Cotton Catchment Communities CRC

FINAL REPORT

(due within 3 months on completion of project)

Part 1 - Summary Details

Cotton CRC Project Number: 4.03.04

Project Title: Ginning (Moisture and Contamination)

Project Commencement Date: 7/2006 **Project Completion Date:** 6/2009

Cotton CRC Program: Value Chain

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Background

Two ambitious objectives were set out for this project. The first objective was to design and build a moisture measuring sensor without the operational shortcomings of current sensors and the connection of this sensor with a moisture replenishing system. The second was to design and build a sensor to detect contamination in loose fibre linked with a system to remove detected contamination from transport ducting. Both objectives are aligned with the industry's strategy of maintaining and improving fibre quality.

The drive to measure and ensure optimum moisture levels for seed-cotton and lint is associated with optimizing the ginning process to allow good cleaning, ginning, baling and safe storage. Dry cotton is easier to clean but will be damaged during ginning and lint cleaning. On the other hand, cotton with excessive moisture is difficult to gin and clean, and will degrade during storage. To optimise processing and fibre quality the amount of moisture taken up or lost by cotton under ambient conditions needs to be balanced with the amount of drying or moisture applied during the pre-cleaning, ginning and baling processes. Accurate moisture sensing is critical in these regards.

The issue with contamination is that even a single foreign fibre can lead to the downgrading of yarn, fabric or garments or even total rejection of an entire batch. Most contamination arises from impurities incorporated into the bale as a result of human interaction during harvesting, ginning and baling. Australia must ensure that its low-contamination 'type' is maintained in order for growers to continue to receive their current premiums. Spinners indicate that low-contamination is one of the most favourable aspects of Australian cotton[1]. However, despite this view some mills have reported concerns over increasing incidences of contaminants, e.g. such as blue polypropylene and jute string (from jute/hessian bags).

Both moisture and contamination sensing systems were designed and built during this project. Of the two, the moisture measuring system progressed further and was tested and improved in industry for two years. At the time of writing a full international patent is being prepared for the moisture sensor, a peer review paper written on its performance in industry and the sensor results linked to a commercial drying management system. The contamination sensor had undergone preliminary testing but had not been tested in industry. Design and implementation of a contamination removal system within the gin is still required before the original objective is fulfilled completely.

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[1] Gordon, S., van der Sluijs, M. and Prins, M., 'Quality Issues for Australian Cotton from a Mill Perspective', *pub* Australian Cotton CRC, June 2004

Project Objectives

The stated objectives of the project and whether they were achieved are listed in Table I below.

Table I – Project objectives, milestones, performance indicators and achievement

Objective	No.	Milestone	Performance Indicator	Achieved
Moisture measurement and replenishment through the gin process.	1.1	Assessment and selection of moisture measurement sensors and design of replenishing system	Appropriate sensing system married with replenishing system able to condition fibre to recommended moisture contents across lint cleaners	**Yes – sensing and replenishing system designed**
	1.2	Fit measurement system to industrial lint cleaner to enable moisture measurement trials in situ of the lint cleaner	Measurement sensing system records cotton moisture accurately on-line	**Yes – sensing system accurately records cotton moisture on-line**
	1.3	Design replenishing system and test in industrial environment	Replenishing system able to condition fibre to appropriate levels before lint cleaning	**Yes – replenishing systems designed and tested** **Addition of moisture improves fibre properties**
	1.4	Accurate moisture measurement at pertinent locations throughout gin and maintenance of correct moisture levels at gin stand and lint cleaner saws.	In combination with modifications made in CTFT9 SFC and nep levels are lowered on average by 60% and 50% respectively.	**Not fully implemented in industry** **Tested combinations of the MLC and moisture systems improve nep levels by >20% and SFC by >15%**
Contamination detection and removal immediately after ginning.	2.1	Assessment and selection of colour detection sensors and design of contamination removal system	Appropriate sensing system married with removal system able to remove contaminated fibre as it flows pre or post lint cleaner	**Sensing system designed and tested** **Removal system not tested**
	2.2	Propose decontamination system and attempt to enable preliminary measurement trials in situ of gin	Prototype decontamination system is demonstrated in a gin, although not necessarily a commercial gin	**Preliminary contamination measurement trials conducted**
	2.3		Successful detection and efficient removal of coloured contaminants from cotton in transport air-flow.	**Removal system not tested**

Methods

Industrial trials were conducted during the Narrabri gin seasons of 2007, 2008 and 2009. Gin seasons in these years were shorter than usual due to drought and typically ran from late April through to late June.

Moisture sensing

The method followed in the design, construction and testing of the moisture sensing device is described in full in the paper entitled 'an non-invasive moisture measuring device for gin ducting' submitted for publication to the American Society for Agricultural and Biological Engineering in October 2009. A copy of the paper is appended to this report (see Appendix 1). An abridged version of this paper was also prepared for the Beltwide Cotton Conferences held in January 2010.

A general description of the device's working elements can be found in the provisional patent document submitted January 2009 entitled 'a system and process for measuring properties'. A copy of this patent is appended to this report (see Appendix 2). At the time of writing a full International Patent Application was being written.

Moisture replenishment - sprays

The effect of adding moisture to cotton lint by liquid sprays was tested during the 2007 season at the Auscott Warren gin. The objective in this work was to test the practicality of adding moisture as a spray to lint prior to the lint cleaner condenser. Figure 1 illustrates the original idea proposed for adding water or humidified air to cotton prior to the lint cleaner.

Stainless steel, fine spray, atomizer nozzles for water and/or a solution of water and wetting agent were installed and tested in a number of places in gin ducting between the gin and lint cleaner, and between pre-cleaning machines before the gin. A peristaltic pump with a capacity of up to 3 dm^3/min, was used to pump water from a 150 dm^3 holding drum into two nozzles, which were connected to equal lengths of 25 mm hose joined to a T-piece after the pump. Nozzle outlets were fixed flush to gin ducting so as to minimize snagging of seed-cotton or lint around the nozzles where dosing occurs. Figure 2 shows the nozzles installed between two pre-cleaning machines at the Auscott Warren gin. Figures 3a and 3b show installation points in ducting prior to the lint cleaner.

A moisture content of 6% was nominated as the level of moisture required in the lint before lint cleaning. Dosing rate was determined by measuring the moisture content of fibre or seed-cotton withdrawn from the ducting using both a CSIRO Rapid Tester Oven and a VOMAX 465 Moisture Gauge and calculating the difference in the weight of fibre with 6% moisture content. Table II lists the water required to achieve 6% moisture content in cotton, processed at a rate of 15 bales/hour/stand (3405 kg/hour/stand).

Temperature and relative humidity (rh) were measured during dosing periods in order to establish the moisture carrying capacity of the air in the gin ducting. Temperature and rh sensors were applied after the dosing area in order to monitor changes in the relative concentration of water held by the gin atmosphere. Hot air from a Samuel Jackson gas burner was introduced during spray tests in the pre-cleaning area in an attempt to increase the water carrying capacity of the transport air.

Fibre samples were withdrawn before lint cleaning and after dosing and lint cleaning to analyse changes in moisture content and to assess the effect of moisture on fibre properties. Pre-cleaning treatment samples were taken from affected (moisturized) stands and compared with samples from non-affected stands.

Table II – Water required to achieve 6% moisture content in lint through one stand

Moisture Content			Dosing Required			Flow Rate	
%	**Weight (kg)**		**%**	**Weight (kg)**		**litres/hr**	**litres/min**
6.0%	204.3		0.0%	0.00		0.0	0.00
5.5%	187.3		0.5%	17.0		17.0	0.28
5.0%	170.3		1.0%	34.0		34.0	0.57
4.5%	153.2		1.5%	51.1		51.1	0.85
4.0%	136.2		2.0%	68.1		68.1	1.13

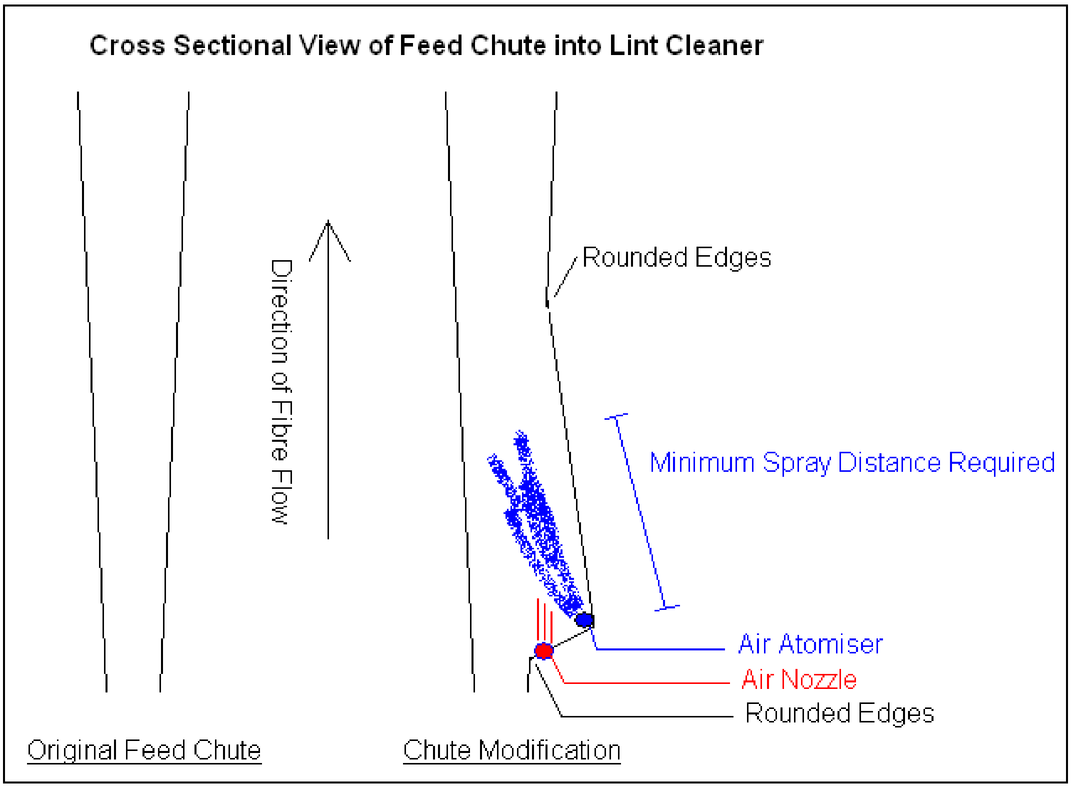

Figure 1 – Original proposal for installation of nozzles in gin ducting

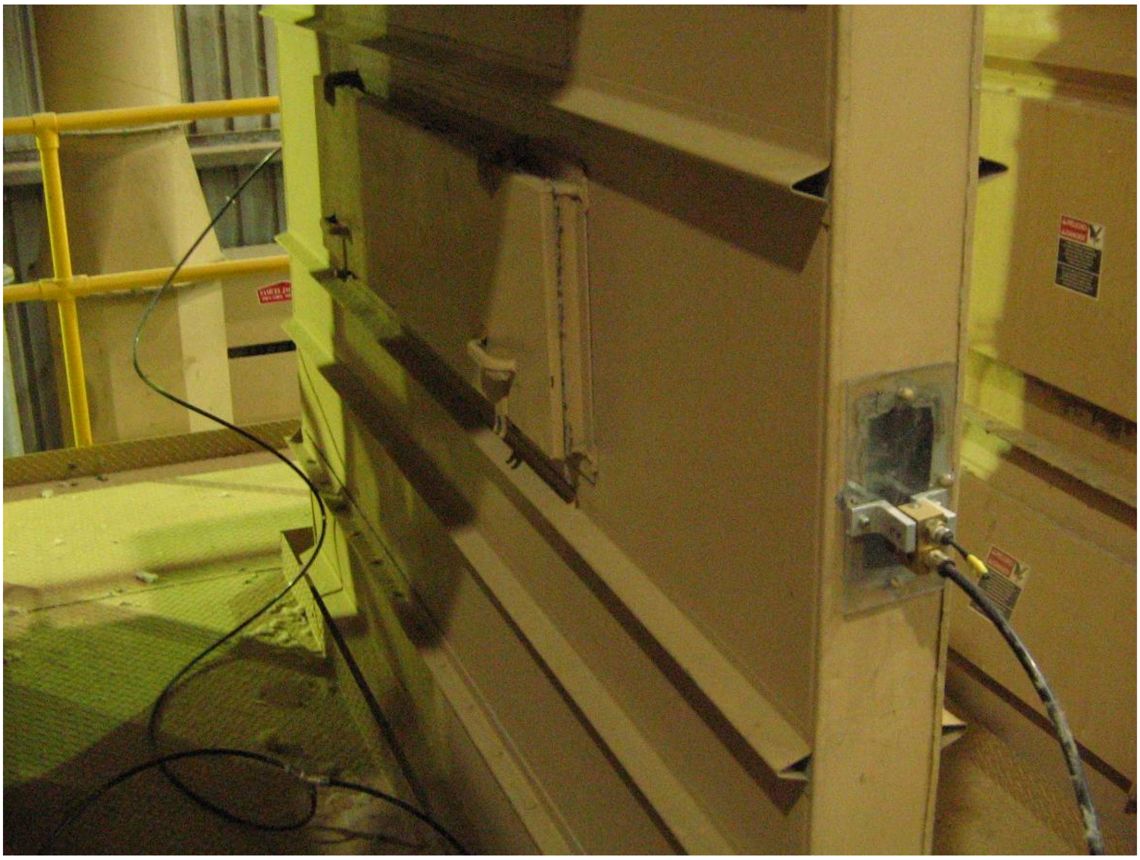

Figure 2 – Nozzles installed into ducting between horizontal pre-cleaning machines at Auscott Warren's gin

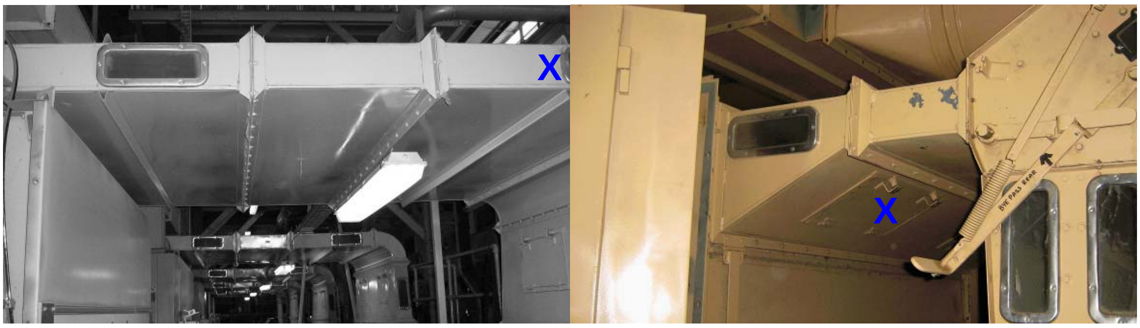

Figure 3 – Nozzles installed into gin ducting at Auscott Warren's gin between gin and lint cleaner at positions marked with X; (a) 2.0 m from lint cleaner condenser; (b) 500 mm from lint cleaner condenser

Moisture replenishment – humidifiers

In addition to testing the efficacy and the effect on fibre properties of adding liquid water via nozzles into gin ducting, the effect of adding humidified air was also tested. It is well known that cotton subject to humidified air prior to ginning has better length and less short fibre and nep content. To demonstrate the effect of humidification, piping and a purpose built steam hopper were installed on Stand One at Auscott's Trangie gin. Figures 4a and b show the hopper prior to installation. A volume of humidified air from the gin's Samuel Jackson Humidaire system, which ordinarily supplies the gin's battery condenser, was redirected to the humidifying hopper inserted between the gin conveyor and extractor.

Trials were conducted in June 2007. The volume of humidified air was varied crudely via a hand-controlled valve in the piping transporting the humidified air to the hopper. Three settings were used; (i) valve shut; (ii) valve half open and (iii) valve fully open. Fibre samples were collected after ginning from the back of the humidified gin stand and the untreated stand adjacent. Samples were also drawn after lint cleaning on both stands. Moisture content was assessed using a VOMAX 465 Moisture Gauge. Fibre properties were measured by HVI at Auscott's Classing House.

Figure 4 – (a) X marks position of humidifying hopper in gin stand and (b) duct that was fitted to deliver humidified air into cotton before ginning

Contamination sensing

A high-speed camera was selected as the detection device over photo-detectors on the basis that greater information, e.g. on colour and shape, could be gained about the contaminant without great expense or loss of detection speed. Preliminary analyses of the contamination sensor were performed using a purpose-built closed 20 m circuit of ducting (see Figures 5a, b & c) designed to re-circulate cotton spiked with an array of contaminants at similar air speeds used in ginning. Table III lists the air-flow capacity of the test duct and the air velocities able to be tested.

