THE ON-LINE INSPECTION OF SEWN SEAMS

PIs: Timothy G. Clapp (Team Leader, NCSU) L. Howard Olson (G. Tech)
Kimberly J. Titus (NCSU) J. Lewis Dorrity (G. Tech.)

Code: **S94-4**

ABSTRACT:

Apparel manufacturing is traditionally very labor intensive due to the extensive style and fabric variation of the products. Most of the sewing machine manufacturers and some of the larger apparel companies have developed semi-automated sewing stations to perform operations which are constant across a large style range. These normally require an operator to load the machine, which then automatically sews and stacks the components. Although such stations improve production efficiency, they remove the almost unconscious operator inspection of the operation. The result is that only major seam faults such as thread breaks are observed. Other faults, skipped stitches or non-included seams for example, may not be detected until the garment is completed or perhaps not until after laundering. At this point, the manufacturer's cost is at a maximum. In order to reduce the number of defective garments it is necessary to develop complete seam monitoring systems that meet the apparel manufacturer's requirements of flexibility, cost, and reliability. Several techniques capable of detecting faulty seams on-line have been investigated which include thread line monitoring and the use of a beta-particle transmission gauge. Prototypes have been developed for testing and demonstration of these techniques. The details and results of these investigations are provided.

GOALS:

SHORT TERM: Design, develop, and evaluate sensor technologies to measure and quantify the quality of seams. The production of proof-of-concept prototypes will demonstrate the suitability of those technologies recommended for real-time monitoring systems.

LONG TERM: Produce a "black box" to be attached to a sewing machine which would provide information that would allow for the real-time adjustment of the sewing machine settings in order to optimize performance.

TECHNICAL QUALITY AND ACCOMPLISHMENTS:

An interdisciplinary team of researchers from the College of Textiles at North Carolina State University and the School of Textile & Fiber Engineering at Georgia Institute of Technology have collectively addressed the following tasks: 1) industrial collaboration in order to compile a technology survey and determine design specifications, 2) the fundamental research of fabric and seams, 3) the investigation of technological concepts which could potentially be used in a seam monitor, and 4) the construction of proof-of-concept prototypes to demonstrate those techniques of greatest feasibility. The technical quality of the research is reflected by progress made thus far in the second year of the project. A brief summary of the research effort for this reporting period is also provided.

Papers:

1. J. Lewis Dorrity and L. Howard Olson, “Thread Motion Ratio Used to Monitor Sewing Machines,” Textile Process Control 2001 International Conference, Manchester, England, May 18, 1995.
2. J. Lewis Dorrity, “New Developments for Seam Quality Monitoring in Sewing Applications,” IEEE Industry Applications Society, 1995 Textile Fiber and Film Industry Conference, May 3, 1995. Note: **This paper was cited as “Best Paper” at this conference.**
3. K.J. Titus, “Opportunities for Physicists in the Multi-billion Dollar U.S. Textile Industry,” submitted to the Forum on Physics and Society Newsletter of the American Physical Society, June, 1995.

Presentations:

1. T.G. Clapp, K. Titus, G.R. Barrett, and Z. Zhu, “On-line Fabric and Seam Characterization Techniques,” presented to the Instrument Society of America, Raleigh, NC, Jan. 10, 1995.
2. K.J. Titus and T.G. Clapp, “On-Line Seam Monitoring Technology,” presented to American Bag Corporation, a subsidiary of Milliken & Associates, Stearns, KY, March 15, 1995.
3. K.J. Titus, “Opportunities for Physicists in the Multi-billion Dollar U.S. Textile Industry,” Invited talk at the Joint Meeting of the American Physical Society and the American Association of Physics Teachers, Wash. D.C., April 18, 1995.
4. T.G. Clapp, K.J. Titus, C.E. Farrington, research presentation for Sunny Ishikawa of Union Special, Raleigh, NC, Feb. 13, 1995.

