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A INDUSTRIAL SEWING MACHINE VARIABLE SPEED CONTROLLER

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ABSTRACT

The apparel industry is attempting to move in a new direction in the coming decade. Since the invention of a electrically powered sewing machine, the operator has been seated. Today, companies are switching from a sit down operation to a stand up operation involving modular stations. The old treadle worked well with the sitting operator, but problems have been found when trying to use the same treadle with a standing operator. This report details a new design for a treadle to operate an industrial sewing machine that has a standing operator. Emphasis is placed on the ease of use by the operator , as well as, the ergonomics involved. Procedures for testing the design are included in the Report along with possible uses for the treadle in other applications besides an industrial sewing machine.

BACKGROUND

The apparel industry in the United States must adopt new manufacturing technologies in order to be competitive in the world market place. Included in this innovation is the re-designing of the work place to maximize production while offering an increase in employee comfort and safety. Presently, work stations in the apparel industry are not designed to the physical and mental characteristics and limitations of the employees.

For years the apparel industry has used industrial sewing machines in which the operator remains seated. However, studies show that standing operators can achieve higher production rates than seated operators, while placing less stress on the human body.1 These studies, performed by Georgia Tech Research Institute (GTRI) ergonomics specialist, showed a significant reduction in musculoskeletal discomfort for standing operations versus seated operations. The standing operation also allows the operator to move from one machine to another in the work module or cell easily. Therefore, stand up assembly or modular assembly has become an attractive alternative to the seated operation.

The problem encountered when changing a seated operation to a standing operation is the lack of adjustibility of the controller or treadle. The result is postural discomfort for the operator, a decrease in the production rate, and a increase in health risk. Therefore, the objective of this project is to design a foot controller or treadle that is a compatible to the characteristics and limitations of the operator. The treadle, which controls the stitches per minute on a sewing machine, will be a variable speed controller to be tested on an industrial sewing machine.

There are different types treadles presently on the market. There is the traditional foot treadle, a knee controller, a voice activated controller, a foot treadle with side to side motion, and a treadle that has only two speeds. Each of these treadles are designed to control the speed of the needle. Some of the treadles have other options added to thetreadle.

The traditional foot treadle is the same basic design as the peddle used on the old human powered machines. The foot is a lever hinged to the floor at the heel and operator has easy control over the lever. The lever pushes down on the treadle to control the speed of the needle. The treadle is a variable speed controller. The mechanical motion occurring from the pressure on the treadle changes a potentiometer and this in turn changes the speed of the needle. A backward movement on the treadle causes the needle to lift up and then an automatic cutting of the thread occurs.

The knee controller uses a spring to change the speed of the needle. The spring turns a potentiometer which in turn controls the needle speed. The knee controller is found more often on home sewing machines than on industrial machines.

Voice activation is the newest controller out on the market. This controller is produced by Efka. There are some limitations with its use. The operator can not have a monotone voice because the computer can not differentiate the commands. There are possible problems with noises in the vicinity. An ergonomic problem might arise from overuse of the operator's vocal cords. Also, the controller must be programmed to the particular operator's voice which does not allow for maximum utilization in the work place.

The side to side controller works on a spring that activates a potentiometer. The changes in the spring change a potentiometer and this controls the speed. An ergonomic problem that from the constant twisting of the ankle. This can produce cumulative trauma disorders.

The two speed controller has four capabilities. It is not a variable speed controller. The controller has four prongs and works on a pneumatic system. One prong controls the up and down movement of the needle, one prong controls the reverse movement, one prong allows for a fast speed, and one prong allows for a slow speed. This controller is produced Textile/Clothing Technology Corporation.

According to a study conducted by the Georgia Tech Research Institute Economic Development Laboratory2, 92.1 percent of the of the operators interviewed and measured for Phase 1 of the "Ergonomic Considerations in Conventional Trouser Manufacturing" study were female. The "typical " female in the study was 40 years old with approximately 103 months experience in industrial sewing. The 95 percentile height results were

(NASA-CR-192066) AN INDUSTRIAL SEWING MACHINE VARIABLE SPEED CONTROLLER (Georgia Inst. of Tech.) 6 p

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171.2 centimeters. Therefore, the designing of a sewing operators work station should consider these results but also be concerned with those whom do not fall into the "typical" operator category. The results of the study, conducted by several specialist in the Ergonomics Department, have been beneficial in collecting background information on the apparel manufacturing industry and determining problems with the present working conditions.