Table III – Air flow properties of the purpose-built duct used to test the illumination and sensing of contaminants

Duct parameters				**Notes**
Sample mass	20000	g		
Sample mass	44	lb		
Air velocity	10	m/s	+ve	
Air velocity	1969	ft/min	+ve	*NB: ginners handbook suggests between 1,500 - 2,000 ft/min to convey lint cotton*
Duct volume	1.509	m^3		*Total volume for 20 m length of duct*
Duct volume	53.289	ft^3		
XS area O	0.071	m^2		*Circular duct with 300 mm diameter*
XS area	0.088	m^2		*Rectangular duct - 700 x 125 mm*
av XS area	0.074	m^2		*Av. XS area for O and ducting*
av XS area	0.801	ft^2		
Volume air	0.744	m^3/s		
Volume air	1577	ft^3/min		*Air velocity x XS area → NB: similar values listed in ginners handbook for 12 inch pipe*
Mass of air	0.885	kg/m^3	(per min)	*Volume air x density of air (@1.19 kg/m^3)*
Vol air/lb material	35.830	ft^3/lb	(per min)	*NB: ginners handbook suggests 15 - 20 ft^3 of air/lb of material - higher rates (20 - 40 ft^3/lb) for drying systems*

Figure 5 – Re-circulating duct for testing contamination illumination and sensing (a) air separator, exhaust connection and material drop zone, (b) contamination illumination, showing later concave reflecting surface and sensing window, and (c) return duct showing bends after sensing area

A high speed camera was used for recording the footage of the cotton circulated in the duct. The colour and the size of the contaminant were chosen after examination of contaminants collected manually from Australian cotton consignments to a large Indonesian spinning mill[2]. Cotton samples were also contaminated with dark red paper circles (6 mm in diameter or ~28 mm^2 in area) (see Figures 6a and b). The size of this artificial contaminant was chosen because it approximates the area of small contaminants, although this size excludes long fibrous contaminants, which are likely to remain undetected by this system. An assumption was made that every contaminant with larger area would be easily detected by the system.

Illumination of contaminants against the white background of cotton requires that the lighting be balanced. During initial trials this was achieved to a reasonable degree by mounting LED arrays at 45 degrees either side of the viewing windows in the duct through which the cotton was circulated (see Figure 7). Later a convex reflecting surface was used to improve the lighting balance and remove the remaining shadows. The camera field of view (fov) covered approximately 150 mm x 150 mm area within the viewing window. An array of cameras would be employed to accommodate the wider dimensions of ducting in industry.

During trials duct air speed was adjusted to approximately 20 m/sec and the camera frame rate was initially set 50 Hz, i.e. 1 frame of the fov taken 50 times per second, while the camera shutter speed was varied between 1/250 and 1/1200 seconds. Cotton spiked with contamination (see Figure 8) was inserted into the duct circuit and filmed. A small black dot was placed on the glass within the camera fov so the contrast of the picture could be adjusted.

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[2] Van der Sluijs, M.H. J., Contamination and its significance to the Australian cotton industry, 31 pp, CCC CRC (pub.), May 2009

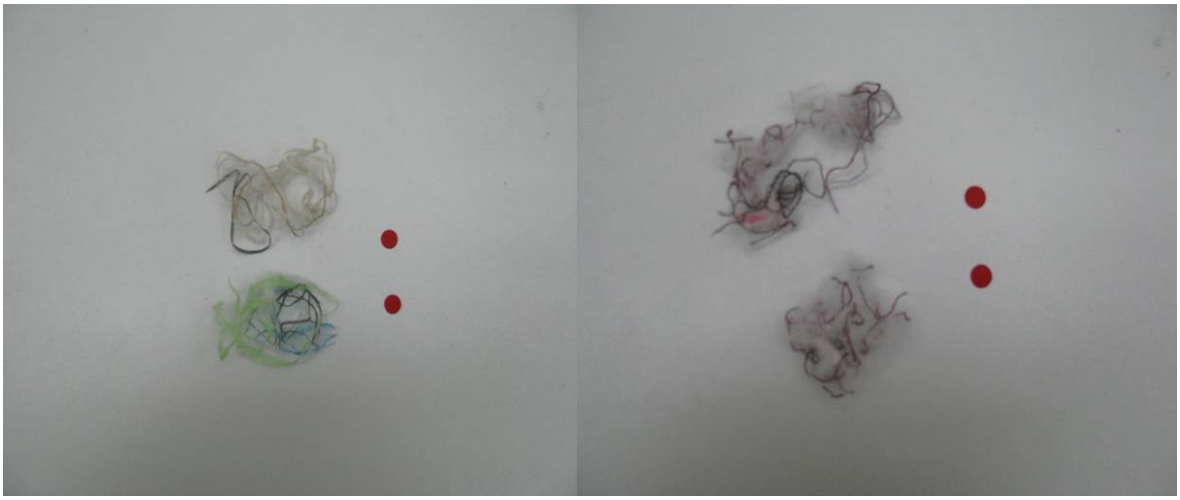

Figure 6 – (a) polypropylene string as contaminant with red circle contaminant indicators and (b) hessian strings with red circle contaminant indicators

Figure 7 – Viewing window showing camera and initial arrangement of LED arrays to illuminate moving fibre samples

Figure 8 – Cotton spiked with ‘contaminant’ before insertion into the circulating duct

Results and Outcomes

Moisture sensing

A discussion of results and analysis from laboratory and trials in industry of the moisture sensing device is given in the paper entitled 'an non-invasive moisture measuring device for gin ducting' submitted for publication to the American Society for Agricultural and Biological Engineering in October 2009. A copy of the paper is appended to this report (see Appendix 1).

Moisture replenishment – sprays and humidifier

Trials investigating the application and affect of sprayed water onto fibre were largely unsuccessful. The main issues associated with spraying water droplets into fast moving air-streams was the coalescing of water droplets at the point of entry into the airstream, which reduced the uniformity of the spray application onto the cotton. The development of a wet shadow on the duct floor from the nozzle spray also attracted dust and fibre and led to tags on and around the nozzle, which quickly (usually within 20 to 30 minutes) built into obstructions and led to stoppages. A range of application (spray) points, deflector configurations, water volumes, air-temperatures and nozzle pressures (droplet sizes) were tried in order to improve application but none of these worked effectively.

Furthermore, even though up to 2% extra water (see Table II) was nominally being added via the nozzles little of this moisture was actually being transferred to the cotton. The average moisture content of cotton prior to dosing was 5.4%. After the condenser the moisture content of un-dosed cotton was 5.19% while dosed cotton had a moisture content of 5.22%. The conclusion from this is that the sprays did not adequately transfer water onto the cotton but instead left water on the duct floor, which in turn attracted lint and dirt resulting in the build up of tags.

Sprays at rates of up to 2% on-weight-of-fibre into pre-cleaning areas with and without heat also caused the build up of tags. Mixing water in air temperatures of up to 70^{o}C did not affect the amount of moisture or rh measured in the atmosphere of pre-cleaning ducts nor in cotton extracted at the gin. It is noted that drying temperatures beyond 90^{o}C affect fibre properties with or without moisture[3].

The application of humidified air prior to the gin stand however did have a positive affect on fibre properties. Length attributes improved significantly when the full capacity of the system was used in trials at the Auscott Trangie gin. Figure 9 shows the effect of each humidification treatment (no humidity, medium humidity and full humidity) on the moisture content of cotton taken post gin and post lint cleaner. Loss of water tended to be higher in cotton subject to higher moisture add-ons (full humidity). There is a question here about the way the water is bound to cotton under the relatively quick exposure to humidified air in this system. Is cotton better able to 'hold' moisture, if it is allowed time to achieve equilibrium in the humidified environment? Moisture is essentially condensed onto seed-cotton as it passes by the duct delivering humidified air on its way through the gin. No extraction fan was used to pull humidified air through the falling seed-cotton and as a result uniform penetration of moisture into the seed-cotton probably did not occur.

Table IV lists fibre properties after each treatment. Length properties were usually better for samples treated with increased moisture. Cotton at 7.4% post lint cleaner (LC) was 1/32nd longer than untreated cotton at 5.5% post LC. Likewise uniformity was greater although SFC was not significantly different. Strength values were typically higher for moisture treated cotton samples and surprisingly leaf grades for all moisture treatments post LC, were an average 0.2 leaf grades better. The XY plots in Figures 10, 11 and 12 show trends in fibre length (UHML), uniformity and strength with increasing fibre moisture content.

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[3] Gordon, S. G., The effect of short fibre and nep levels on Murata Vortex spinning efficiency and product quality, Report to the CRDC, 14 pp, October 2001

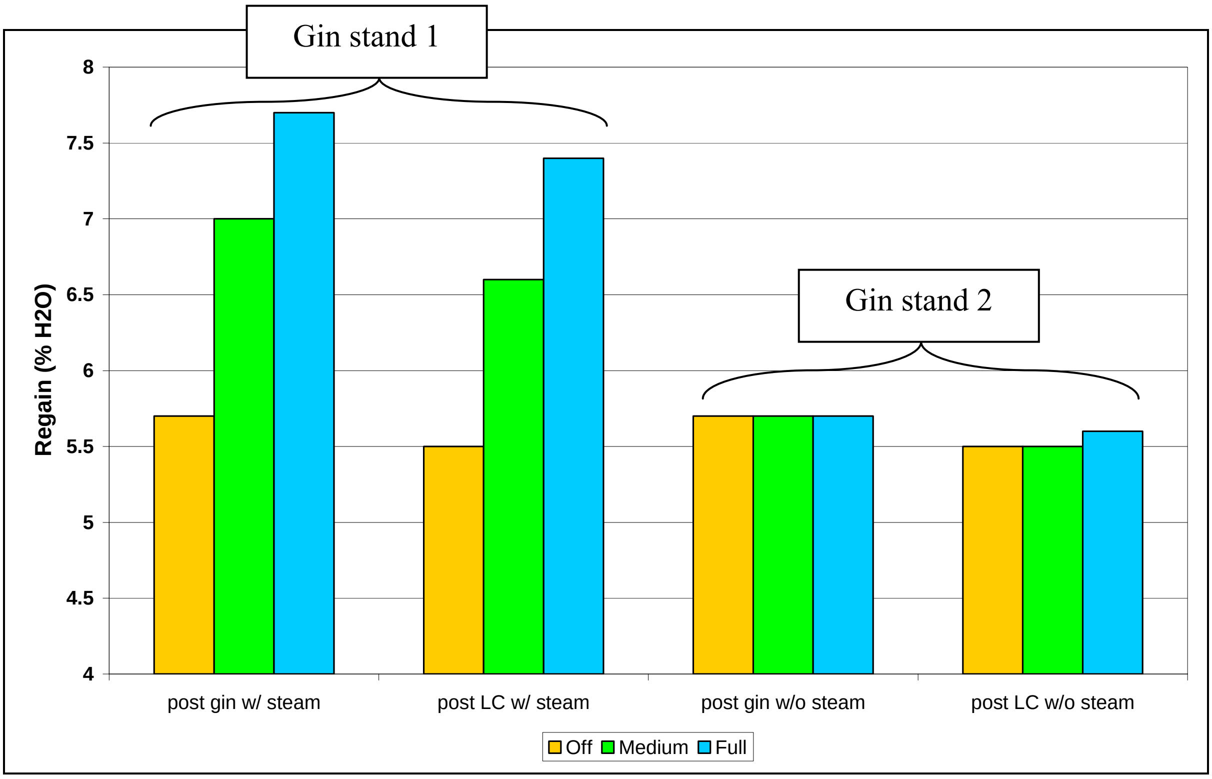


Figure 9 – Humidification treatments and their effect on moisture content in cotton before (post-gin) and after lint cleaning

Table IV – Fibre properties of cotton subject to humidification; gin stand (1), and cotton with no moisture treatment; gin stand (2). Leaf Grade values averaged in tenths of a grade.

Treatment & Moisture content	**Length (inches)**	**Uni (%)**	**SFC (%)**	**Strength (cN/tex)**	**Leaf Grade**
Post-gin (1) 7.7%	1.25	83.30	7.96	32.18	3
Post-gin (2) 5.7%	1.21	82.44	8.22	30.74	2.8
Post LC (1) 7.4%	1.22	83.08	8.08	32.40	2.2
Post LC (2) 5.5%	1.19	81.78	7.96	31.06	2.4
Post-gin (1) 7.0%	1.23	83.14	8.06	32.66	3
Post-gin (2) 5.7%	1.20	82.72	8.04	31.08	3
Post LC (1) 6.6%	1.19	82.52	8.06	31.28	2.4
Post LC (2) 5.5%	1.18	81.86	8.32	31.06	2.6
Post-gin (1) 5.7%	1.20	82.22	8.00	33.20	3
Post-gin (2) 5.7%	1.21	82.86	8.06	32.68	3.2
Post LC (1) 5.6%	1.17	81.96	8.06	31.60	2.4
Post LC (2) 5.5%	1.18	81.82	7.96	30.94	2.6

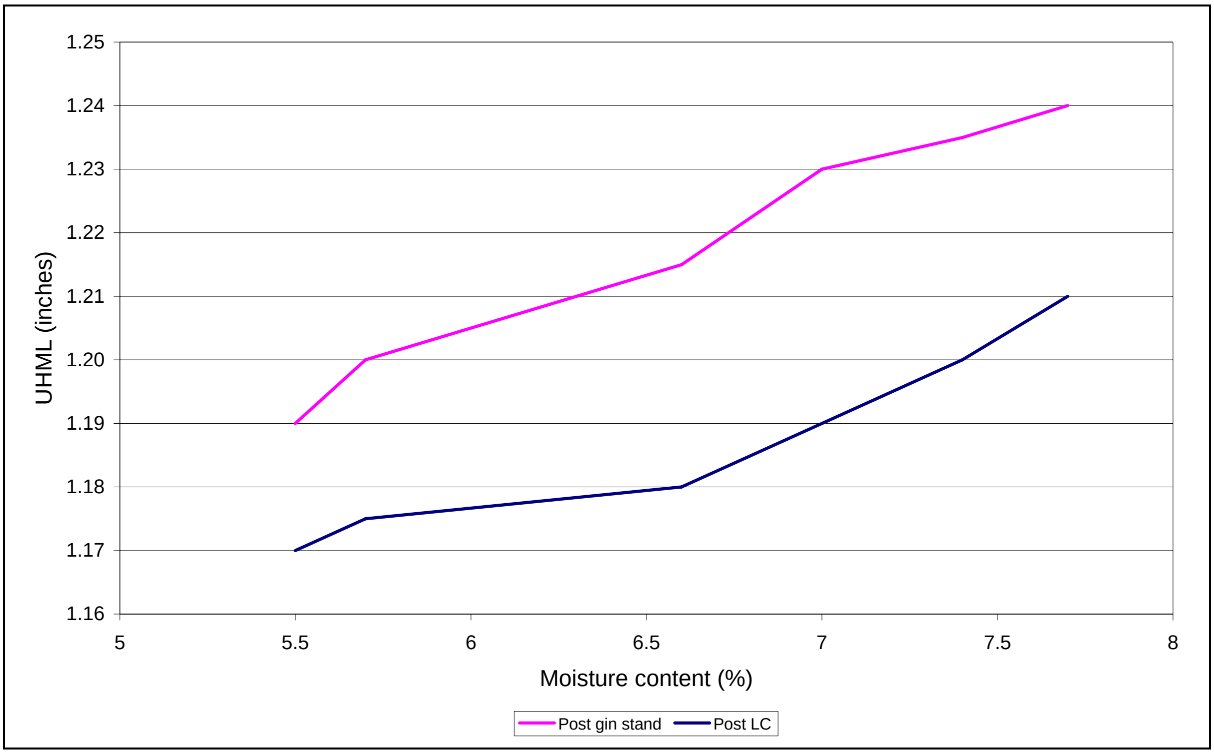


Figure 10 – Upper half mean length with increased moisture content; post gin and post LC

