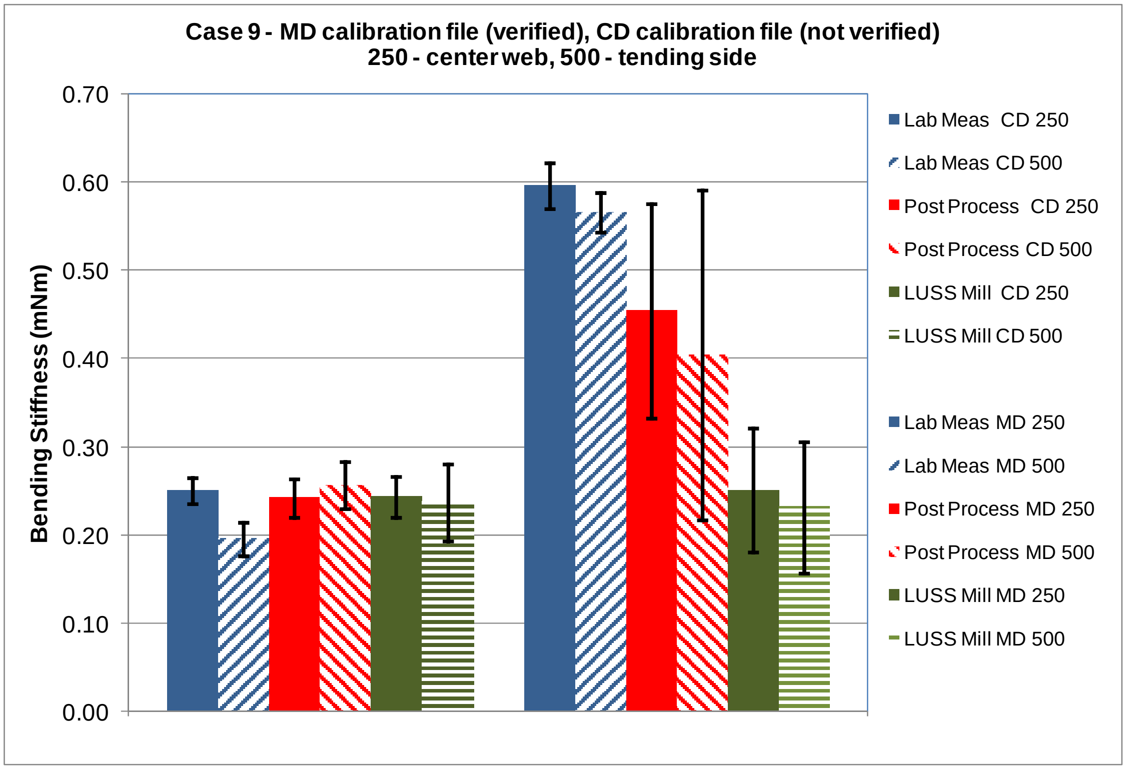
Case 4 - CD calibration file (verified), MD calibration file (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500