PROBLEM STATEMENT

The development of a variable speed controller that will enable a standing operator to control the stitches per minute on an industrial sewing machine is needed.

The Controller Must:

-be hands free.
-have a range of 0 to 4000 stitches per minute.
-be no longer than 3 feet in width.
-be no longer than 2 feet in depth.
-be no higher than 2 inches in height.
-cost no more than 350 1992 American dollars.
-be mobile so that it can be placed in the best possible position for each operator.

The Controller Will Have:

-a potentiometer.
-110 volts AC input.
-4-20 milliamperes output.
-an automatic shutoff.
-a pad surrounding the device.
-the pad will weigh no more than 15 pounds.
-a pad with a nonslip contact area.
-a compression type spring for pedal return.

Constraints

Several constraints were placed on the design of the foot controller. The controller was to be designed ergonomically with the physical and mental characteristics and limitations of the operator in mind. The controller must be easy to use, therefore the ease of trainability of an operator on the controller is important. Operator safety during operation of the controller is also very important. The controller was required to have an emergency shutdown. Other factors which an emphasis wasplaced on were the reliability of the controller, the maintainability of the controller, and the availability of technology.

VARIABLE SPEED CONTROLLER

Ergonomics

Ergonomics is one of the major forces necessitating the need for a new variable speed controller. According to the Georgia Tech Research Institute Economic Development Laboratory report3, approximately 30% of the seated apparel workers surveyed reported discomfort in the upper leg, the knee, and the lower leg. Of the standing apparel workers, greater than 45% of the people reported discomfort in the left foot and 36% - 45% reported discomfort in the right foot. According to Mike Kelly of GTRI, this can be attributed to the operators placing all of their weight on one foot and then using the other foot to operate the treadle.

Other ergonomic factors that had to be considered were the length of a person's foot, the angle at which the foot is turned out normal to the body, the pressure exerted by the foot, and the force that could be used to turn an object.

It was found that the average length of a woman's foot is 228 mm with a standard deviation of 11 mm. The 95% female right foot is 258 mm. The 5% right foot length is 223 mm. The area that the foot covers is 89 cm2 with a standard deviation of 10 cm2. There is not a statistical difference between the left and right foot. A man's foot was approximately 32 mm longer and it covers 19 cm2 more. The 95% male right foot is 288 mm. The 5% male right foot is 240 mm.

It was found that the average angle at which the right foot is turned out a position normal to the body is 6.80 with a standard deviation of 5.10. A man's foot is turned out 2.30 more than a woman's. It was also found that one can turn their left foot out further than the right foot. A typical person can rotate their right foot clockwise 500 and counterclockwise 450.

The pressure exerted by the female foot averages .33 kg/cm2. The standard deviation is .052. The least pressure exerted was .27 kg/cm2. S. Konz and V. Subramanian4 determined the pressure data by dividing thebody weight in 2 and then dividing by the contact area. The pressure in
lbs/cm2 is .727. This translates into an average force of 64.748 lbs exerted by each foot for a woman.

According to Woodson and Conover5, the upper-force limit for hip movement only is 40 pounds. It is possible to develop a CTD (cumulative trauma disorder) in the hip if the force of the motion involved is greater than 40 pounds. According to Mike Kelly of GTRI, there is no hard evidence to back up the possibility of CTD's occurring yet, but logical thought processes would lead one to this conclusion without needing evidence.

Occupational Safety And Health Administration Requirements

The foot controller must follow OSHA (Occupational Safety and Health Adminstration) Regulations. These regulations are stated in the Code of Federal Regulations published by the Executive departments and agencies of the Federal Government. The following regulation is located in the labor Code of Federal Regulations.

Labor 1910.217 (4) Foot pedals (treadle). (i) The pedal mechanism shall be protected to prevent unintended operation from falling or moving objects or by accidental stepping onto the pedal. (ii) A pad with a nonslip contact area shall be firmly attached to the pedal. (iii) The pedal return spring(s) shall be of the compression type, operating on a rod or guided within a hole or tube, or designed to prevent interleaving of spring coils in event of breakage.

Presently there are no OSHA standards concerning ergonomics. However, the Federal Government is in the process of making ergonomic standards in order to improve working conditions for employees. These standards will make an impact on all industries and their present working environments.