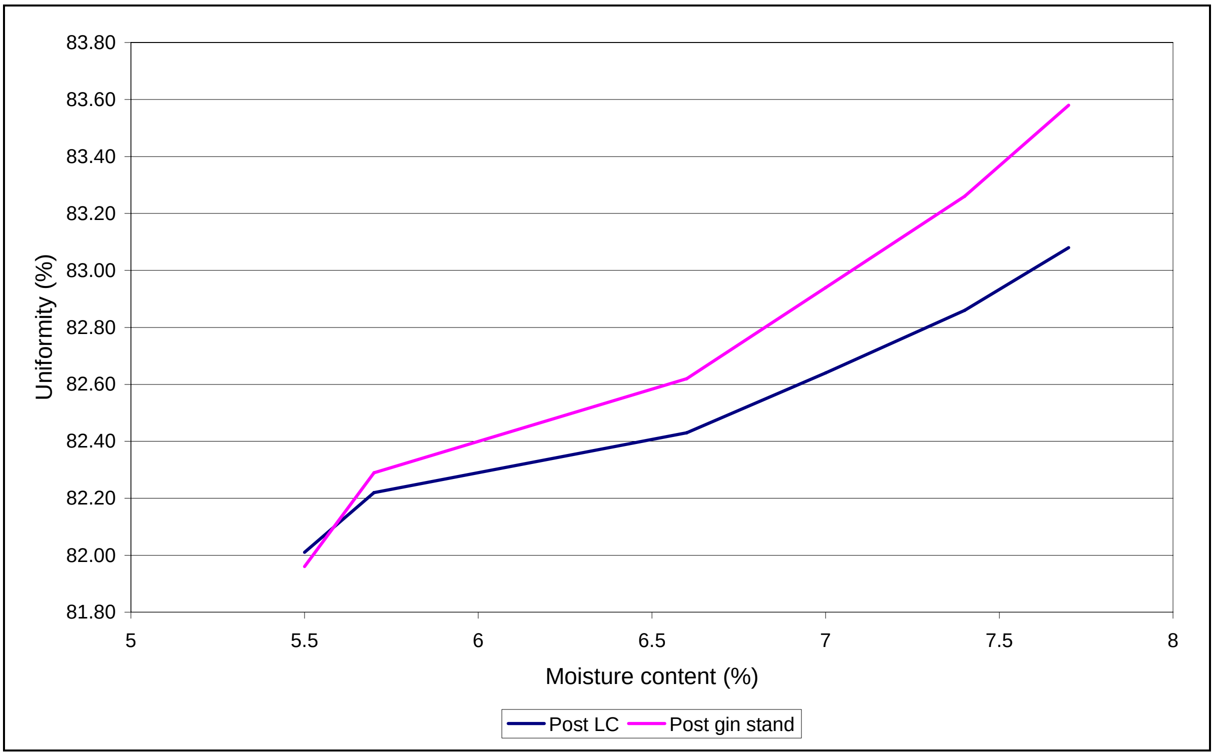


Figure 11 – Length uniformity with increased moisture content; post gin and post LC

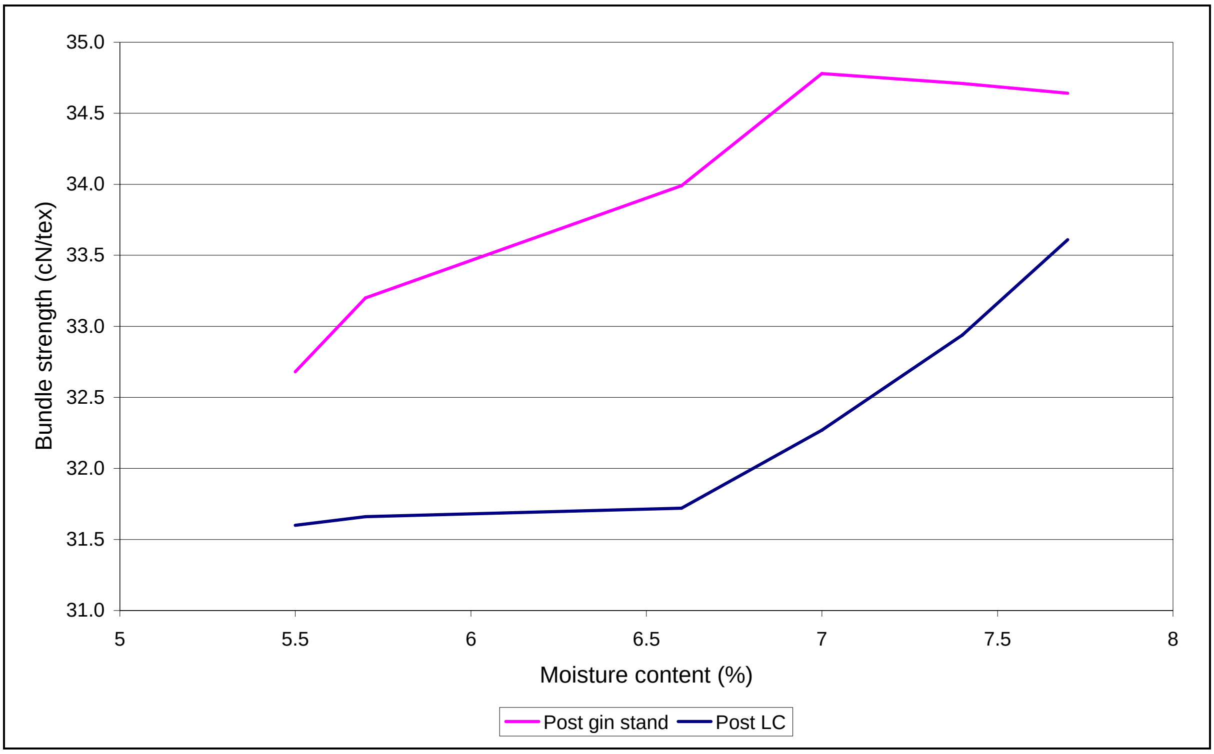


Figure 12 – Fibre bundle strength with increased moisture content; post gin and post LC

Contamination sensing

Initial experiments were aimed at developing a balanced illumination of the cotton in the duct. As reported 4 arrays of LEDs (2 arrays spaced 300 mm apart fixed each side of the duct fov) angled at around 45 degrees to the horizontal provided reasonable balanced lighting of specimens (see Figure 7). The pictures in Figures 13 to 20 show various contaminants against a bed of cotton in this lighting arrangement. It is difficult to 'see' light coloured contaminants under this current white light arrangement and further work is required to resolve these (see Figures 14, 15, 18 and 19). It is thought that a combination of dark field illumination and UV light ports might provide a way of seeing light coloured and fluorescing contaminants. More work is required to investigate the potential of these lighting arrangements.

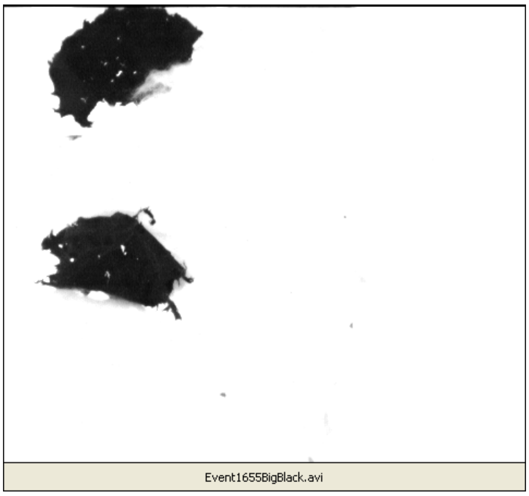


Figure 13 – Black plastic contaminant under prototype illumination

Figure 14 – Yellow coloured plastic under prototype illumination

Figure 15 – Multicoloured plastic under prototype illumination. Slight shadowing of cotton batt is evident (see arrows)

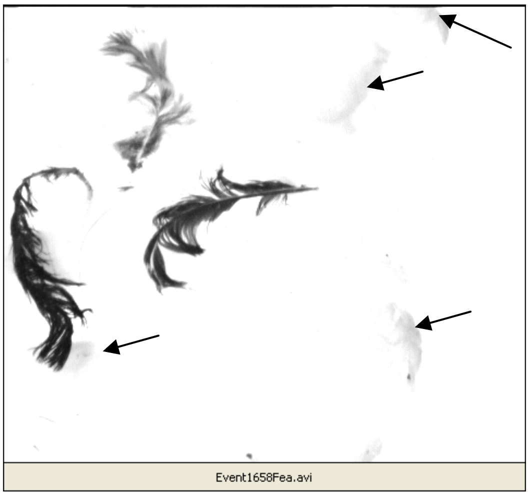


Figure 16 – Feathers of various colours under prototype illumination. Slight shadowing of feathers and cotton batt is evident (see arrows)

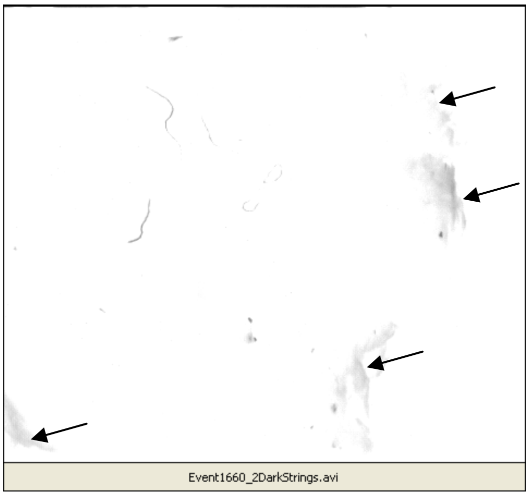


Figure 17 – String (dark cotton, polypropylene and hessian) under prototype illumination. Slight shadowing of cotton batt is evident (see arrows)

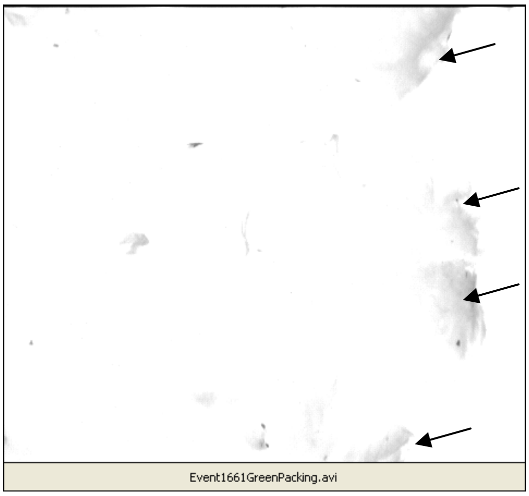


Figure 18 – Light-green coloured packing material under prototype illumination. Slight shadowing of cotton batt is evident (see arrows)

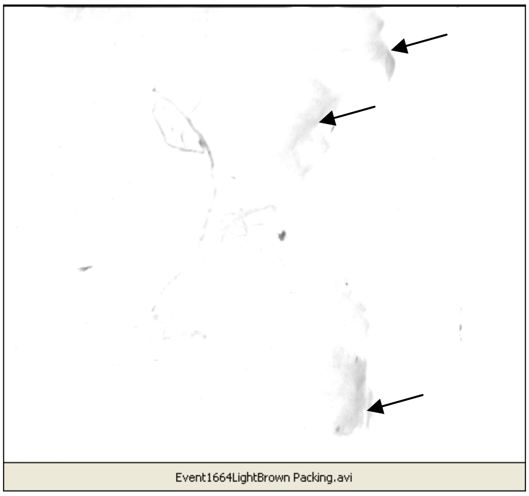
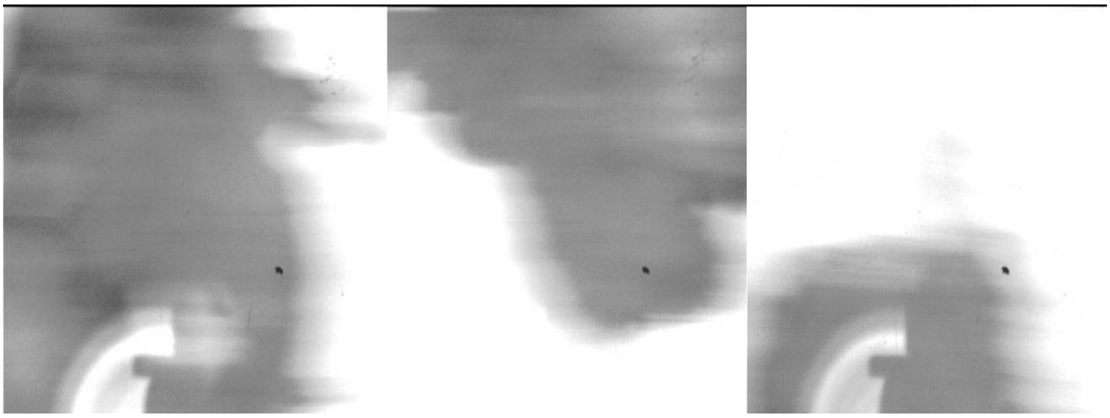


Figure 19 – Light-brown coloured packing material under prototype illumination. Slight shadowing of cotton batt is evident (see arrows)

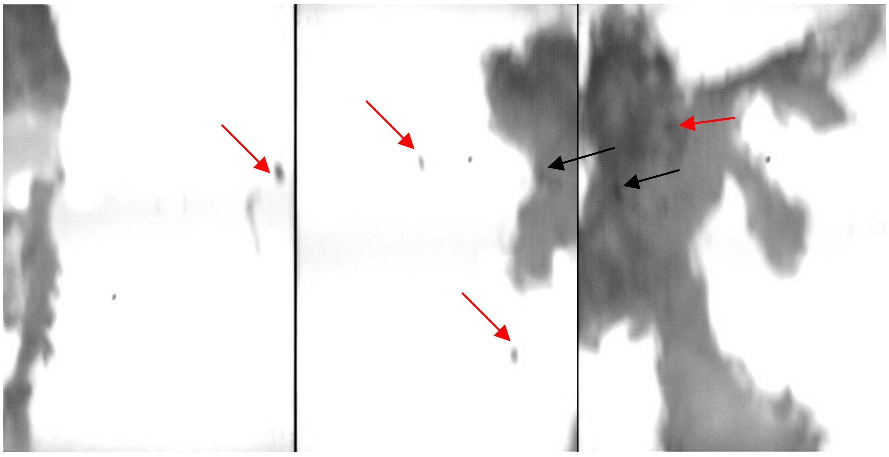
Figure 20 – Black coloured packing material under prototype illumination. Slight shadowing of cotton batt is evident (see arrows)

The pictures in Figures 21 a, b and c were taken at a frame rate of 50 Hz and a shutter speed of 1/250 seconds. They show cotton moving in the duct at 20 m/s and the small black dot on the glass to allow the contrast of the picture to be adjusted. While the stationary black dot is resolved and the cotton appears reasonably well illuminated, the system at a shutter speed of 1/250 seconds failed to recognize any contaminants (red paper dots) contained within the cotton.



Figures 21(a), (b) and (c) show cotton clearly illuminated and moving at 20m/s across the camera fov. No contaminants contained within the cotton can be seen at a shutter speed of 1/250 seconds, although the stationary black dot is resolved.

The experiment was repeated at a shutter speed of 1/1200 seconds with the frame rate remaining at 50 Hz. Footage of the contaminated cotton taken at the faster shutter speed is shown in Figures 22 a, b and c. In these pictures the red paper dot contaminants can be seen both within and outside the moving cotton. Further work is required to resolve these images further. More uniform illumination using a reflected light source to illuminate the moving cotton and faster shutter speed (up to 1/2000) should enable this to occur.



Figures 22(a), (b) and (c) show cotton that is clearly illuminated and red paper circle contaminants (red arrows) within the moving cotton. The stationary black dot is identified by black arrows.

Conclusion

Moisture has a marked effect on cotton fibre properties through the gin. In this study the method of adding moisture to lint was reviewed and some options tested in industry. Adding moisture to cotton by exposing it to humidified air is more effective than addition by sprays, which are largely ineffective and give rise to tags that reduce processing efficiency. Fibre treated with humidified air had an extra 1/32nd in UHML, between 0.5% and 0.9% more length uniformity, and was >1 cN/tex stronger than unconditioned fibre. Leaf grade was largely unaffected by adding moisture and in fact was 0.2 leaf grade units better than unconditioned fibre after passage through one lint cleaner.

A non-invasive and accurate moisture sensor was designed, built and successfully tested in industry during the course of this project. At the time of writing the moisture device was being connected into a commercial moisture management system manufactured by Samuel Jackson Incorporated of Lubbock TX. An international patent and continued communication with Samuel Jackson are planned in the early part of 2010, followed by further industrial trials at Auscott's gin in Narrabri. A paper describing the moisture sensor and results from laboratory and industrial trials has been submitted to Transactions of the American Society of Agricultural and Biological Engineers.

A prototype contamination sensor was designed and tested in parts at industry speeds through a purpose-built circulating duct at CSIRO Belmont. The system utilizes balanced white light to see the dark coloured contaminants and a high speed digital video camera to record images of the contaminant travelling at high speed. Shutter seeds in excess of 1/1200 seconds are required to record contaminants travelling at 20 m/s through cotton gin ducting. The advantage of a digital camera is that more detailed information can be used to decide the nature of the 'contaminant' that is seen by the camera. Further work is required to properly illuminate lighter coloured contaminants that are not seen under balanced white light.

Extension Opportunities

Information and progress on the moisture sensor has been extended throughout the project to Australian cotton ginners through visits to gins, at ACGA meetings and at CRDC industry meetings. A paper on the moisture sensor is being presented to the Ginning Conference at the Beltwide Cotton Conferences in January 2010.

Publications

1. Krajewski, A. S. and Gordon, S. G., A system and process for measuring properties, provisional patent document submitted January 2009 (PCT application being prepared December 2009)
2. Krajewski, A. S. and Gordon, S. G., An non-invasive moisture measuring device for gin ducting, paper submitted for publication to the American Society for Agricultural and Biological Engineering in October 2009
3. Krajewski, A. S. and Gordon, S. G., An non-invasive moisture measuring device for gin ducting, paper submitted to the Beltwide Cotton Conferences, New Orleans, January 2010

Moisture has a marked effect on cotton fibre properties through the gin. In this study the method of adding moisture to lint was reviewed and some options tested in industry. Adding moisture to cotton by exposing it to humidified air is more effective than addition by sprays, which are largely ineffective and give rise to tags that reduce processing efficiency. In this project fibre treated with humidified air had an extra 1/32nd in UHML, between 0.5% and 0.9% more length uniformity, and was >1 cN/tex stronger than unconditioned fibre. Leaf grade was largely unaffected by adding moisture and in fact was 0.2 leaf grade units better than unconditioned fibre after passage through one lint cleaner.