Visits:

1. Magnolia Finishing Plant of Milliken and Associates, Magnolia, SC.
2. AMTEX Annual Report, Wash. D.C., March 2, 1995.
3. American Bag Corporation of Milliken and Associates, Steams, KY.
4. Russell Corp., Alexander City, AL.
5. Levi R&D Center, Dallas, TX.
6. Milliken, LaGrange, GA.
7. Eltex of Sweden, Greet-, SC.
8. Haggar, Dallas, TX.
9. Royal Home Fashions, Durham, NC.

Collaboration:

1. NCSU Department of Nuclear Engineering
2. Levi Strauss & Co.
3. Russell Corp. R&D in Alexander City, AL
4. (TC)^2 in Cary, NC
5. Southern Tech Apparel Demonstration Site, Atlanta, GA
6. Union Special, Huntley, IL
7. On-Line Sensors, Waxhaw, NC

RESEARCH SUMMARIES:

In the first year of the project, a technology survey was conducted by the team members at NCSU and Georgia Tech to determine the specifications for a seam monitoring device. The major stitch types identified for the study were the single and multi-needle chainstitches, lockstitch, safety stitch, and overedge stitch. Seam types for both knit and woven goods included the single-fold knit hem, leg hem, and felled inseam and riser. Common seam defects for these seams included raw edges, needle cuts, non-inclusions, seam allowance and hem-width variations, puckering, mis-matched seams, pleats, improper thread tensions, incomplete operations, and skipped stitches. A "black box" could be located between the folder and the presser foot, within a few inches behind the presser foot, or on the body of the sewing unit.

Our research efforts were divided into two categories: those focusing on stitch formation and those considering the formation of the seam. The first approach included techniques such as Thread Motion Ratio (TMR) determination as well as the use of optical sensors. Techniques to determine seam quality include the transmission of radiation such as beta particles and infrared light as well as the investigation of needle penetration forces. The highlights of these investigations are presented below.

Thread Line Monitoring of Seam Quality

The proposed efforts for this project were directed to multiple thread sensing of sewing defects. The principle involved is that of measuring the time of thread motion and comparing that to the time of a single sewing machine cycle to arrive at a measure termed the Thread Motion Ratio or TMR. This concept works if the true thread motion velocity with time is consistent from stitch to stitch. Although there is indeed variability in the formation of stitches, a great deal of experimental work has shown that averages of sets of stitches provide sufficient consistency to TMR that errors or false indications of error occur much less than once per million cycles, in fact being set in the research to about once per eight hour work shift in a plant.

Prior work, including the initial proof of concept tests, had involved a lo&stitch machine (stitch type 301') with a needle and bobbin thread. Other stitch formations which had come to the forefront through recommendation of the Technical Advisory Committee members were candidates of value to industry. These were the two needle chainstitch (type 406) and the overedge stitch (type 504). Both stitches are formed with three sewing threads. Stitch type 406 has two needle threads and a bottom looper to lock them in place while the type 504 has one needle thread and both bottom and top looper threads. The first assumption was that a multiple thread sensor, i.e. one with three or four thread sensing positions, would be needed to achieve positive results with stitches such as these latter two.

There is a direct cost associated with the sensors, and while some savings is had in multiple sensing heads, the total cost is at least double that of a single threadline sensor. Thus, a first effort went into reviewing feasibility of a single sensor, multiple thread environment. The bottom line results of the experiments is that a single sensor can work quite effectively, and that sensor location is important to overall effectiveness. The initial lockstitch work had been done with needle thread sensing since the bobbin is inaccessible to an external sensor. In contrast, the needle thread is not an efficient point for sensing defects with either the type 406 or 504 stitches.