Design Process

After the initial problem was discussed, a brainstorming session took place. Information was gathered from Georgia Tech Research Institute (GTRI) on ergonomics. A consultant in the apparel industry was contacted to discuss modular apparel manufacturing. The Georgia Tech data bases were used to find books on different types of controls. From this information gathered, the alternatives were narrowed down to five. The five remaining were 1) lasers, 2) vacuum or air flow, 3) roller bar, 4) push bar, and 5) pressure sensors in the floor.

The laser would be able to control the change in needle speed by determining the number of beams broken by the operator's leg. The operator would have been able to move the leg forward into the path of the beams. Ergonomically, this design had its advantages. Weight could be distributed on both feet. The operator's motion would be in the forward direction as he/she started to place the fabric into the sewing machine. There would be little trouble with operator safety. The major disadvantages to this design were the space necessary for its use and the trip hazards developed by the receptors for the lasers.

The vacuum or air flow idea was very similar to the laser idea. As the air receptacles were covered, the speed of the needle speed would increase. The operator would step into the air flow. Ergonomically, there was little problem with this design. The operator would be able to maintain weight on both feet. The operator's motion would be in the forward direction as he/she started the needle and pushed the fabric into the sewing machine with a forward motion. There would be little trouble with operator safety. The major disadvantages were the same as those for the lasers.

The idea of using a push bar with the thighs is similar to the knee press that is already on the market. As the bar is pushed in, the needle speed would increase. Ergonomically, this design had few disadvantages. Weight could be distributed on both feet. The operator would be able to use either leg or both legs to operate the machine. The operator's motion would be in the forward direction as he/she started the needle and pushedthe fabric forward into the sewing machine. The major disadvantages with this design were the possible hazards from having a bar sticking out and the construction of a fail safe switch.

The idea of the roller bar is similar to a computer mouse. As the mouse is moved in a forward normal direction, the needle speed would increase. A spring mechanism would have been installed so that weight could be distributed to the foot operating the control. Ergonomically, this had some disadvantages. The constant rolling of the pedal, if directed from the hip, could cause hip problems. The operator's motion would be in the forward direction as he/she started the needle and pushed the fabric forward into the sewing machine. The major disadvantage to this design is the possibility of the operator tripping due to the rolling motion of the bar.

The pressure rug alternative would increase or decrease the speed of the machine depending on where the operator is standing on the rug. Ergonomically, there were no disadvantages to this idea. There would be an anti-stress mat or carpeting for the operator to stand on. The operator would be able to maintain even weight on both feet. The sensors could be placed so that the operator's motion would be in a forward direction as he/she started the needle and pushed the fabric forward into the sewing machine. The major disadvantage with this design was the precision. The operator would have to be on just the right spot to reach the desired speed.

A trip was taken to Southern Tech to visit the apparel laboratory. Several types of controllers were seen. A discussion took place with Carol Ring about the controllers presently on the market and the controller alternatives. The design group took her expertise and re-evaluated the design alternatives. Lasers and the vacuum or air flow seemed to be over engineered. The roller bar would be too large of a safety hazard and the push bar would get in the way of the fabrics being processed. This left the pressure rug.

The pressure rug needed to have more precision, so the design group went back to the decision matrix to see what ideas could possibly be combined with the pressure rug to get precision. The idea of a disk thatcould be turned by the foot seemed to work, but pressure sensors did not apply. Carol Ring was asked to evaluate the design. After a discussion with her and with Dr. Dorrity and Mr. Brazell, it was decided to proceed with the design of a disk placed in a anti-stress mat.

DESIGN ANALYSIS

The final design is based on a disk that will rotate no more than 150. This rotation will activate a potentiometer. The potentiometer will change the voltage and this in turn will change the speed of the needle. The disk will be placed in an anti-stress mat to help alleviate strain on the body. The actual designed foot controller is described in the Foot Controller Design section in detaill.. A working model was built to simulate the designed model. Details of the working model are in the Model section.

Foot Controller Design

The general design consists of three parts. They are the base, the pedal, and the potentiometer.