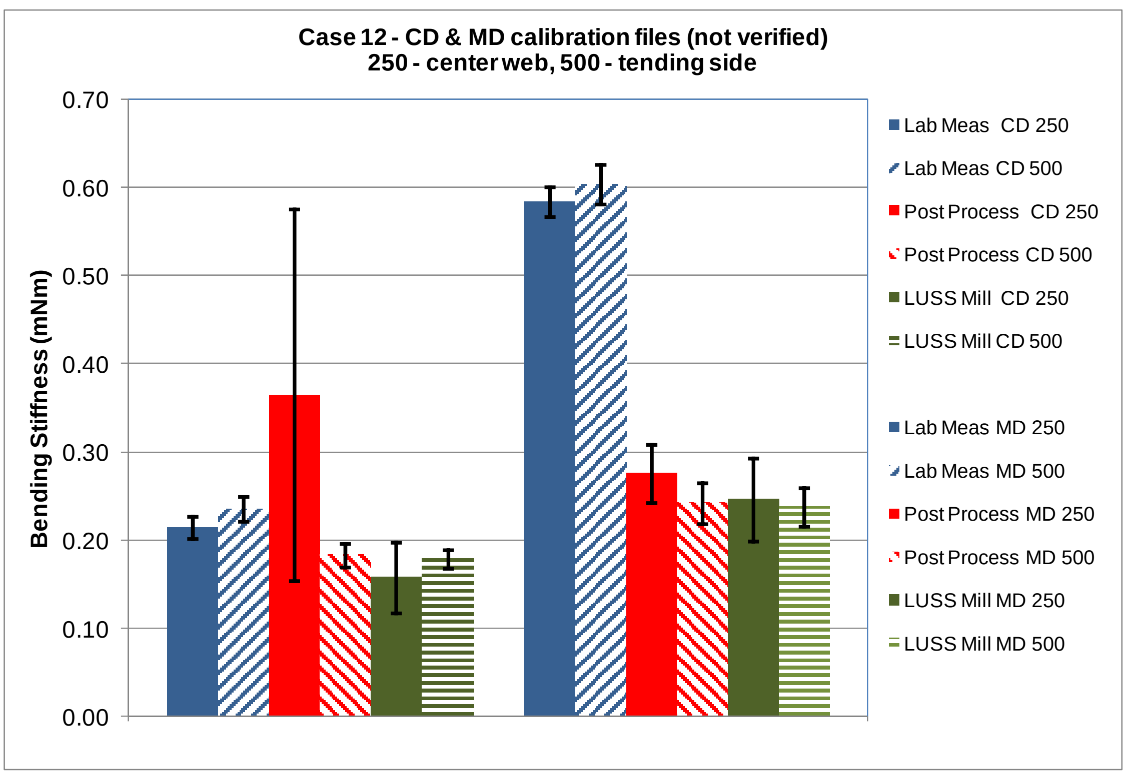

Case 5 - CD calibration file (verified), MD calibration file (not verified)
250 - center web, 500 - tending side
Bending stiffness (mNm)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500

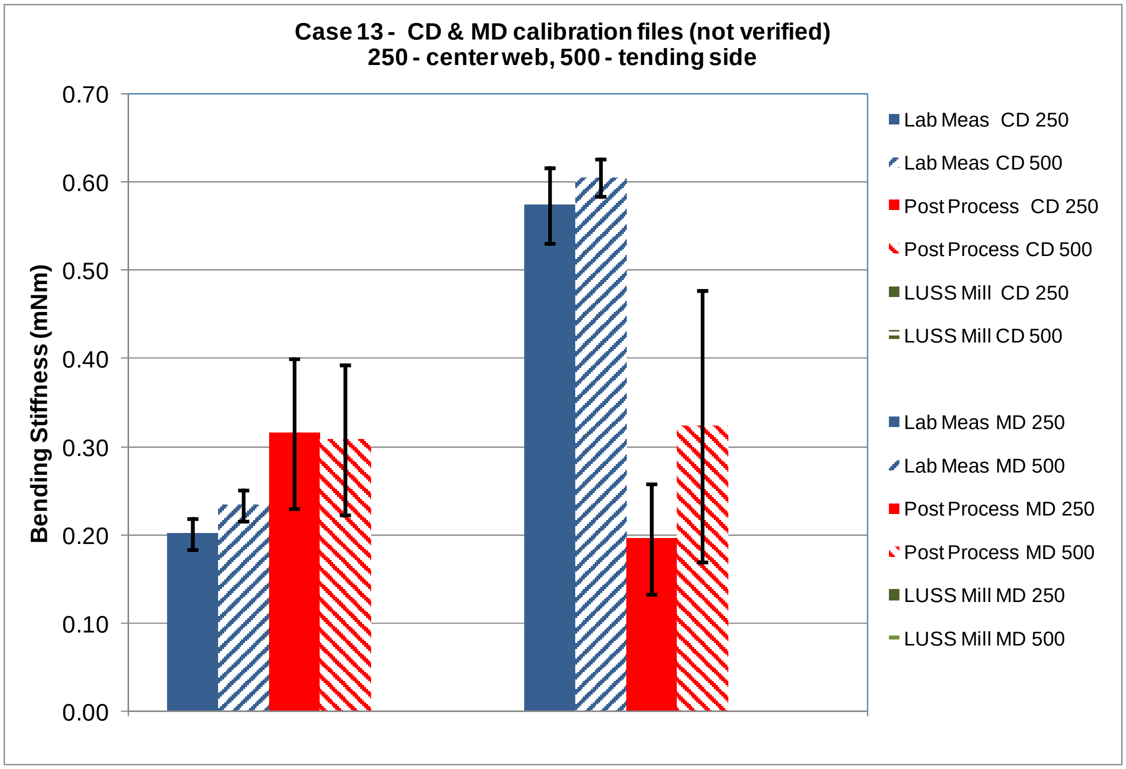

Case 6 - CD & MD calibration files (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500


Case 7 - CD & MD calibration files (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500


Case 8 - CD & MD calibration files (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500


Case 9 - MD calibration file (verified), CD calibration file (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500


Case 12 - CD & MD calibration files (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500


Case 13 - CD & MD calibration files (not verified)
250 - center web, 500 - tending side
Bending Stiffness (mNm)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Lab Meas CD 250
Lab Meas CD 500
Post Process CD 250
Post Process CD 500
LUSS Mill CD 250
LUSS Mill CD 500
Lab Meas MD 250
Lab Meas MD 500
Post Process MD 250
Post Process MD 500
LUSS Mill MD 250
LUSS Mill MD 500