With the two needle chainstitch (406). neither of the top needles offers best sensing, but rather the bottom looper thread. The bottom looper thread has the greatest consumption since it traverses the gap between the two needles on each stitch. The features which govern a thread being “best” appear to be the amount of thread consumed, tension balance among the threads, and the geometry of the stitch. With the type 406 stitch, if either needle thread breaks or is missed in the formation process, then a large change in TMR occurs. Figure 1 illustrates a 406 stitch as viewed from on top and from underneath. This illustrates that more than simple break conditions can be detected.

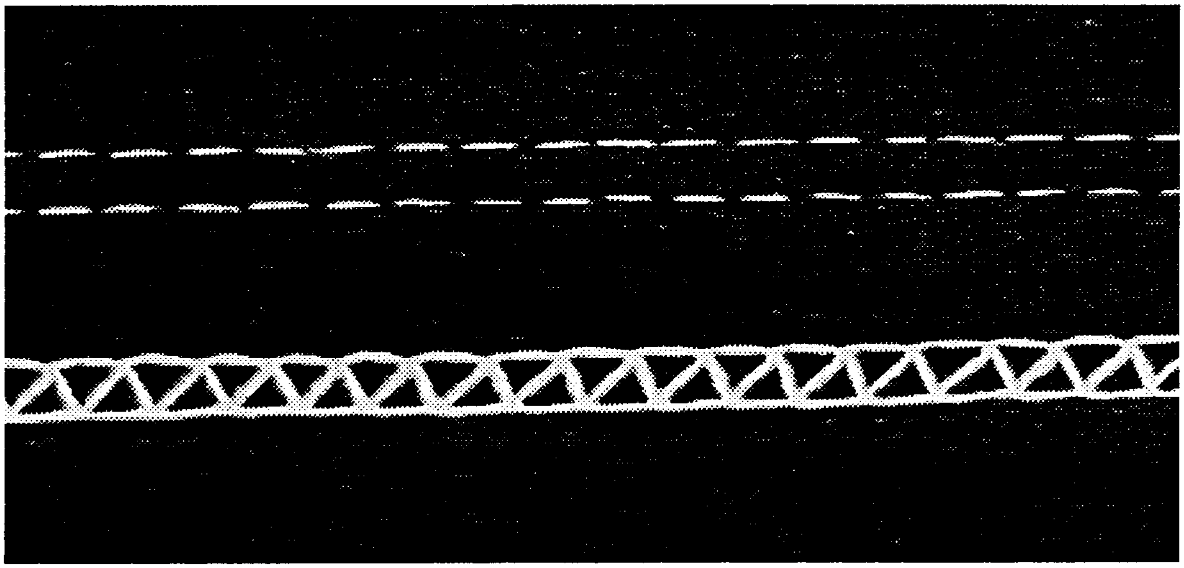

Figure 1 Two needle chainstitch (both sides)

The stitches are obviously fairly uniform, but not perfect. The nonuniformity is handled through averaging of individual stitches and using a large control limit before declaring a seam error condition. Four standard deviations as a control limit accomplishes the reduction in false indications as was mentioned in the introductory comments. An example of results is that at 4300 RPM and sensing the looper thread, the control limits were at 5% above and below a mean TMR of 40%, while needle thread breaks were at least 15% below the mean or three times the control limit.

In contrast to efforts with the chainstitch, the overedge stitch offered two looper threads which consumed the majority of thread. Of the two, the top looper thread is much better in giving clear, certain results. Due to the balance of thread tensions and stitch geometry, the top looper thread is most affected by a loss of either the needle thread or the bottom looper thread. With an average TMR of 20% and control limits at 2% above and below, the top looper thread had at least a change of 15% with the loss of either remaining thread. Figure 2 illustrates the stitch, and despite appearing less uniform, does give fairly consistent TMR values.