The base is a polyisoprene rubber that provides excellent resiliency, durability, and chemical resistance. The resistance includes, the ability to resist moisture and dirt as well as more dangerous chemicals. This type of rubber also provides an easy surface to cut into and mount the other pieces. The mat is 35 inches wide and 24 inches long. The base height is 2 inches. The corners of the base are rounded to prevent a trip hazard. The size of the base should allow it to be placed anywhere in front of the machine that the operator wishes. This alleviates the problem associated with the treadle used now. The presently used treadle can not be adjusted due to its height and its need for mounting.

The pedal is made of aluminum and is mounted with bearings to support the load as well as provide easier turning of the pedal. The pedal is designed in a shape similar to a human foot to allow easy placing of the operator's foot. There is a guard attached to the right side of the disk that will aide the operator in the movement of the pedal and it will also aide in the placement of the foot. This guard provides a greater area for the rotational force to be directed. The guard is made of aluminum. A rotational spring provides the force to rotate the disk back to the neutral position. The rotational spring is made out of music wire ASTM-A228. The bearings turn on a track of stainless steel to reduce the friction and abrasion wear between the rollers and the rubber of the base. This trackis known as the roller guide. The pedal is placed on the mat such that the operator has room to place his/her left foot on the mat also. The pedal has a radius of 13 inches. The outer edge of the pedal has a turn of 350. The pedal rotates under the edge of the mat. There are dust sweeps on the edge of the mat to prevent dust particles and thread from getting inside the controller.

The potentiometer is connected to the disk by an aluminum rod. The rod is attached to the disk and as the disk turns, the rod turns the potentiometer. The disk can not turn unless 15 pounds force is placed on the heel area. There is a spring placed under the heel that is rated for 15 pounds force. The spring is 7/8 of an inch in diameter. When the 15 pounds force is met, the shaft can engage and the pedal can rotate. The shaft is 1.75 inches deep. Underneath the shaft sits a disk which prevents the shaft from digging into the rubber. The potentiometer is turned by the motion of the foot pedal. This can be seen in drawing number 9. The potentiometer provides a voltage that varies from 0 volts to 20 volts. This in turn feeds the circuit connected to the servo motor. The circuit on the sewing machine allows certain settings to add resistance to the circuit. This limits the current going to the motor and therefore limits the speed of the motor. The variable resistance within the circuit of the microprocessor allows for speed control other than that of the foot pedal. It adds a range to the device for being able to sew many types of items with less risk of mistakes.

Materials List

Mat	Rubber
Pedal	Aluminum
Guard	Aluminum
Shaft	Aluminum
Disk	Stainless Steel AISI 304
Roller Guide	Stainless Steel AIAI 304
Rollers	Stainless Steel AISI 304
Shaft Spring	Music wire ASTM-A228

Model

The model consists of three basic parts. They are the base, the pedal, and the potentiometer controller. The base is made of plywood with one inch dowels attached as stops and as axis of rotation for the foot pedal. The foot pedal is a fourteen inch radius, twenty-five degree arc piece made of plywood. There is an aluminum rod attached to both the potentiometer and the pedal. This rod changes the potentiometer and it also allows the needle up action and automatic thread cut to take place. The controller is a standard part obtained from the JUKI research facility in Duluth, Georgia. The part is a series of four potentiometers linked together to add and subtract their voltages to obtained the desired ranges. The voltage's are processed by the microprocessor of the sewing machine. This processing changes the current being received by the servo motor, thus changing the speed of the sewing machine.

The model was made with the ability for the pedal to lay flat against the base or to be mounted on rollers. The stop for the left side would be moved back to provide the necessary range for these functions to take place. The rod could also be the spring for the device if a different potentiometer from the standard JUKI part was used.

COST

The cost of the treadle could not exceed 350 dollars. A middle quality motor costs $150. Motors range from $60 to $250 depending on where the motor is made. The treadle costs $50. The brackets needed to mount the treadle cost $10. The wiring costs on the average $30. a complete rewiring of the treadle would cost more than this. It is rare that the treadle needs to be replaced. The wiring may need to be replaced once during the lifetime of the sewing machine. A treadle is considered to have the same lifespan as the sewing machine.

The new treadle had to have a cost that would be comparable to the replacement cost for a treadle. It would be expected that the new design would be installed when new machines are purchased. Industry would consider purchasing the new design if it could be proven that the company would benefit from increased production rates and deceases in absenteeism and health expenditures.