Following this work two key objectives were set for this project. The first objective was to design and build a moisture measuring sensor without the operational shortcomings of current sensors and the connection of this sensor with a moisture replenishing system. The second, unrelated to moisture management, but no less important in terms of fibre quality preservation, was to design and build a sensor to detect contamination in loose fibre linked with a system to remove detected contamination from transport ducting. Both objectives are aligned with the industry's strategy of maintaining and improving fibre quality.

Both moisture and contamination sensing systems were designed and built during this project. Of the two, the moisture measuring system progressed further and was tested and improved in industry for two years. At the time of writing a full patent is being prepared for the moisture sensor, a peer review paper written on its performance in industry and the sensor results linked to a commercial drying management system. The contamination sensor had undergone preliminary testing but has not been tested in industry. Design and implementation of a contamination removal system within the gin is still required before this objective is fulfilled completely.

Appendix 1

Krajewski, A. S. and Gordon, S. G., An non-invasive moisture measuring device for gin ducting, paper submitted for publication to the American Society for Agricultural and Biological Engineering in October 2009

AN IN-LINE, NON-INVASIVE COTTON MOISTURE MEASUREMENT DEVICE FOR GIN DUCTS

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Keywords:	cotton, cotton ginning, moisture
Abstract:	The management of moisture in cotton during ginning remains one of the most important factors in determining final quality. Resistance plates are typically used to measure moisture in seed-cotton and lint as it is processed through the gin, but these are limited by inaccuracies that arise from the small proportion of cotton tested, contamination of the sensor, and by the non-linear response to low and high moisture levels. In this paper, we present a new sensing device that has potential for measuring the moisture of both seed-cotton and lint. The device combines large area capacitance plates with light detectors to measure the mass and moisture of material travelling quickly under pneumatic pressure or gravity through gin ducts.

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AN IN-LINE, NON-INVASIVE COTTON MOISTURE MEASUREMENT DEVICE FOR GIN DUCTS

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Abstract. *The management of moisture in cotton during ginning remains one of the most important factors in determining final quality. Resistance plates are typically used to measure moisture in seed-cotton and lint as it is processed through the gin, but these are limited by inaccuracies that arise from the small proportion of cotton tested, contamination of the sensor, and by the non-linear response to low and high moisture levels. In this paper, we present a new sensing device that has potential for measuring the moisture of both seed-cotton and lint. The device combines large area capacitance plates with light detectors to measure the mass and moisture of material travelling quickly under pneumatic pressure or gravity through gin ducts.* ***Keywords: Cotton, Ginning, Fiber quality, Moisture, Capacitors, Light sensors***

INTRODUCTION

The moisture content in seed-cotton at harvest through to lint in the bale can have significant effects on the quality of fibre sold to the spinning mill. There are optimum moisture levels for seed-cotton and lint (fiber) for each harvest and ginning process that enable efficient harvesting, ginning, cleaning, baling, and safe storage (Hughs *et al*, 1994). Likewise, there are similar considerations in the processing of other loose fiber, such as wool, and other commodities, such as grains and minerals.

To optimize processing efficiency and fiber quality, seed-cotton and lint need to be at particular moisture contents at different stages of the ginning process. For example, a low moisture content of around 5% during pre-cleaning enhances the cleaning of seed-cotton, while during ginning the moisture content of the fiber on the seed needs to be between 6% and 7% in order to prevent excessive fibre breakage. There have been many studies that have shown the detrimental effect of ginning and cleaning on fiber that is too dry or wet (Childers and Baker, 1977, Anthony *et al*, 2001, Anthony and Griffen, 2001, Gordon, 2001), and the ameliorating effect on fiber damage after the proper amount of moisture has been metered onto or preserved in the lint or seed-cotton, (Moore and Griffin, 1964, Mangialardi *et al*, 1965, Mangialardi and Griffin, 1966, Leonard *et al*, 1970 and Anthony and Griffin, 2001).

There are many challenges associated with the management of moisture at each stage of ginning. The main challenges are the accuracy and speed with which lint and seed-cotton moisture can be measured and controlled. Despite development of systems that measure and then provide for drying or moisture replenishment of seed-cotton or lint through the gin (Griffin and Mangialardi, 1961, www.samjackson.com), there has not been widespread uptake due to the cost and the speed and accuracy of the response. Indeed it is the limitations in moisture measurement that prevents optimum moisture content being achieved for particular processes and the further automation of these systems.

Current moisture management systems in gins use either on-line or a combination of on-line and off-line moisture measuring methods based on instruments that measure electrical charge, e.g. the measurement of resistance or transmission (of micro or radio-waves), through the sample. On-line resistance-based sensors are typically used to measure the moisture of moving lint or seed-cotton. Their accuracy, whether used on- or off-line, is limited by specimen presentation, contamination of the sensor, and diminished sensitivity for very wet or very dry samples, not all of which can be adequately controlled inside the gin. Resistance-based moisture sensors do not work well when water droplets are sprayed directly on the surface of the cotton fiber. The combination of absorbed and surface moisture can cause errors in resistance-based moisture sensors because of the conductive effect of surface moisture that distort (increase) the measurement. Nor do these sensors work well when moisture content is low, e.g. <4.5%. According to Hearle (1953), the specific resistance of cotton at low moisture content becomes very large, with a converse reduction in current. A consequence is that resistance-based sensors need specially designed circuitry to manage the wide range of currents flowing between test electrodes subject to the normal range of moisture contents, i.e. 4% to 10%. It is also the case that signal distortion and noise in measurements are amplified when the specimen is not applied correctly or consistently between or around electrodes.

Microwave and radio-wave transmission-based instruments require the sample be compacted to a reasonably high density, which limits their application to seed-cotton in module form (150 – 200 kg/m^3) or to lint pressed into a bale

(320 – 540 kg/m^3). The application of microwave and radio-wave transmission sensors is currently restricted to the inputs and outputs of the ginning process but not to the actual control of the gin.

In this paper we introduce a new on-line moisture measurement device that can be used for measuring moisture content in seed-cotton or lint as it is being moved quickly by air (up to 20 m/sec) or gravity in transport ducts between gin machines. The device uses a large capacitance sensor, and light emitters and detectors as the active elements for sensing moisture and mass. Measured values are achieved through the changes to the permittivity (ε) between the plates associated with the cotton and the water (moisture) content of the cotton. Moisture content is defined as the ratio of mass of absorbed water in cotton lint or seed-cotton, determined by a standard thermal gravimetric method, to the total lint or seed-cotton mass. The light sensor is designed and calibrated so it measures the cotton mass through the measurement of the transmitted light through and scattered light from the cotton lint. The advantage of the device is that it can be situated within the gin at points prior to where the lint or seed-cotton undergoes conditioning and/or cleaning. That it is non-invasive and that the moisture value represents an average of all the material passing through the duct at a particular time differentiates the sensor from current on-line moisture sensors. Moreover, we note clear linear relationships between the device's sensor signals and the measured moisture and mass values of the sample.

In the device two sets of capacitor plates measure the permittivity (ε) of the duct material (fiberglass resin) and the air and material (cotton and moisture) moving between the plates (as per Equation 1):

$$\varepsilon_{total} = \varepsilon_{\mathrm{cotton}+moisture} + \varepsilon_{airhumidity} + \varepsilon_{fibreglass} \qquad .(1)$$

Significant changes in permittivity between the capacitor plates are related to changes in the permittivity of the cotton and moisture complex. Variations in permittivity associated with air humidity, which occur as a result of changing conditions within the duct, contribute to a level of stray-capacitance. However, these are assumed to be correctable according to in-duct measurements of temperature and humidity. More significantly, variation in moisture and temperature inside the duct also affects the device's relatively large sensor plates, which must be structurally insulated, shielded and braced to reduce distortions in the electric field. This variation is partly compensated using stray-capacitance immune measurement circuitry such as that employed by Huangt *et al* (1988) and feedback and auto-balancing techniques such as those described by Marioli *et al* (1993), Toth *et al* (1995), Karlsson (1999) and Pennisi (2005). These techniques are applied to capacitance sensors that require high accuracy.

They allow static signals to be zeroed and slow fluctuations of both the transducer and stray-capacitance to be significantly reduced.

The total capacitance (C) measured by the device follows the formula described in Equation 2.

$$C_{total} = C_{stray} + \left(\frac{\varepsilon_{total} * A * (n-1)}{d}\right) * f \qquad (2),$$

where A = the (copper) plate surface constant in m^2, n = number of plates, d = distance between plates in m and f = capacitor edge field coefficient. The permittivity of the fiberglass (or glass) used as support for the capacitor plates is constant and is taken into consideration during design of the capacitive sensor. Due to the distance between the capacitor plates in the industrial device (around 150 mm) the edge field is also considered.

The range of moisture values observed in cotton moving through the device is encapsulated in a capacitance range between 10 - 17 pF. The changes in the permittivity of the cotton-moisture mass complex occurring largely as a result of the relatively larger dielectric constant associated with water; 80.4 @ 20^oC, compared with air; 1.0 @ 20^oC, and cotton cellulose between 3.3 and 3.9 @ 20^oC.

The cotton mass and moisture relationship is highly correlated so there is a need to normalize the mass signal to extract the moisture signal. In this device an array of LED light sources and detectors are used to provide an estimate of the fibre mass in the duct. Light passing through a particulate fluid medium can be described by the Lambert-Beer Law (Equation 3):

$$I = I_0 * e^{-k*x*c} \qquad (3),$$

where; I = the incident light from the source flux, I_0 = source light flux, x = distance through the medium (mm), k = excitation coefficient and c = concentration of material in the specified volume. This law is used to measure light traveling through liquids (turbidity measurements). It is applied here because the signal, averaged over several seconds, can be envisaged as a response to the particles (the cotton or seed-cotton) suspended in a fluid.

The distance between the light source and detectors in the device is fixed (at around 350 mm) so that a fixed volume for the light measurement is assumed, enabling the assumption that the amount of light transmitted through to the detector depends on the concentration or mass of fibre in the duct. Cotton fiber is highly reflective of light, so detectors were fitted to measure both occluded and scattered light. In preliminary tests, the measured relationship between the mass of cotton and the amount of light reaching detectors closely followed the above mentioned equation.

The proposed device also has to be low cost in order to keep the overall instrument commercially viable. An example of low-cost capacitance measurement circuitry is discussed in Toth *et al* (1995). The interface between sensors and the acquisition card should also be both simple and accurate. Some low cost interfaces are also considered in Ignjatovic *et al* (2005). The extraction of cotton moisture from the overall cotton signal is achieved by combining the capacitance signal with signals from optical, temperature and humidity sensors. The sensor device is designed to fit in the duct between the gin stand and lint cleaner, but can be built in ducting between any other gin machinery.

METHODOLOGY

CAPACITOR SENSOR DEVELOPMENT AND TESTING

A capacitive sensor test rig was built to conduct preliminary tests on the use of large capacitance plates and the data acquisition circuitry to sense static cotton fibre mass and moisture. The capacitor test rig took the form of the two 200 mm x 600 mm, insulated copper plates fixed to a fiberglass sheet and placed at a distance equal to the height of a standard commercial gin duct (~150 mm), such as that connecting the back of a commercial gin stand with the first lint cleaner. The capacitor was then placed into a metal sheet box imitating the electrical condition inside the duct. Figure 1 illustrates the form of the test rig and the basic instrumentation for data acquisition. Tests were conducted under constant ambient laboratory conditions of 25°C and 60% relative humidity.

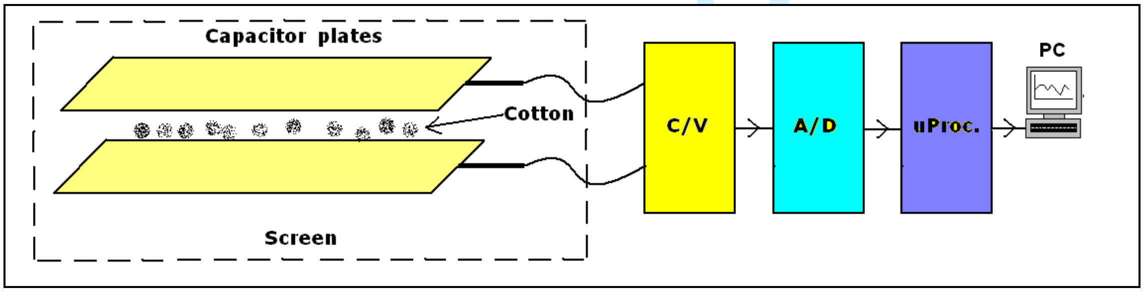

FIGURE 1. Testing capacitor and data acquisition circuit; C/V = capacitance/voltage convertor; A/D = analog to digital convertor; uProc. = micro-processor

The relationship between the mass of cotton and changes in capacitance was tested by inserting increasing weights of conditioned fibre between the two capacitance plates. Static fibre samples varying from 10 g to 50 g were tested under the same conditions. Figure 2 shows the relationship between the recorded capacitance and cotton sample mass between the two plates. Noticeable is the linear relationship ($r^2 = 0.998$) over the range of capacitance values

10.25 pF to 10.45 pF, the small range reflecting the low dielectric co-efficient for cotton. Small capacitance changes mean that a temperature-stable and low-noise capacitance-to-voltage converter is essential.

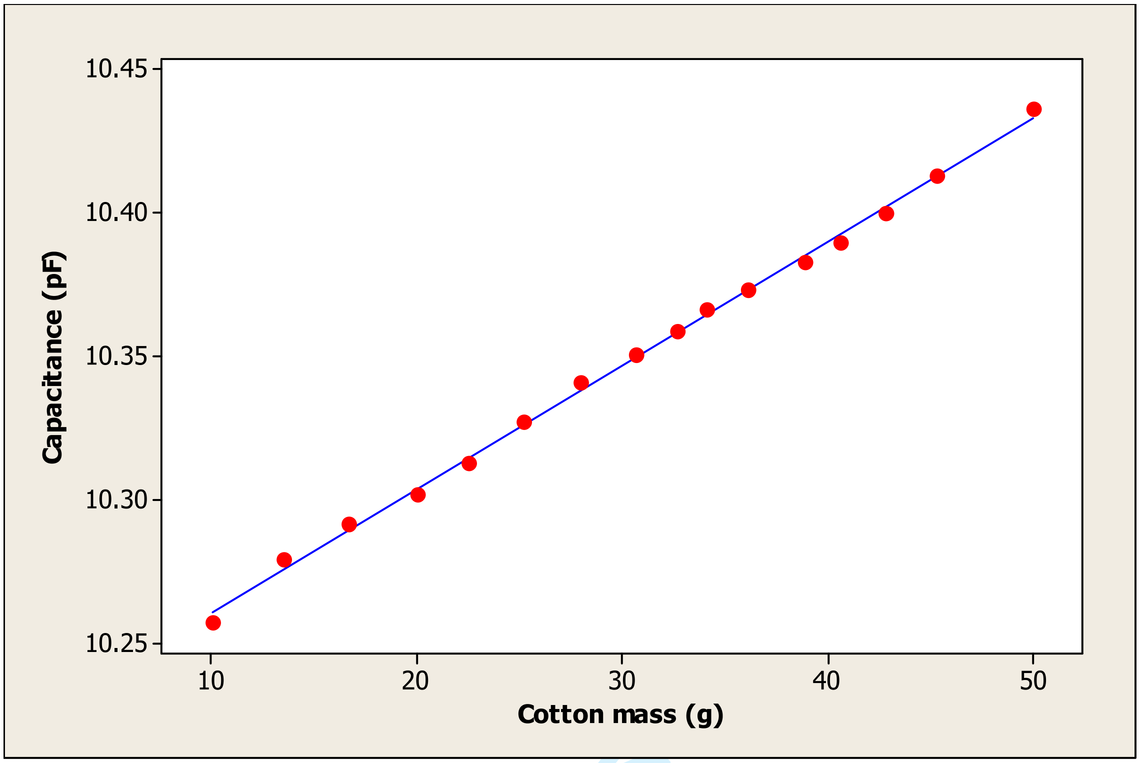

FIGURE 2. Relationship between capacitance and the mass of the cotton fibre samples ($r^2 = 0.998$).

Tests were then conducted to establish the relationship between the amount of water added to cotton and variations in capacitance. For these tests, 25 g of cotton was placed between the capacitor plates to which increasing amounts liquid water (2, 3, 6, 7, 8, 12, 14, 16 and 18 ml) was added using a syringe. Water was syringed into the middle of the cotton sample bundle, which was placed in the middle of the capacitor plates. Figure 3 shows the response in capacitance as water was added to the cotton and the proportionally greater change in capacitance as a result of the greater dielectric of water.