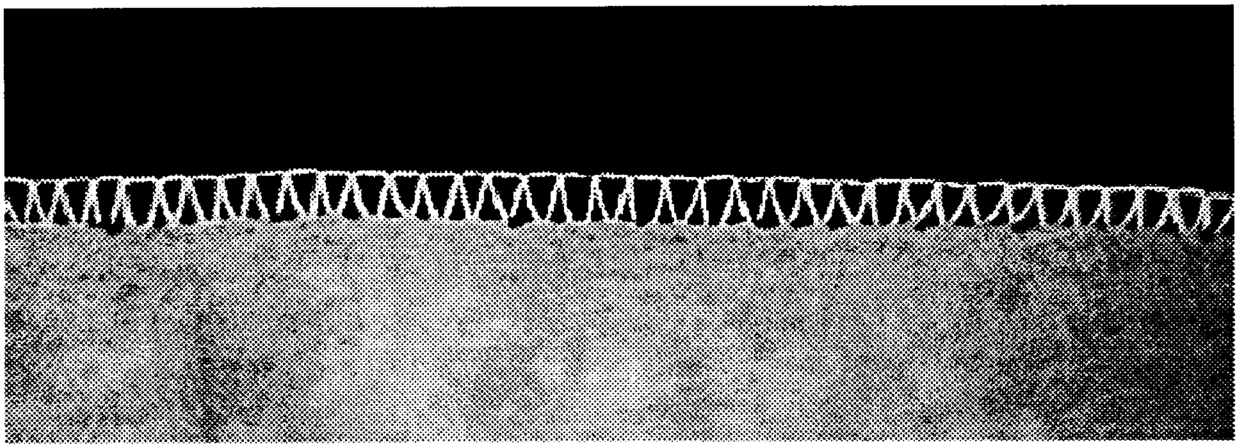

Figure 2 Overedge Stitch

While investigating bottom looper monitoring, snags of the top and bottom looper threads occurred. Both resulted in positive excursions of TMR to values three or more times the control limits (thread breaks are negative excursions).

A second phase of effort in this research period has been to revise the code used by the microprocessor to speed up the sensing and comparison process. With results giving changes three times the control limits, the question being asked was could the control limits be changed. The reason behind this was to reduce the number of data points in an averaged TMR value, in fact looking to the use of single data points in the TMR process, at least for “well behaved” sewing machines or stitch types. Fewer data points in an average increases the value of a standard deviation, and hence, the control limit value.

This work was done in response to external industrial input to our research. An industrial concern making air bags for the automotive industry reported that rapid detection of a defect was quite important. At a fairly small number of “bad” stitches, the air bag part had to be scrapped and all added value to that point lost. The new code is in place in a second Motorola 68HC811 processor. Tests to confirm the code’s reliability are underway currently. The research team is trying to avoid problems like those had by Intel with its Pentium processor. Tests involved direct chip to chip comparison of the code, allowing the number of stitches per averaged group and machine speed to vary.

Yet another path in the research has to do with optimizing the sensor for the sewing machine and stitch type being sewn. The input variables with these experiments were threshold voltage to the sensor’s analog section and sewing machine speed. The results show that the standard deviation of results for groupings of three stitches has a minimum value. That value changes some with speed. Therefore, there is an optimum value of threshold for a particular stitch type and perhaps machine type as well.

Table 1 Effect of Threshold Voltage on Sensing Variability

Volts	Upper 4 σ	Lower 4 σ	Mean %TMR	%CV	RPM
5.0	134	0.0	64	27	5485
4.0	77.5	0.0	38	27	5441
3.32	43.5	8.5	26	17	5681
2.0	23.7	6.1	15	15	5589
1.5	20.2	6.5	13	13	5482
1.0	17.8	5.6	12	13	5728
0.5	16.6	4.2	10	15	5625
0.0	18.9	13.1	11	18	5307

The table also illustrates that setup can affect results with the sensor. Threshold voltage can act to shield noise, but at some point critical information is lost, effectively creating noise. Other factors can contribute too. For example, a poorly maintained machine certainly behaves poorly with respect to consistent stitch formation and consistent value of TMR. This was seen in plant trials.

---

[1] The stitch types are defined in U.S. Federal Standard 751a, “Stitches, Seams, and Stitchings”, General Services Administration, Washington, DC, January, 1965.