COST ANALYSIS

Old Treadle		New Controller	
Motor	$250	Motor	$250
Treadle	$50	Pedal	$30
Brackets	$10	Pad	$30
Wiring	$30	Potent.	$20
		Extras	$10
Totals	#350		$350

HAZARDS

Several hazardous conditions had to be considered in the designing of the foot controller. The following hazards were addressed: tripping on the mat, tripping on the actual controller or disc, electric shock, spills, and the sewing needle.

One requirement of the design is that it must be fail safe. This requirement was attained by using a tension spring to place the disc back in the neutral position. The shaft under the heel has a cut away area that allows the disc to move when at least 15 pounds force is applied. A 15 pound rated spring will be located under the heel.

Another hazardous condition that needed to be addressed was the mat in which the foot controller is embedded. This is raised enough off the floor to be considered a tripping hazard by OSHA regulations. This hazard can be alleviated by painting the area surrounding the anti-stress mat a bright yellow color. This is required by OSHA Regulation 1910.144(a)(3). Sloping the edges of the mat to the floor and rounding the corners will also help.

Tripping over the actual foot controller in the mat can also be a hazard. Therefore, the controller is flush with the floor when inactive, and at least 15 pounds force is necessary for the disc to move.

In order to prevent electric shock, the disc is made of a insulating material. The material of choice is aluminum.

The needle on a industrial sewing machine is a potential hazard. A tension spring is used to return the disc to the neutral position, so that the needle does not remain in the up position. Therefore, the needle will not be active when the foot is not on the disc. Also, sewing machines presently have a thumb guard to prevent fingers from getting under the needle.

Possible oil spills and other liquid spills had to be addressed. The rubber mat would need channels in it to allow the liquid to be at a lower level than the foot until clean up can take place. The aluminum disc would have a nonslip contact area attached to it. This is required by OSHA Regulation 1910.217 (4)(ii).

TESTING THE CONTROLLER

Mechanical Testimg

The mechanical reliability and durability of this device should be tested in two main phases. Phase one consists of laboratory testing of a full scale model. The device would be tested to failure under the specified operating constraints by a continuously running apparatus. The apparatus would apply the weight of the ninety-fifth percentile textile worker and rotate the pedal. The voltage variation of the potentiometer would be measured as well as the friction of the pedal to the mat. Also, the performance of the springs and the actual parts would be evaluated for resiliency and tensile strength over approximately 4-6 weeks. The second phase of the mechanical testing would be the periodic testing of devices in an industrial environment. The designed foot controller would be placed in an manufacturing plant for approximately 6 months. After these 6 months the controller will be removed and tested for the same properties considered in phase one. Some additional test results would be required. These include testing for dirt resistance and for sustained ergonomic problems. Ergonomic testing can be done in conjunction with the second phase of Mechanical Testing.

Ergonomic Testing

Ergonomic testing will be required on the foot controller. The operators should be asked their opinion of the controller the first two weeks that it is in use. Questions on physical discomfort should be asked as well as questions concerning ease of use of the controller. The same operators should be interviewed six months later to report on physical discomfort that could be contributed to the use of the controller.

It is necessary to test six months later because new discomforts may develope over a long period of time. The operator might not feel discomfort until repetition of the new motion. The test data from both interviews should be compared and problems determined. If the problems existing are contributed to the designed foot controller, steps must be taken to re-design the controller to eliminate the problems.

POSSIBLE APPLICATIONS

Throughout the design process, it was kept in mind that this design could possibly be used in other applications besides an industrial sewing machine. Some of the possibilities are to use the variable speed controller on any turning operation such as a lathe or a pottery wheel. It could also be used on any motorized vehicle. The gas pedal on a car or truck could be replaced. This has definite possibilities with the upcoming production of electric cars. However, a larger potentiometer would be needed because the required voltage variation would be much larger. The controller could also be used on vehicles such as power boats, lift trucks, and the lunar rover.

CONCLUSION

A variable speed controller was needed which would allow an operator to control the speed of a needle when the operator was in a standing position. An attempt was made to make the controller more ergonomically sound than the foot treadle normally used in a sit down sewing operation. Whether or not the new controller was ergonomically more sound could only be proven true of false after a testing period.

The final design consists of a disk that rotates clockwise and counterclockwise placed in an anti-stress mat. When the disk is rotated, a potentiometer is turned by a rod connected to both the potentiometer and the disk. The change in the turns on the potentiometer changes the speed of the needle. The controller can not operate unless 15 pounds force is placed on the spring under the disk. The compression spring also acts as the return mechanism for the disk. The disk has two bearings that are placed under the disk approximately where the ball of the foot would sit.