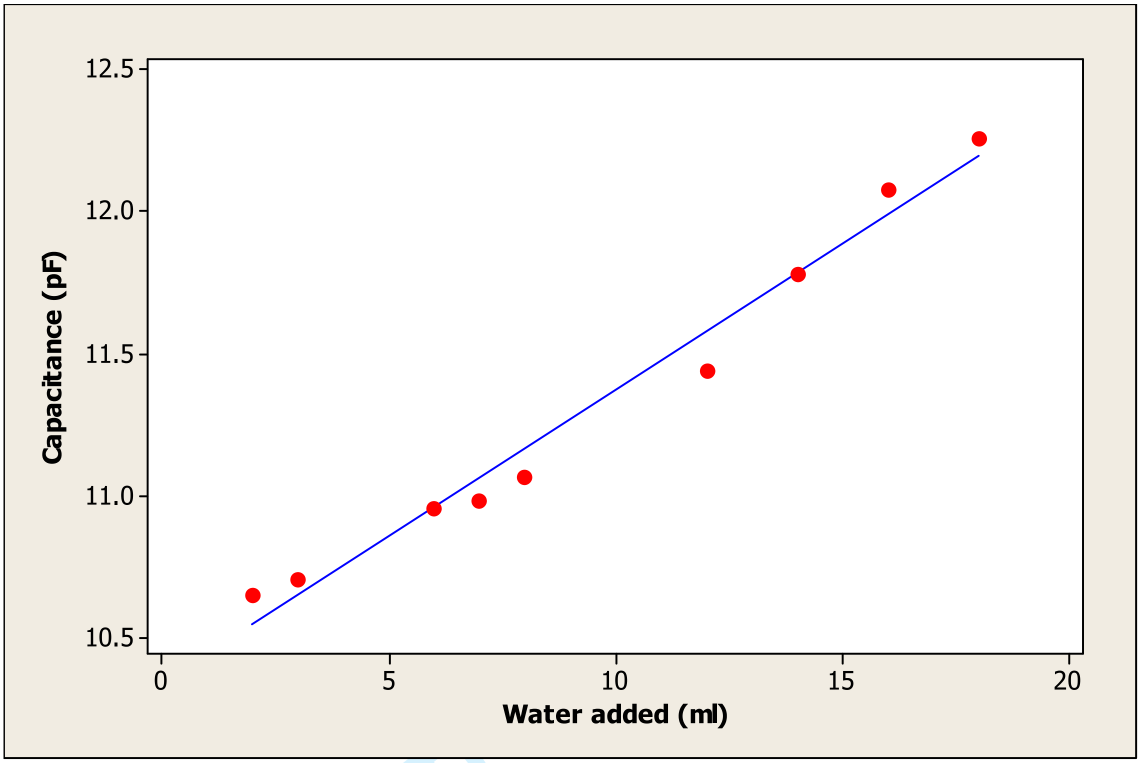

FIGURE 3. Relationship between water added to a sample of cotton placed between the capacitor plates and capacitance ($r^2 = 0.979$).

Following determination of the capacitor response, a capacitive mass-to-voltage converter was designed and tested. The data from the converter was acquired via an analogue-to-digital converter and then fed into a micro-processor and a PC (as per Figure 1). The relationship between the mass of cotton between plates and the output voltage of the capacitance-to-voltage converter was tested by placing incremental amounts of cotton between the capacitor plates and measuring the output voltage of the converter. The voltage response was highly linear as indicated by the high correlation coefficient (see Figure 4).

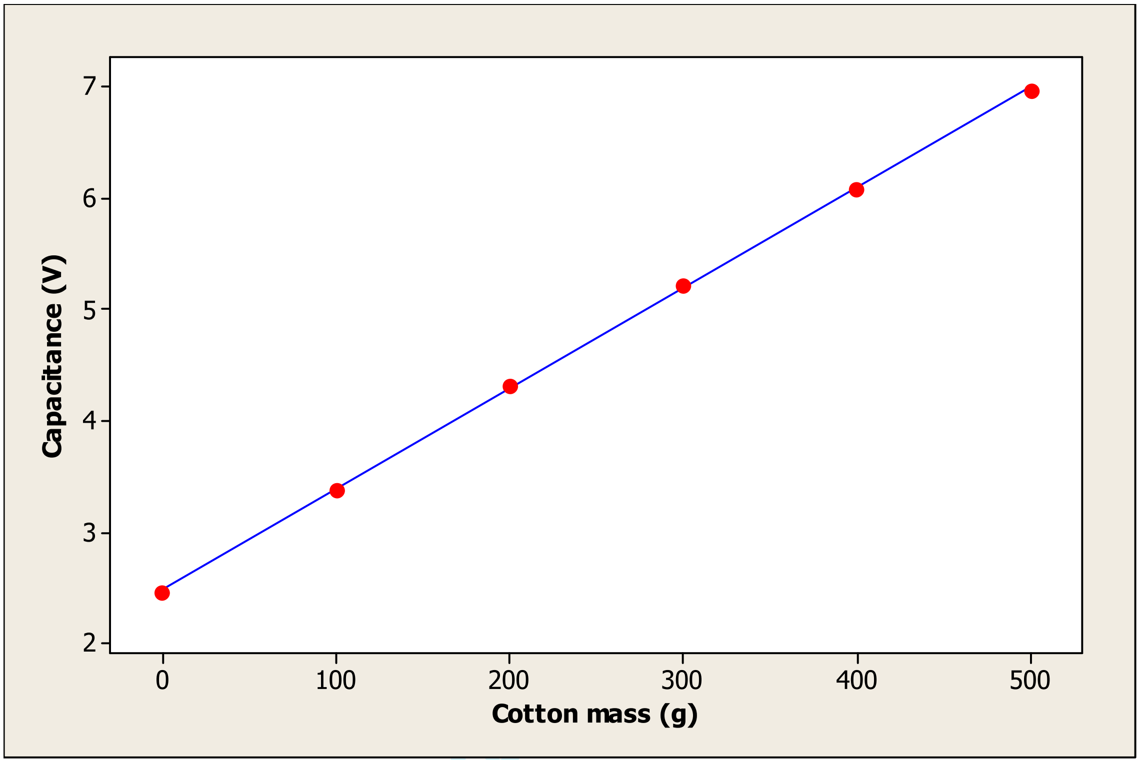

FIGURE 4. Relationship between the mass of cotton between the plates and the output voltage of the capacitance sensor ($r^2 = 0.9998$)

LIGHT SENSOR

The previously mentioned capacitance-to-voltage and light-to-voltage converters were designed to link capacitance and light variations together. The light-to-voltage converter was designed so that the mass of cotton fibers passing through the duct is directly proportional to the light reaching the detectors (Figure 5). The light testing circuitry includes the LED-based light source (three white LED lamps 24 V & 1.3 A available through TENROD Australia – www.tenrod.com.au) and custom built photodetector arrays. The arrays used 24 standard SFH213 PIN photodiodes manufactured by OSRAM GmbH. In the test rig, the light sensor was enclosed to prevent ambient light influencing the measurement and variations in the LED's sensor with temperature changes were compensated for in the final calculation of the light response (in volts) to sample mass.

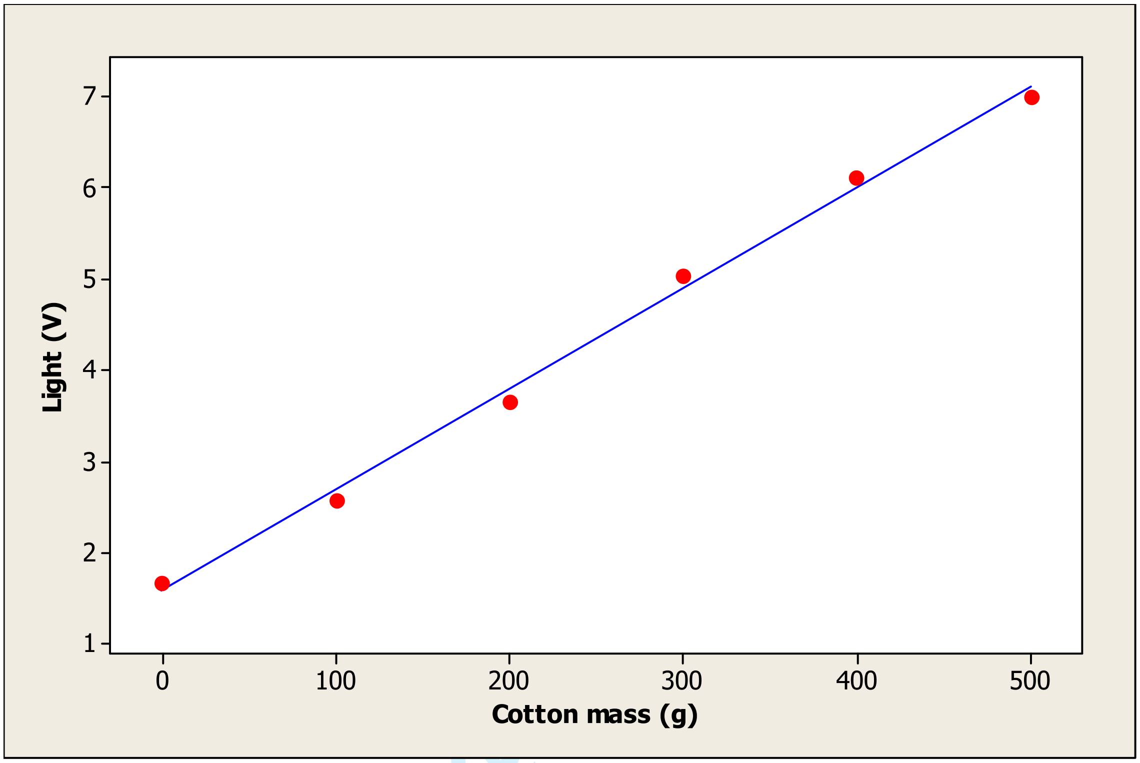

FIGURE 5. Light sensor response against the mass of cotton ($r^2 = 0.996$)

INDUSTRIAL SENSOR – PRACTICAL IMPLEMENTATION

Following initial assessment of the test rig and data acquisition circuitry an industrial-scale capacitance sensor was built for trialing in a commercial gin. Design features of this device included the previously mentioned approaches for reducing stray-capacitance, incorporating humidity and temperature sensors and the alignment of high precision capacitance-to-voltage and light-to-voltage converters. The output of the capacitance-to-voltage converter in the industrial device covered a range between 1 V to 12 V that enabled high resolution capacitance changes between 10 pF and 17 pF to be recorded. The capacitance plates were manufactured from copper sheets. Holes in the plates allowed light to be transmitted through the cotton stream to the detector arrays opposite (see Figure 6).

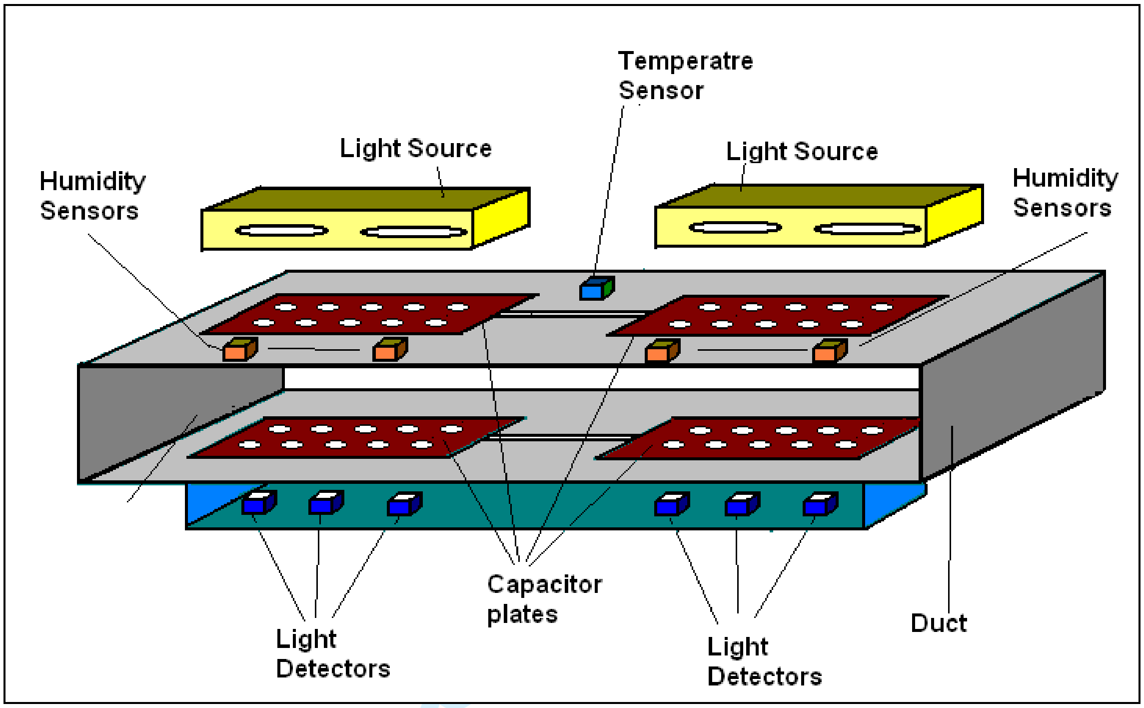

Figure 6. Arrangement of sensors, light sources and capacitor plates within the device.

Capacitance-to-voltage and light-to-voltage converters together with an Innovative-Sensor-Technology TSic 301 temperature transducer and a Honywell HIH 4000 Integrated Circuitry Sensor humidity transducer were coupled with a National Instrument NI-USB-6216 data acquisition unit and connected to an ARK-3399 computer (www.advantech.com.au) that was used to process and save the data. Figure 7 illustrates the electrical components of the device and their location to each other in the device. The capacitance sensors delivered linear and rapid responses to variations in cotton mass and moisture to a sensitivity of ~±1 femtofarad of the nominal capacitance value. The accuracy of the system strongly depends on mechanical robustness of the duct sensor to vibrations, thermal expansion and contraction and electrical interference. The effect of external electrical field disruptions was reduced by shielding the electronic circuitry and cables. Vibrations were reduced by bracing the duct sensor to the self-standing scaffold. The sensor was isolated from vibration in the duct by flexible joints (Figure 8). Sensors and light sources were sealed from the outside environment so that dust would not affect the measurement. The position of the glass window used to separate the light sensors from the material and dust inside the duct means that it was largely self-cleaning.

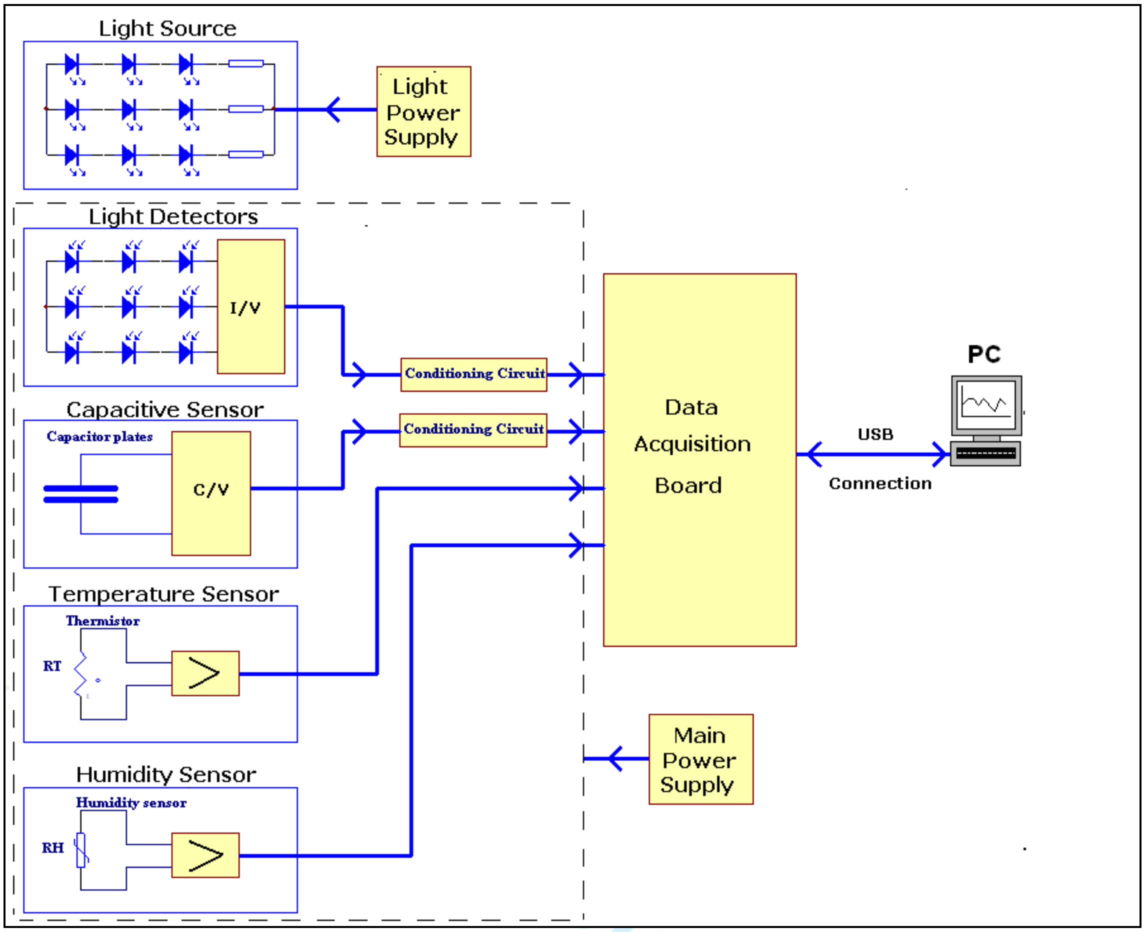

Figure 7. Arrangement of sensor and data acquisition circuitry within the device.