Beta-particle Transmission Gauge to Determine Seam Quality

Another approach to detecting faulty seams is to monitor the formation of the seam. Numerous seam defects, such as raw edges, non-inclusions, seam allowance and hem width variations, and pleats, result from an improper number of fabric plies folded and caught by the stitching. By determining the number of plies folded within the seam and secured by the sewing thread, the quality of the constructed seam may be assessed. Although optical ply detectors are commercially available, their use is limited to fewer plies and lower weight fabrics. Other radiation systems such as beta-particle gauges, however, can provide a solution.

Beta gauges are commonly used on-line in manufacturing processes to monitor the thickness of materials made in continuous sheets such as paper, plastics, and metal foils. Such sheet materials are of relatively uniform density such that their thicknesses may be computed from their density thickness. Density measurements such as those used to monitor tobacco packing density in cigarettes can also be made. Beta ray transmission designs have been used on-line in textile manufacturing to measure nonwoven fabric basis weights within a tolerance of

0.25% [1]. Unlike X-rays, microwave, infrared, and visible light radiation, beta rays can adequately separate the product from its environment and are not as composition-sensitive to additives and fillers.

A beta particle is a high energy electron or positron which is emitted from the nucleus of a radioisotope atom as a result of radioactive decay. This process for the strontium-90 radioisotope used in this study is described as

$$^{90}_{38}\mathrm{Sr} = {}^{90}_{39}\mathrm{Y} + \beta + \nu \qquad (1)$$

which yields a beta particle, β and a neutrino, v, when it decays to yttruim-90. In this particular case, yttrium-90 subsequently decays with the emission of another beta particle. Individual beta particles generally travel in a straight line, losing energy in small increments due to ionization interaction. Occasionally, they drastically change direction when they undergo rare elastic interactions with a nucleus or experience bremsstrahlung interactions. The path length, or distance between successive collisions, is proportional to the density of the absorbing material. For most of its range, the intensity of beta particles transmitted through an absorbing material can be described as exponential attenuation according to

$$R(\rho T) = R(0)\exp[-(\mu/\rho)\rho T] + B \qquad (2)$$

where R(0) is the counting rate of beta particles when no material is present, μ/ρ is the absorption coefficient of the material (area per unit mass), ρT is the absorber density thickness (mass per unit area) where p is the sample density and T is the sample thickness, and B is the background counting rate. The absorption coefficient μ/ρ can be determined empirically for a given arrangement of source, sample, and detector. Generally, it is found that for a given beta source μ/ρ depends primarily on the "arial" density or area per unit mass of the sample and depends on sample composition, particularly the presence of heavy elements, to a much lesser degree. Eqn. 2 is easily solved for the thickness to yield

$$T = (1/\mu)\ \mathrm{In}\ [R(0)/(R(\rho T)-B)] \qquad (3)$$

The parameters μ, B, and R(0) are easily determined by least-squares methods with experimental data on samples of known thickness for a particular material. Then, Eqn. 3 can be used directly with the known density to determine unknown sample thicknesses.

The beta-particle transmission gauge used in our experiments consists of a 1.0 milliCurie ^{90}Sr-^{90}Y radioisotope sealed in steel. The point source is enclosed in Plexiglas with a circular 1.0 mm diameter opening to collimate the beta rays. A Geiger-Mueller tube located 12 inches from the source is biased with 900 volts to detect the intensity of particles penetrating the sample. The source and detector remain stationary while samples are translated through the area between them. Standard counting electronics are used. Counting times range from 2 to 20 seconds.

The variety of fabrics chosen for this study are intended to represent those commonly used throughout the industry as determined from our first year survey. Significant attention is given to high volume textiles, namely twill denim and jersey knit. Prior to investigating sewn seams, the transmission of beta particles through single and multiple plies of fabric was studied. Counting rates for transmission through 1, 2, 3, and 4 plies of denim are illustrated in Figure 3.