Cleaning of the controller after each shift is recommended. A thorough blowing off of lint, thread, and dust will help to prevent mechanical down time. It is also recommended that oil be wiped off of the mat when it is dropped on the mat during regular maintenance.

One design recommendation is to change the shape of the disk so as to optimize the operator's comfort and to reduce the open area on the mat. Another recommendation is finding a rubber that is either porous or one that has better resistance to oil. This would eliminate the problem with the isoprene rubber not having good resistance to oil. The design could also be amended to have two potentiometers and a switch that would allow the operator to use either the right or left foot. Our final recommendation is to place the mat and controller in the floor to prevent a tripping hazard if a new facility is being constructed or if a facility is being remodeled.

ENDNOTES

1Ortiz D. J., M. J. Kelly, T. K. Courtney, and D. J. Folds. 1989. Phase 1 Report: Ergonomic Considerations in Conventional Trouser Manufacturing, Design and Development of A Self Study Course for Apparel Supervisors in the Practical Application of Ergonomic Principles. Atlanta GA: Economic Development Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology.

2ibid. , 4

3ibid, 16

4Konz, S. and V. Subramanian. 1989. Engineering Anthropometry, Advances in Industrial Ergonomics and Safety 1. Philadelphia: Taylor &Francis, INC., 203-205

5Conover, Donald W. and Wesley E. Woodson, 1964. Human Engineering Guide for Equipment Designers. Los Angeles: University of California Press.,
2-111

6Ortiz D. J., M. J. Kelly, T. K. Courtney, and D. J. Folds. 1989. Phase 1 Report: Ergonomic Considerations in Conventional Trouser Manufacturing, Design and Development of A Self Study Course for Apparel Supervisors in the Practical Application of Ergonomic Principles. Atlanta GA: Economic Development Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology., 16

BIBLIOGRAPHY

Behan, R. A. 1973. Some NASA Contributions to Human Factors Engineering: A Survey. Washington DC: NASA.

Code of Federal Regulations. Labor, Title 29, Parts 1900 TO 1910 (&&1901.1 TO &&1910.441)

Conover, Donald W. and Wesley E. Woodson, 1964. Human Engineering Guide for Equipment Designers. Los Angeles: University of California Press.

Dieter, George E. 1991. Engineering Design - A Materials and Processing Approach. New Jersey: McGraw-Hill, Inc.

Gilbert, Charles. Management Consultant. Gilbert and Associates. Marietta, GA.

Grader, Jerome E.. Technical Data, Basic Process Control. Rochester, New York: Taylor Instrument Companies.

Kelly, Michael J. Principle Research Scientist. Georgia Tech Research Institute. Atlanta, GA.

Konz, S. and V. Subramanian. 1989. Engineering Anthropometry, Advances in Industrial Ergonomics and Safety 1. Philadelphia: Taylor &Francis, INC.

Ortiz D. J., M. J. Kelly, T. K. Courtney, and D. J. Folds. 1989. Phase 1 Report: Ergonomic Considerations in Conventional Trouser Manufacturing, Design and Development of A Self Study Course for Apparel Supervisors in the Practical Application of Ergonomic Principles. Atlanta GA: Economic Development Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology.

Ortiz D. J., M. J. Kelly, T. K. Courtney, and D. J. Folds. 1989. Phase 2 Report: The Impact of a Chair as an Ergonomic Intervention in Conventional Trouser Manufacturing, Design and Development of A Self Study Course for Apparel Supervisors in the Practical Application of Ergonomic Principles. Atlanta GA: Economic Development Laboratory, Georgia Tech ResearchInstitute, Georgia Institute of Technology.

Popov, Egor P. 1990. Engineering Mechanics of Solids. New Jersey: Prentice-Hall, Inc.

Ring, Carol. Technician, Southern College of Technology.

Rodriguez, Ferdinand. 1989. Principles of Polymer Systems. New York: Hemisphere Publishing Corporation.

Roebuck, J. A., K. H. E. Kroemer, and W. G. Thomson. 1975. Engineering Anthropometry Methods. New York: John Wiley & Sons.

Sesek, Richard. Economic Development Laboratory, Georgia Tech Research Institute.