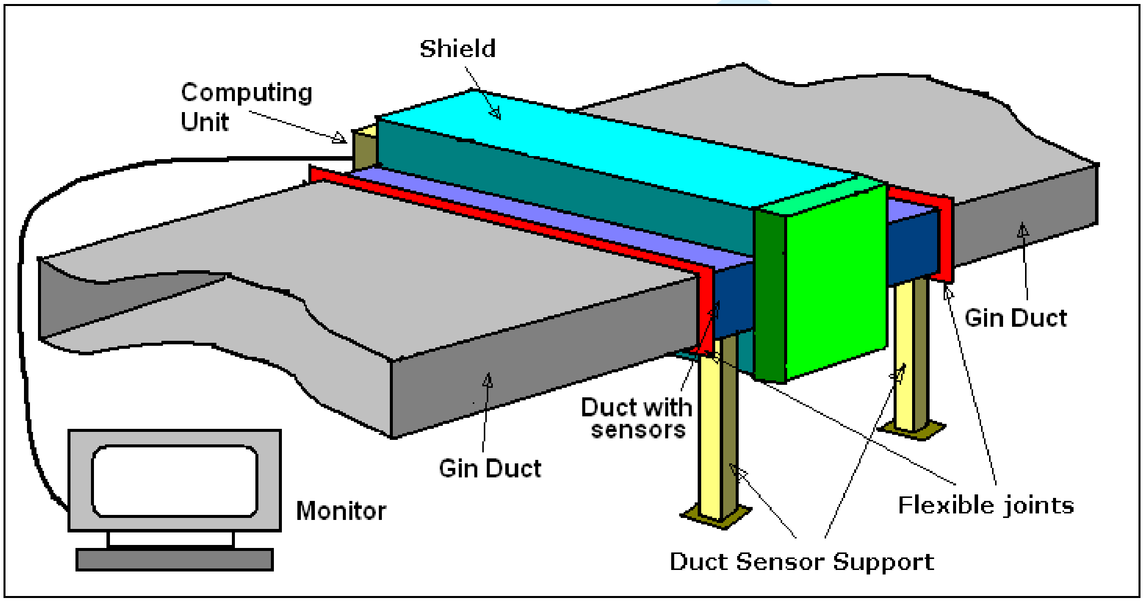

FIGURE 8. Diagram showing shielding and support of sensor device within gin duct.

Thermal expansion (or contraction) of the duct sensor brought about by ambient and in-duct temperature variations are compensated by software calibration. In-duct humidity changes affect the cotton moisture measurement. The humidity and temperature sensors are used to compensate for those errors in the device. Humidity and temperature sensors are placed at the top part of the duct, with the humidity sensor protected against dust deposits by a wind shield. In the Honeywell sensor, true relative humidity varies according to:

$$RH_{True} = \frac{V(RH)_{Sensor}}{f(V(T)_{Temp.Sensor})} \quad (4),$$

where *f(V(T))* is the function of temperature sensor output voltage and *V(RH)* is the relative humidity sensor output voltage. The in-duct temperature was obtained from a commercial temperature sensor according to:

$$T = 200 * V(T)_{sensor} + 50 \quad (5),$$

where *V(T)* is the sensor output voltage. The plates and the lighting system are incorporated within the duct width and height of 2500 mm x 150 mm, however the design and location of active components is flexible to accommodate different duct dimensions.

EXPERIMENTAL DATA

Figure 9 shows the location of the device within the duct system of Gin 9 at Auscott Limited in Narrabri, NSW, Australia, where the industrial trials of the device were carried out. On-line experimental data from the device's sensors were collected over two separate one-week periods during the 2009 ginning season. The data acquisition system was set to average each sensor's signal and store the data every 60 seconds. This allowed a reasonable sample frequency and sensitivity and also enough time to withdraw fibre samples for off-line moisture measurement in order to 'calibrate' the device's sensor data.

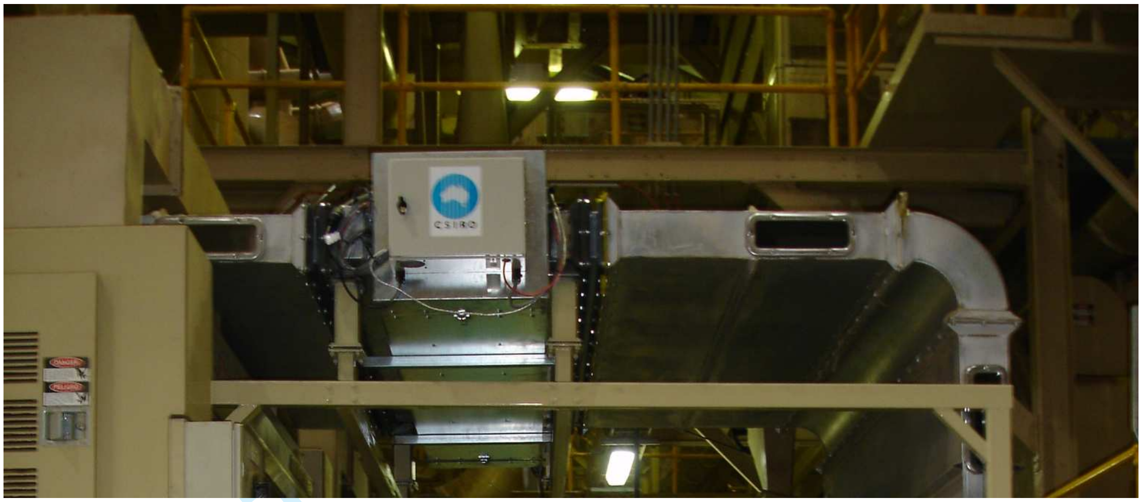

FIGURE 9. Position of the device in ducting between the gin stand and first lint cleaner.

Ginning shifts during the 2009 season were limited to 12 hour day shifts starting at 0700 hrs. Ambient conditions were typically cooler and wetter in the early morning (12°C & 50% RH) and hotter and drier during midday and late afternoon (30°C & <25% RH). Fibre samples were periodically withdrawn throughout each shift from the sampling door in the duct just prior to the sensor device. The time at which each sample was withdrawn was synchronized with the on-line PC clock using a handheld timer-clock to allow alignment and correlation of the on- and off-line data, in order to generate a calibration.

Withdrawn fibre samples were quickly sealed in a zip-lock plastic bag to preserve their equilibrated moisture content, which was measured immediately using a VOMAX 465 Bench Top Moisture Gauge manufactured by VOMAX Instrumentation Inc., Adelaide, South Australia. The VOMAX 465 is calibrated to gravimetric moisture content according to an oven-drying standard similar to ASTM Standard designated 2495-07. A reported correlation (r^2) between moisture content by oven-drying and the VOMAX 465 for cotton fiber samples with moisture contents between 4 and 10% was 0.964, with a standard error of (moisture) prediction of ±0.36% (Kelly, 2006). The advantage of the VOMAX 465 is the ability to gain a moisture values within a minute after the fibre sample has been weighed, which enables more frequent sampling and testing than would be possible using a gravimetric oven test method. Over two separate one week periods >200 specimens were collected and tested this way.

DATA ANALYSIS

To determine moisture values from the device's sensor values, capacitance and light sensor data were aligned and then rescaled with average moisture content values from the VOMAX 465 and corrected for humidity using Equation (6):

$$moisture = (A \frac{M_{cap}}{B * M_{light}} + d) * m_{VA} - C * H_{true}(T) \quad (6),$$

where M_{cap} is the mass indicated by the capacitance sensor, M_{light} is the mass indicated by the light sensor, m_{VA} (in %) is a rescaling factor determined by the average moisture content (over the calibration test period) measured by the VOMAX 465 and H_{true} is the relative humidity. The value of m_{VA} used in these tests was 5.5%. Four other constants are used: A and d allow for the rescaling and alignment of the normalized capacitance signal to the final *moisture* value, while B depends on the difference between the cotton mass as indicated by the capacitor and light sensors. During the testing reported here, the value of B was determined as being ~1.12, but it is possible for the value of B to be affected by changes in the dimensions and orientation of the capacitor and/or light sensors. The constant C describes a portion of the in-duct humidity that is subtracted from the capacitance signal to compensate for external humidity and temperature changes that affect the permittivity of the sensor materials in the capacitor. This constant is positive and ranges in magnitude from 0.1 to 0.001. In the study reported here, C has a value of 0.0012. Values of A and d were 0.8 and 0.7 respectively. Constants A, B, and C are empirically established during the calibration process and they may change for different dimensions of the capacitive sensor, different type of light sensor, and humidity and temperature sensors. Statistical analyses of the measured and calculated data were conducted using Minitab 15.

RESULTS AND DISCUSSION

Figure 10 shows raw capacitance and light sensors voltage values measured by the device throughout one afternoon of the 2009 trials. The signal lines show the minimum voltage numbers for the capacitance (3) and light sensors (0.5) when no lint is passing through the device. Also noticeable is the deviation in capacitance from the light signal line as a run of drier modules was started (@1350 hrs) through the hotter and drier afternoon. The lines show that while the particulate 'concentration' of lint measured by the light signal remains constant, the mass of lint measured by the capacitance sensor is reduced as a result of the lower moisture content of the in-coming module and the dry conditions of the afternoon.

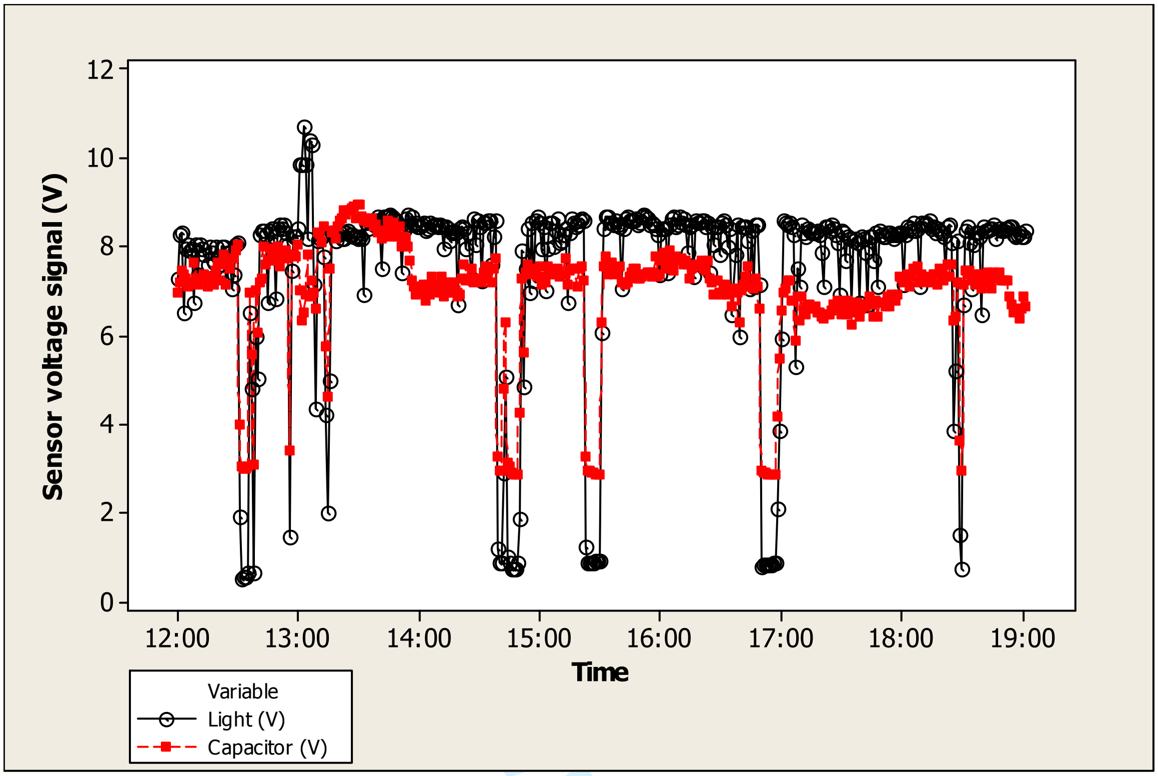

FIGURE 10. Capacitance and light sensor values from the device within the duct of Gin 9, Auscott.

VOMAX 465 moisture values (N = 205) measured on separate lint samples withdrawn from the duct during the trial period were paired with capacitance and light sensor values and converted to moisture values using Equation (6). Calculated moisture values were then regressed against the measured VOMAX 465 moisture values in order to provide a measure of the device's accuracy. Paired values were retained in the regression on the basis of their standardized residual (SR); paired values with a SR > 2.0 (> 2 standard deviations) were eliminated from the regression set. On this criterion N was reduced to 172 paired values. Statistics describing the distribution of these remaining calculated (device) and measured (VOMAX) values appear in Table I.

Rejected values are most likely to have occurred as a result of abnormal VOMAX readings, where sample extraction, handling and presentation in the measuring cylinder prior to measurement were not optimized or where withdrawn samples did not adequately represent the greater mass of fibre in the duct at the time. For example, offline measurements were made on cotton samples collected directly from the duct. These samples represented only a small amount of the cotton 'seen' by the device, which continued to average its data at around >25 kg/min. Indeed, herein are the main challenges associated with any 'live' calibration for this type and scale of industrial sensor.

Table I – Distribution statistics of the device and VOMAX moisture results

Sample Set	Mean	Std. Dev.	Min.	Q1	Median	Q3	Max.
Device (calculated)	5.517	0.276	4.952	5.297	5.494	5.721	6.116
VOMAX (measured)	5.436	0.265	4.800	5.200	5.400	5.600	6.100

Figure 11 shows a scatterplot of the paired data. The analysis of variance for their relationship appears in Table II. While the regression correlation coefficient (r^2 = 36.1%) is not large, the relationship is significant (P = 0.000), especially in light of the narrow range of moisture contents measured (between 5% and 6%) and the experimental errors associated with sampling and the VOMAX and device measurements, which likely accumulate to give measured values an error of at least ±0.5%. A spread of this magnitude is seen in Figure 11. Indeed, the expected experimental error plus some difficulty in exactly aligning the VOMAX moisture values of withdrawn fibre samples with the device's calculated average values are nominated as the main reasons for some of the insensitivity of the VOMAX data to the calculated moisture content by the device. Expanding the range of moisture values would of course improve this regression further and reduce the affect of extreme-points (VOMAX values of 4.8% and 6.2%) in this set. Figure 12 shows the 205 consecutive VOMAX and paired calculated (device) moisture values including values rejected on the basis of their standardized residual. Evident in this plot is the very reasonable relationship between the VOMAX and calculated device values.