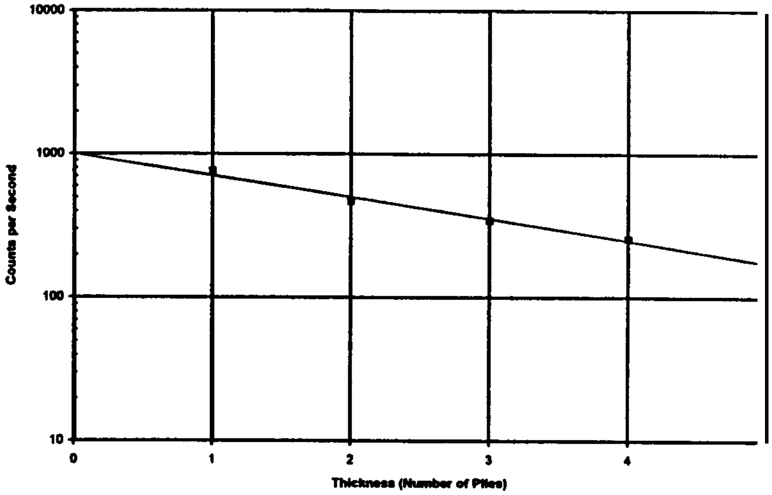

Figure 3 Beta-particle Transmission through Denim

Statistical fluctuations, calculated as the square root of the counting rate, are within 2% of the average. Clearly, the number of layers can be determined up through 4 layers or more for all fabrics tested, including 16 oz. denim. The observed counting rates differ only slightly from those predicted from the exponential relationship of Eqn. 2, indicated by a line least-squares fit through the data. This deviation is attributed to the variation in fabric density as observed across the 1.0 mm collimated beam which is more pronounced for ribbed knits and corduroy.

To continue this fundamental evaluation of the beta-particle transmission gauge, various quality sewn seams were investigated. Two types of seams have thus far been considered: the single-fold edge finish (EFc-2) commonly used for knits and the felled seam constructed from twill denim. The single-fold edge finish EFc-2 often forms the sleeve and bottom hems for knit garments. Those investigated in this study were automatically fed through a mechanical folder and secured by a double lo&stitch. As a result, extra plies can be unintentionally introduced into the stitching which results in pleats and puckering which jeopardizes the quality of the seam. The hem appears uneven and unusually bulky in places and results in an off-quality garment. Defective single-fold hems are less likely to be “overlooked” than felled seams. A felled seam, used throughout the jeans industry to construct inseams, risers, and seat seams, is a folded seam secured by two or three rows of stitching. Because no raw edges are visible on either the inside or outside of the garment, defects are not obvious even to a skilled operator.

A correctly sewn felled seam constructed of twill denim is depicted in Figure 4a. Since the quality of felled seams cannot be assessed visually without removing stitching and consequently destroying the sample, seam quality is confirmed from a radiographic study. X-ray exposures obtained from the sample seams clearly indicate the number of plies within the stitching and the location of the panel edges relative to the stitching lines. This seam contains four plies of fabric from stitching to stitching and each folded edge remains within 1/16" of the nearest stitching line. A defective seam is shown in Figure 5b. The four layers of fabric within the seam do not sufficiently overlap such that only two plies are present at the midpoint. Both of these seams would most likely appear acceptable to an operator yet would create problems downstream in the manufacturing process. The beta-particle gauge correctly identifies the number of plies within the seam, allowing for a proper assessment of the seam quality. Data analysis for the prototype beta-particle gauge continues.

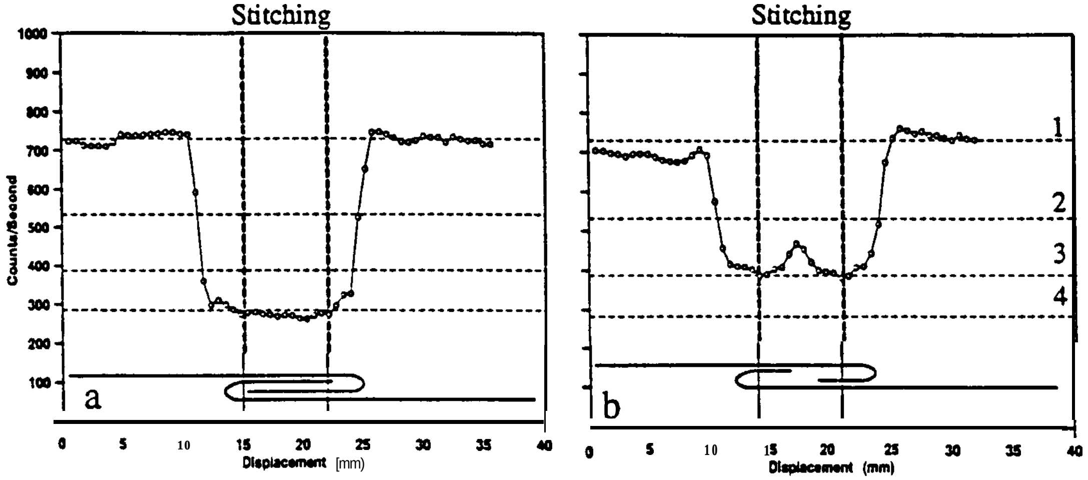

Figure 4 Acceptable and faulty felled seams

The introduction of a radiation source such as a radioisotope into a non-automated manufacturing environment may encounter a great deal of concern regarding operator safety. Several precautions should be taken to greatly reduce this concern. First of all, a source with a proper level of activity should be used. The source activity should be as low as possible while yet providing a satisfactory counting rate for the desired application. Providing a greater distance between the source and operator also serves as protection, for the intensity of the radiation falls off as the inverse square of the distance from the source. Particularly in industrial environments, shielding the source serves as a solution to operator safety. Since beta particles are energetic electrons, they can be absorbed by moderate shielding. For the ^{90}Sr beta source used in this research, 1/4" Plexiglas adequately shields the source from the user. Minimal bremsstrahlung will be produced since the amount of this radiation is proportional to the square of the atomic number and Plexiglas is composed of low atomic number (Z) elements. As with radiation gauges currently incorporated into manufacturing environments, beta-particle transmission gauges could be safely used at semi-automated apparel assembly stations without posing a threat to the operator.

References

1. Boeckerman, P.A., “Meeting the Special Requirements for On-line Basis Weight Measurement of Lightweight Nonwoven Fabrics,” *Tappi Journal,* Dec. 1992, 166-172.

RESOURCE MANAGEMENT

The management structure of the project is based on the establishment and pursuit of common goals and objectives by a team of interdisciplinary researchers while maintaining a sense of individual ownership and responsibility to meet those goals. The management team is led by Dr. T.G. Clapp, who coordinates reporting, communications, and resource allocation for the project. Meetings are held as necessary to discuss ideas and disseminate results of specific tasks. A list of contributors to the project in addition to the PIs reflects the diversity of backgrounds and interests of the individuals.

Other Faculty: Dr. Robin Gardner, Dr. Kuruvilla Verghese (NCSU, Nuclear Eng.)
Visiting Scholar: Dr. Joachin Gayler (Wuppertal, Germany)
Graduate Students: Robert Cox (NCSU, TE/EE), Zhaofeng Zhu (NCSU, Nuclear Eng.),
Howard Foster (NCSU, Physics/Textile Material Science), Rob Schoenborn (G.Tech),
Melissa Wetherington (G.Tech), Susan McWaters (G-Tech),
Elizabeth McFarland (G.Tech, TE), Wendy Bishop (G. Tech, EE)
Undergraduate Students: Adam Davis (TE), Neal Baldwin (TE)