Table II – Analysis of variance between the device and VOMAX moisture results

Source	DF	SS	MS	F-value	P
Regression	1	4.3211	4.3211	95.99	0.000
Residual Error	170	7.6526	0.0450		
Total	171	11.9737			

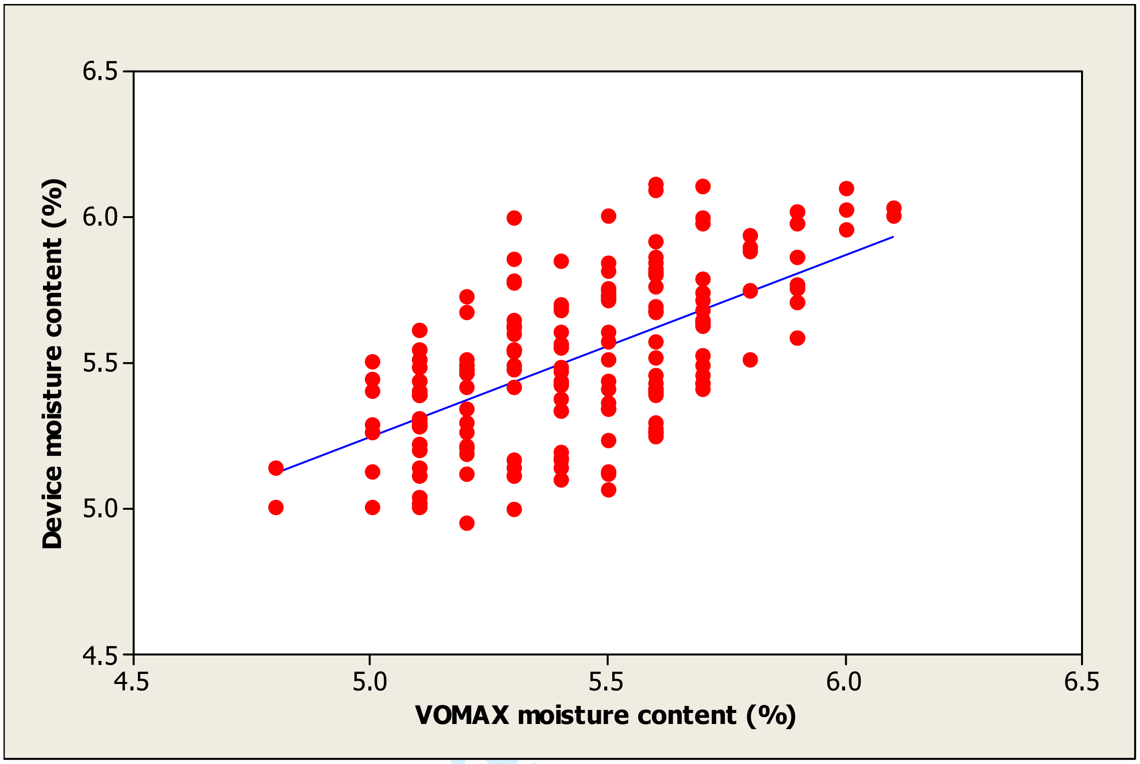

FIGURE 11. Regression between paired VOMAX 465 and device moisture values

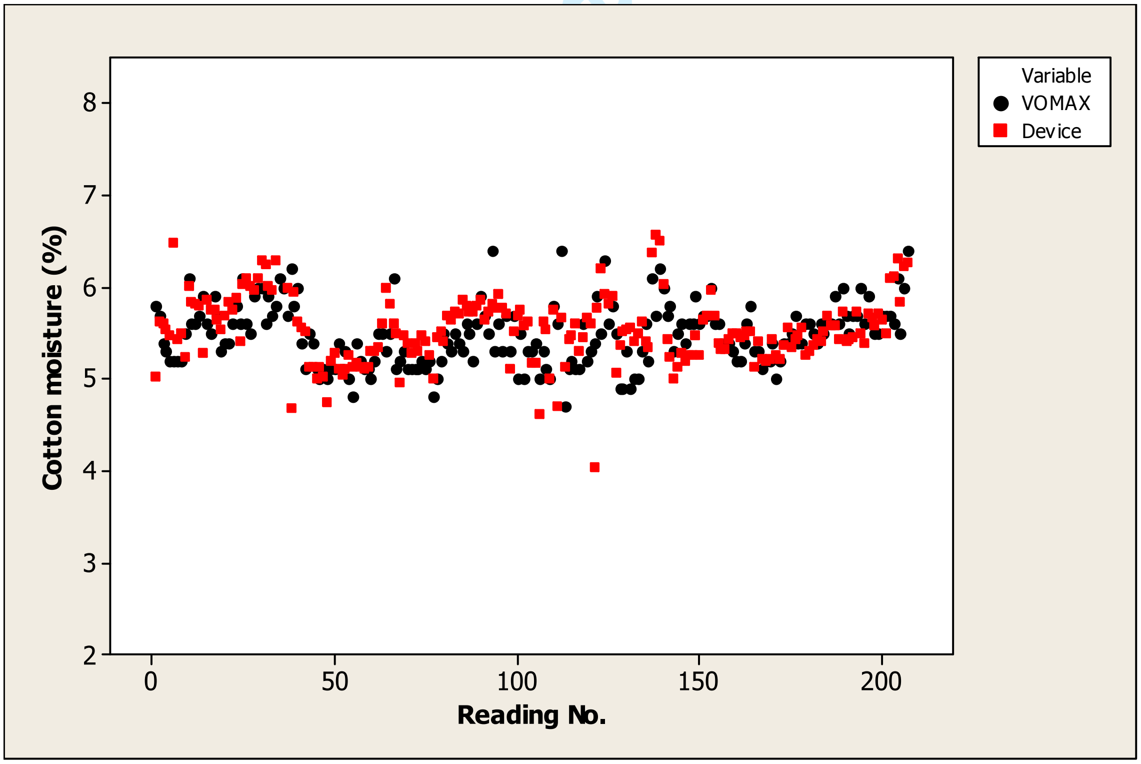

FIGURE 12. Line graph showing consecutive paired VOMAX 465 and device moisture values

CONCLUSION

In this paper we present a new mass and moisture sensing device that has good potential for measuring the moisture of seed-cotton before ginning and/or the moisture in lint before it undergoes cleaning and or baling in the gin. The design of the device combines large area capacitance plates with light detectors to measure the mass and moisture of lint travelling quickly under pneumatic pressure through gin ducting. Although not tested in this study, the application of the method to seed-cotton, ginned seed, and grains is also feasible.

In this study the device successfully tracked moisture in lint travelling at 20 m/sec through the ducts of a modern, commercial gin. Moisture values produced by the device were checked against values measured using a VOMAX 465 Bench Top Moisture Gauge. The advantages of the device under trial are that it measures the moisture content and mass of all the cotton or material in the duct and that it is non-invasive. Combined these properties make the device potentially very useful in managing the use of moisture on cotton to enhance its resilience before ginning and lint cleaning and/or managing the application of heat for cleaning and drying cotton. Further trials in industry will continue with a focus on using the online sensor to control ginning and examining its performance across a wider range of moisture levels.

ACKNOWLEDGEMENTS

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Appendix 2

Krajewski, A. S. and Gordon, S. G., A system and process for measuring properties, provisional patent document submitted January 2009 (PCT application being prepared December 2009)

A SYSTEM AND PROCESS FOR MEASURING PROPERTIES

FIELD OF THE PRESENT INVENTION

The present invention relates to a device and system for measuring physical properties of fibrous and non-fibrous materials. For example, and without limitation, the present invention may be suitable for measuring moisture levels of fibrous materials such as cotton while being handled by processing machinery.

BACKGROUND OF THE PRESENT INVENTION

With respect to cotton, the level of moisture at harvest through the lint in the bale can have significant effects on the quality of fibre sold to the spinning mill. There are optimum moisture levels for seed-cotton and lint that provide good and efficient ginning, cleaning, baling and safe storage. Likewise there are similar considerations in the processing of other materials and fibres. In the case of moisture, to optimise processing and fibre quality the amount of moisture in a fibre under ambient conditions needs to be balanced with the amount of drying or moisture applied during the various processes.

Despite development of systems that measure and then allow drying or moisture replenishment to be metered onto fibre there has not been widespread uptake due to disadvantages associated with the measurement technique. The main disadvantages of current moisture measurement techniques are their low accuracy and/or that a long time period is required to conduct the tests.

The techniques currently used for measuring the moisture in cotton lint can be classified into five groups. The techniques that are currently used are typically based on either one of:

- thermal drying (gravimetric);

- chemical reaction analysis;
- spectroscopy;
- electrical resistance or microwave transmission of water; and
- compression and resiliency properties of fibre.

The use of thermal, chemical and compression methods is excluded from in-line applications on the basis of inadequacy of measurement speed.

Electrical resistance and microwave transmission can be used for in-line applications or *in situ*. However, both techniques have shortcomings. For instance, resistance meters is carried out using electrode probes that are affected by surface contaminants, which can alter immediate and short-term future readings, and measurements are diminished by very wet or very dry samples, which affect the accuracy of resistance readings. Moreover, resistance systems measure only a small part of the production; hence the problem with contamination of electrodes.

Microwave radiation transmission relies on the sample having a minimum density between the microwave transmitter and antennae. For example, microwave systems are applied very successfully at either end of the cotton ginning process, i.e. to modules of seed-cotton and to compressed bales of cotton lint, where the density of the accumulated fibre is in excess of 100 kg/m^3. The application of microwave systems to transport ducts where the density of material is less 15 kg/m^3 is considered not viable.

It is an object of the present invention to provide an alternative system and process that can be used to measure, amongst other things, the moisture levels of materials such as fibrous materials.

SUMMARY OF THE PRESENT INVENTION

System

According to the present invention there is provided a system suitable for measuring a physical property of a material, the system comprising:

- **i) a capacitor that generates an electric field and when in use, the material whose physical properties is to be measured is disposed in the electric field and changes in capacitance of the capacitor caused by the material provides a first output signal;**
- **ii) a detector and/or detectors that provide a second output signal that relates to physical properties of the material; and**
- **iii) a processing unit that determines for the desired physical property of the material with reference to the first and second outputs, and suitably an absolute value for the desired physical property.**

In an embodiment, the first output signal relates to at least two physical properties of the material in the electric field, at least one of which is the desired physical property and a second physical property.

In an embodiment, the second output signal relates to the second physical property of the material.

According to the present invention there is provided a system suitable for measuring a desired physical property of a material, the system comprising:

- **i) a capacitor that generates an electric field and when in use, the material whose physical properties is to be measured is disposed in the electric field and changes in capacitance of the capacitor caused by the material provides a first output signal that is related to at least two** physical properties of the material in the electric field, at least one of which is the desired physical property and a second physical property;

ii) a detector and/or detectors that provide a second output signal that is related to the second physical property of the material; and

iii) a processing unit that determines the desired physical property of the material with reference to the first and second outputs and, suitably an absolute value for the desired physical property.

In an embodiment, the desired physical property is the moisture content of the material and the second physical property is the mass of material, and suitably the mass of the material in the electric field.

In an embodiment the system includes a passageway, suitably in the form of a duct through which the material being measured is conveyed. For example, the material is pneumatically conveyed along the duct.

In an embodiment, the capacitor forms an electric field across the passageway and the first output signal is based on the changes in capacitance as the material is conveyed along the duct and through the electric field. In addition, the detector measures the second physical property of the material as the material passes through the electric field.

Although it is possible that the detector may be balance scales or even a second capacitor configured to detect the absolute mass of material, suitably the detector is an optical device that estimates a physical property of the material in the electric field such as the mass of the material in the electric field.

Suitably, the optical device comprises a light source and a light receiver that are arranged such that the material at least in part, is located between the light source and the light receiver and the second output signal is a signal of the light receiver. We have found that changes in the amount of light received by the receiver caused by the material shielding the receiver is a function of the mass of the material.

In an embodiment, the optical device is configured to radiate the material in the electric field with light that may extend into the UV and/or NIR spectrums. Suitably, the optical device radiates the material as it passes through the electric field.

In an embodiment, the processing unit also uses a known set of reference data for the type of material in the electric field in determining the physical property. The set of reference data may include data of values of output from the light receiver relating to the mass of material, and suitably the mass of the material in the electric field. The set of reference data may also include data of changes in electric field as a function of the mass of the material in the electric field and the desired physical property, such as moisture content of the material.

In the situation in which the system is operated to measure the moisture content of a fibre such as cotton fibre, suitably the capacitor is operated to generate an electric field that is sensitive to the presence of the material. For this embodiment, we have found that we can adjust the electric field such that it is suitable for measuring a sample of cotton fibre having a total mass up to approximately 4,000 grams in the electric field, and suitably up to 2,000 grams and even more suitably in the range of 200 to 900 grams. These operating parameters are suitable for measuring moisture content of natural fibre up to 20% and, when the fibre is cotton, changes in electric field of this strength is suitable for measuring a moisture content in the range of 0.1% to 16% weight of the fibre.

In an embodiment, the capacitor comprises charged plates, suitably copper plates that have dimensions encompassing the width of the conveyance duct.

In an embodiment, the system further includes a converter that converts either one or a combination of the first and second signals from an analogue signal to a digital signal.

In an embodiment, the system further includes a shield about the capacitor to shield the electric field of the capacitor from other electromagnetic fields from external devices.

In an embodiment, the system further includes a temperature sensor for sensing the temperature in the electric field. The temperature sensor may be any suitable thermocouple device. A signal from the temperature sensor may be communicated to the processing unit and the processing unit may activate an alarm when the operating temperature falls outside upper and lower preselected temperature limits.

In an embodiment, the system further includes a humidity sensor for sensing the humidity of air in the electric field. A signal from the humidity sensor may be communicated to the processing unit and the processing unit may activate an alarm when the operating humidity falls outside an upper preselected humidity limit.

In an embodiment, the system further includes a flow sensor for sensing the flow rate of air in the electric field. Under most operating conditions, the flow rate of air can be equated to the flow rate of material passing

through the electric field.

Process

According to the present invention there is also provided a process for determining a physical property of a material, the process including the steps of:

a) introducing material into an electric field of a capacitor;
b) measuring changes in the capacitance of the capacitor caused by the material introduced into the electric field in step a) for a given mass of material in the electric field; and
c) determining an absolute value for the physical property based on changes in capacitance measured in step b) with respect to a known set of reference data for the type of material in the electric field.

In an embodiment, step a) involves conveying the material through the electric field. Suitably, step a) involves conveying the material pneumatically through the electric field. Even more suitably, a stream of air carrying the material travel at up to 20 m/s.

In an embodiment, the change in capacitance measured according to step b) relates to at least two physical properties of the material in the electric field, of which one is the desired physical property and the mass of the material in the electric field.

In an embodiment, the process further includes estimating the mass of the material in the electric field of step b).

In an embodiment, estimating the mass of the material in the electric field involves optically measuring the mass of the material.

In an embodiment, optically measuring the mass of the material involves exposing the material to a light source and measuring light intensity from the material using a light receiver. Suitably, optically measuring the mass of the material involves directing a light source toward the material and measuring the intensity of light radiating away from the material using a light receiver. Even more suitably, the light source and light receiver are arranged such that at least part of the material is located between, or passes between, the light source and the receiver. We have found the changes in an amount of the light received by the light receiver from the light source relates to the mass of the fibre located between the light source and the light receiver.

In an embodiment, estimating the mass of the material involves comparing a running value of the output of the light receiver to a known set of reference data. The set of reference data suitably comprising: data of values of output from the light receiver relating to the mass of material, and suitably the mass of the material in the electric field. The values of the set of reference data may change for different operating conditions and for different types of material. For example, the set of reference data may vary based on operating temperatures or temperature ranges; or operating humidity or humidity ranges. In the situation in which the material is pneumatically conveyed through the electric field, the operating conditions may also include the flow rate of air, or a range of flow rates of air through the electric field.

In an embodiment, the process also includes sensing the temperature of the air in the electric field, or suitably the air flowing through the electric field. The set of reference values may include values of the mass and light received for different operating temperatures.

In an embodiment, the process also includes sensing the relative humidity of the air in the electric field, or suitably the air flow through the electric field. The set of reference values may include values of the mass of materials based in the light received by the receiver for different operating humidity.

Although the process may be suitable for handling a range of different types of materials, in the situation in which the material is a fibre such as cotton fibre, the desired physical property is moisture content of the fibre. In this situation, the capacitor has a resolution in the electric field such that the system is sensitive to a total mass of the fibre in the electric field of up to approximately 4,000 grams, and suitably up to 2,000 grams and even more suitably in the range of 300 to 800 grams.

In an embodiment, step c) involves determining the desired physical property with reference to another known set of reference data for a given type of material in the electric field. The set of reference data may also include data of changes in electric field as a function of the mass of the material in the electric field and the desired physical property, such as moisture content of the material.

In the situation in which material is cotton fibre and measuring the moisture content of the fibre is the objective, step c) suitably involves determining the moisture content to an accuracy of ± 0.5% weight of water on the weight of the fibre, or even more suitably to an accuracy of ± 0.25%.

In an embodiment, the process may involve controlling the flow rate of material passing through the electric field.

In an embodiment, the process may involve controlling the humidity of the air passing through the electric field.

In an embodiment, the process may involve measuring any one or combination of the following operating conditions and activating an alarm when the operating condition falls outside a predetermined limitation for the operating condition.

According to the present invention there is provided a process for determining moisture content of cotton fibre, the process including the steps of:

a) conveying a stream of cotton fibre through an electric field of a capacitor;

b) measuring changes in the capacitance of the capacitor as a result of the fibre passing through the electric field;

c) estimating the mass of the fibre in the electric field based on an optical measurement of the fibre in the electric field by comparing values of the optical measurement with a known set of reference data for cotton fibre; and

d) determining the moisture content of the fibre based on the changes in capacitance measured in step b) and the mass of the material of step c).

According to the present invention there is also provided a process for determining a desired physical property of material, the process including the steps of:

a) introducing material into an electric field of a capacitor;

b)measuring changes in the capacitance of the capacitor caused by the material introduced into the electric field in step a), wherein the change in capacitance relates to the desired physical property of the material and another physical property of the material in the electric field;

c)estimating the other physical property of the material;

d)determining an absolute value for the desired property using the changes in capacitance measuring in step b), the other physical property of the material from step c) and a set of known reference data for the type of material.

It will be appreciated that the process of the present invention, either in its broadest form or an embodiment thereof may also include any one or a combination of the features described above under the heading *System*. Similarly, the system of the present invention, either in its broadest form or an embodiment thereof may also include any one or a combination of the features described above under the heading *Process*.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described with reference to the accompanying drawings, of which:

Figure 1 is a schematic perspective view of a system for measuring moisture of cotton fibre flowing in a duct of the cotton gin according to a preferred embodiment;

Figure 2 is a schematic exploded view of the working components of the system shown in Figure 1; and

Figure 3 is a block diagram of the process steps of the present invention.

DETAILED DESCRIPTION

A system and process of a preferred embodiment of the present invention will now be described with reference to the accompanying Figures. The system and process shown in the Figures is also specifically adapted for measuring the moisture content of cotton fibres. However, it will be appreciated that the invention may be used with respect to other types of the materials or fibres and may also be used for measuring different types of properties

of the material being measured.

With reference to Figures 1 and 2, the system includes a duct or conduit that can be retrofitted to existing ginning equipment to allow an in-line or *in-situ* testing of the fibre. The size of the duct can be modified as required to suit particular types of ginning equipment. In particular the duct 9 shown in the Figures is designed to fit to a ducting between a gin stand and a lint cleaner of cotton processing equipment and is adapted so that a stream of fibre entrained in air flows along the duct 9.

The system also includes a capacitor suitably in the from of a pair of copper capacitor plates 1 on upper and lower sides of the duct 9, and an optical device in the form of an array of LEDS 2 and 4 that are located in top and left sides of the duct respectively and light receivers or photo-optic sensors 3 and 5 located on the bottom and right hand side of the duct 9 respectively that are coupled to a digital micro-processing unit 10 and personal computer. The purpose of the optical device is to optically measure the mass of the fibre flowing through the duct 9. A cover is fitted over the capacitor plates 1 to minimise the impact if the external electromagnetic fields over the fibre passing between the capacitor plates 1.

Although not shown in Figures 1 and 2, the system also comprises a power source for applying a charge to the capacitor plates 1 and a converter such as a delta-sigma C/D converter for converting analogue output signals of the capacitor and the photo-optic sensors 3 and 5 into a digital signal.

The perforated capacitor plates 1 are placed on the both sides of the duct 9 on glass or fibreglass sheets in order to prevent them touching the duct 9 or conduit

chassis. The array of LEDS 2 is placed directly above the top (or below the bottom) of the capacitor plate 1 so the light can travel through the mesh or holes in the capacitor plates 1. Partially transparent glass finished with vaporised metal can be used instead of the perforated capacitor plates 1. The photo-optical sensors 3 are placed directly below the bottom or above the top of the capacitor plate 1 so that light directed through the perforated plates can reach the photo-optic sensors 3.

The capacitor plates 1 may be substituted with multiple plates that are connected in series or parallel. Moreover, it is possible that the optical device for detecting the mass of fibre in the electric field of the capacitor be substituted with another capacitor operating under conditions suitable for measuring the mass of the fibre conveyed through the duct.

In use, cotton fibre is conveyed through the electric field of the plates 1 of the capacitor. The capacitor is supplied pulsed excitation. Changes in capacitance of the capacitor are converted from an analogue to digital signal by the convert and supplied to the microprocessor. Changes in capacitance are a function of the mass of the fibre and the moisture content of the fibre. Ideally, changes in the electric field caused by the fibre passing through the electric field are resolved in terms of the changes in capacitance. In practice we have found that the electric field can provide a resolution in the order of 0.015 grams i.e., 0.1% or 0.2 grams of a 200 gram sample of the cotton fibre in the electric field. We have also found that up to 4,000 grams of fibre can be entrained in air passing between the plates. These operating parameters have proven suitable for measuring moisture content of the fibre of approximately 0.1 weight % at very low relative humidities near 0% to approximately 16 weight % at almost 100% relative

humidity.

In addition, the array of LEDS 2 at the top, and optionally at the bottom of the capacitor plates 1 are connected to a pulsed current source, which allows greater light output over time and reduces the influence of ambient light on the sensors. The additional set of LEDS 4 placed at the side of the duct are also connected to a pulsed current source but suitably at a different frequency to the frequency to that of LEDS 2. A different switching light frequency allows differentiation between the two light sources using simple Fourier Form Transform analysis (FFT).

In the event of high fibre weight between the LEDS and the light receivers, the light power can be increased by increasing the amplitude of current pulses and accommodating the logarithmic amplifiers for the light receivers. If heavier weights of material are used, and the transmitted light power is occluded by the fibre, the mass flow may be predicted by the scattered light from the top surface of the moving fibre.

The light radiating from the LEDS 2 or 4 that is not shielded or by the fibre passing through the duct 9 is detected by the light receivers 3 and 5. We have found that the light received by the receivers 3 and 5 and, therefore, the output of the light receivers is related to mass of the fibre passing through the duct 9 at any moment.

The micro-processor 10 compares the output of the light receivers 3 and 5 to a known set of reference data comprising date of values for the light received by the receivers to the mass of fibre in the duct 9, and thereby determining the mass of fibre being conveyed through the duct 9. Moreover, the particular arrangement of the LEDS 2 and 4 and light receivers 3 and 5 on outsides of the

capacitor plates 1 as shown in Figure 2, ensures that the mass of the fibre detected by the optical device is the mass of fibre in the electric field of the capacitor.

The determination of the mass of the fibre in the electric field is then used by the microprocessor 10 to normalize the capacitance output signal, or a change in capacitance output signal for mass flow. The normalized capacitance output signal or a change in capacitance can then be compared to a known set of the reference data comprising data of changes in electric field as a function of the mass of the material in the electric field and the moisture content of cotton fibre.

The system is designed to be fast so that each individual scan of the fibre takes very little time and the material moves only by the distance of the physical width of the capacitor per scan. The signals can be processed in real time before the next scan. The resolution of the system therefore depends on the speed of the cotton in the duct. At 20m/sec this associates with a time between scans of less than 10 milli-seconds, which allows the material to travel 0.2 m matching the width of the capacitor sensor. The scanning process is continuous and reliability of the system is enhanced by deterring the mass in the electric field and measuring changes in capacitance substantially simultaneously.

In addition, the system also includes a humidity sensor 8, a temperature sensor 7 and an air flow sensor 6 placed in the duct 9 so as to monitor in-duct conditions. Each if the sensors 6, 7 and 8 are coupled with the micro-processing unit through analogue-to-digital converters. The signals from all sensors 6, 7 and 8 are pre-processed and conditioned by the micro-processing unit before being sent to the PC for further real time processing. In other words, the output of the sensors 6, 7 and 8 may be used by the micro-processor to change between different sets of the reference data, in which each set of data correlates to the operating conditions detected by the sensors 6, 7 and 8.

With reference to Figure 3, the process of present invention involves conveying material, such as cotton fibre through the electric field and measuring changes in the electric field of the capacitor. In addition, the process also involves estimating the mass of fibre being conveyed and suitably the mass of fibre conveyed through the electric field. Although estimating the mass of the fibre in the electric field may involve measuring the dielectric properties including changes caused by the fibre in another electric field, suitably estimating the mass of the fibre is carried out using a detecting device in the form of an optical detector which optically measures changes in light received by a light receiver caused by the fibre being conveyed between the light source and the light receiver. Output from the light receiver is communicated to the processing unit which in turn estimates the mass of fibre in the electric field at any one moment by comparing the signal to a known set of reference data (20) that is retrievable by the micro-processor.

Changes in the electric field caused by the fibre relates to the mass of the fibre in the electric field and other physical properties such as moisture content in the fibre. The output of the electric field is normalised to remove the influence of mass of fibre in the electric field using the mass detected by the optical measurement.

Finally, the moisture content of the fibre is determined with reference to the normalized output of the electric field which may also include a comparison to another known set of reference data (30). As can be seen from Figure 3, the output signals of the capacitor and optical

device may be used by a micro-processor form manipulating the output signals as described to arrive at the moisture content.

The sensors 6, 7 and 8 can also be used for controlling moisture and mass flow, by feeding back via a PC or microprocessor, to the process feed and/or humidifier or dryer systems of a gin (not shown in the Figures).

It will be understood by persons skilled in the art of the invention that many modifications may be made without departing from the spirit and scope of the invention.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

CLAIM

A system suitable for measuring a physical property of a material, the system comprising:

- i) a capacitor that generates an electric field and when in use, the material whose physical properties is to be measured is disposed in the electric field and changes in capacitance of the capacitor caused by the material provides a first output signal;
- ii) a detector that provides a second output signal that relates to physical properties of the material; and
- iii) a processing unit that determines for the desired physical property of the material with reference to the first and second outputs, and suitably an absolute value for the desired physical property.

Figure 1

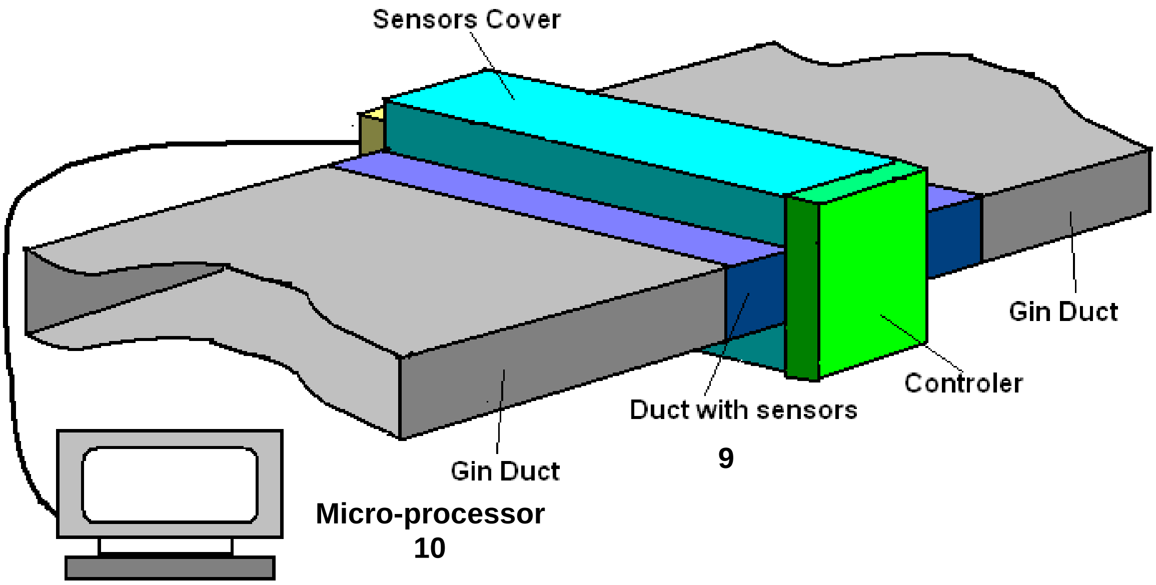


Figure 2

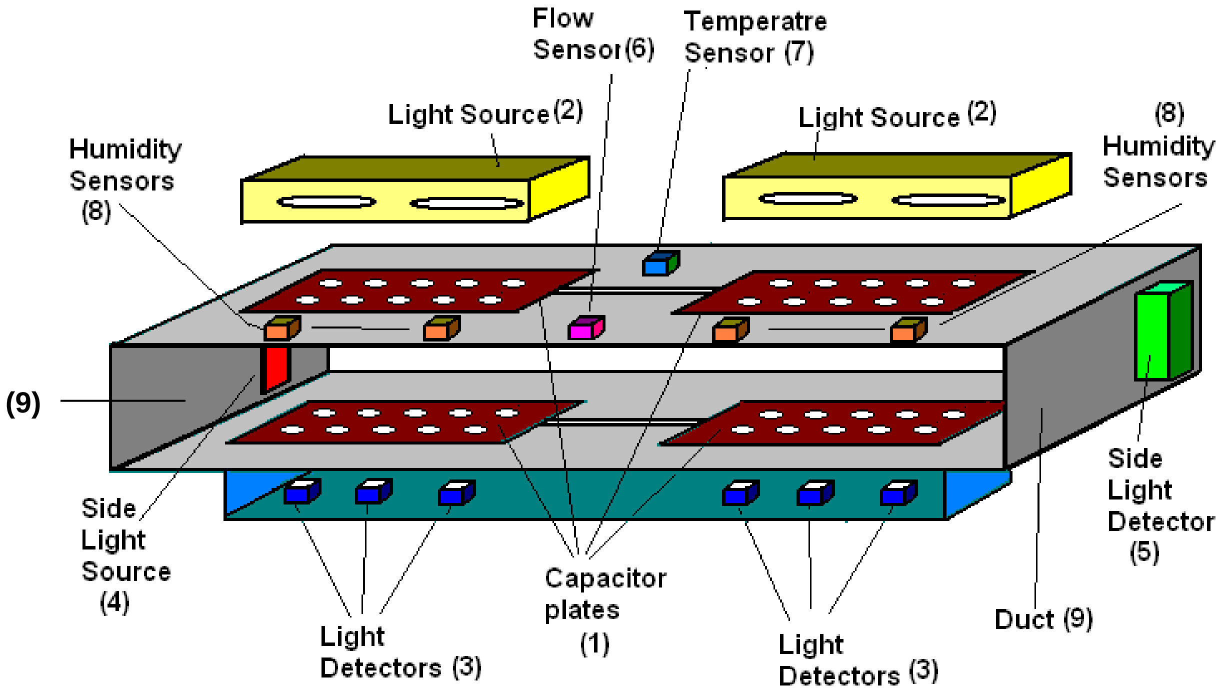
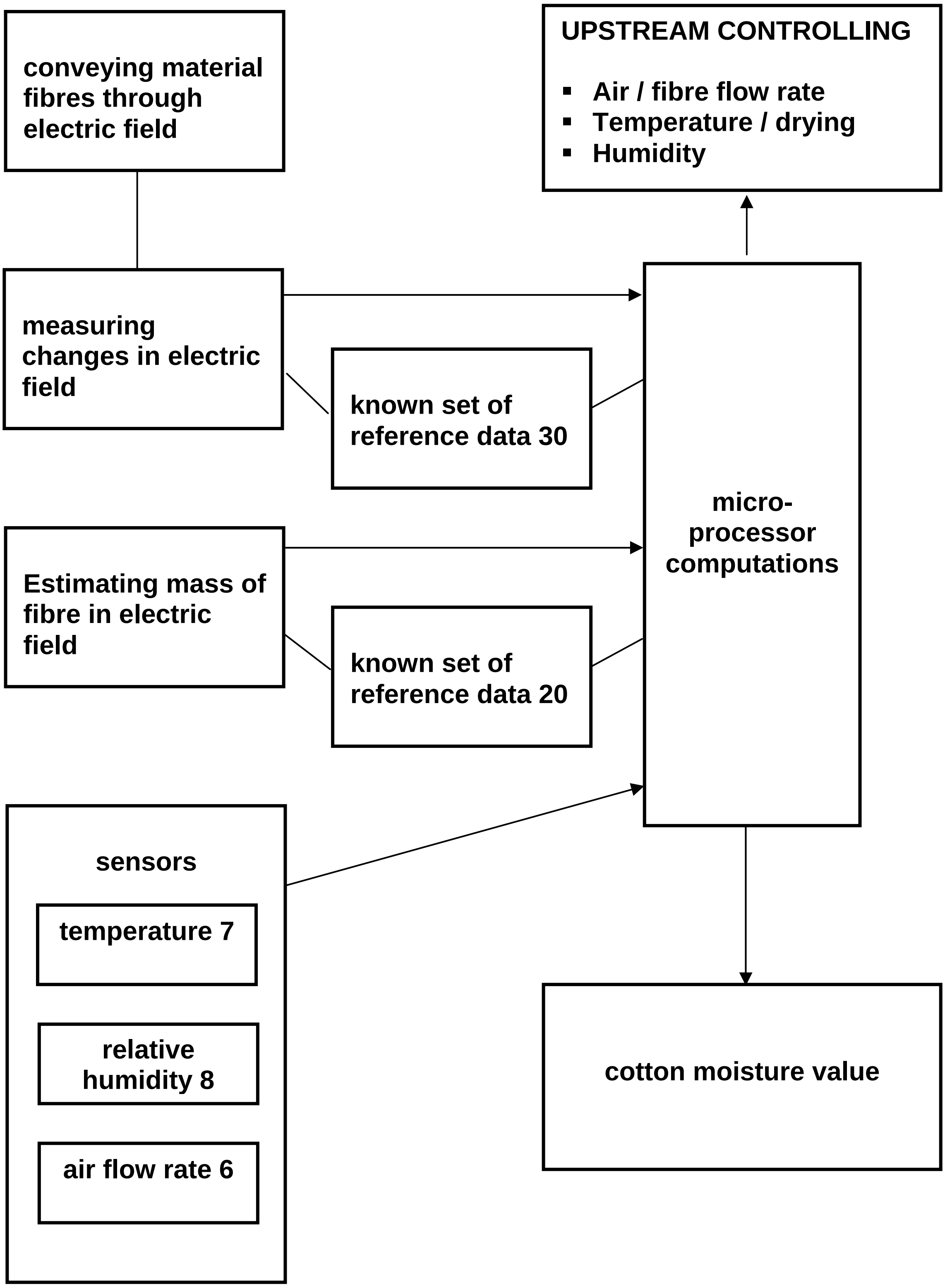


Figure 3


conveying material fibres through electric field
UPSTREAM CONTROLLING
Air / fibre flow rate
Temperature / drying
Humidity
measuring changes in electric field
known set of reference data 30
micro-processor computations
Estimating mass of fibre in electric field
known set of reference data 20
sensors
temperature 7
relative humidity 8
air flow rate 6
cotton moisture value