Design of a Braiding Machine to Produce Wide, Flat Woven Structures at a Significantly Increased Production Rate

(Code A92C3)

PRINCIPAL INVESTIGATORS: Walker, Adanur, Beale, Broughton and Nelms

This project involves development of an innovative weaving process that may significantly increase the production rate of flat goods by bias slitting a tubular braided structure. Progress has been made in the following areas.

Research Team Activity

The research team consists of five faculty members (3 from Textile Engineering, 1 from Mechanical Engineering and 1 from Electrical Engineering) and four graduate students (1 PhD student from ME and 3 MS Degree students, 1 each from ME, EE and TE). The following graduate and undergraduate projects have been developed:

Zhang, Qiang (PhD, ME): “Parameter Optimization and Dynamic Analysis of a New Braiding Loom”; to include 1.) structure and mechanism design, 2.) optimum design of machine parameters and 3.) a study of the kinematics/dynamics of weaving and braiding.

Hunt, Richard (MS, EE): Untitled study involving an electronic control system to accomplish unlimited interlacing patterns in woven structures produced by braiding; to include 1.) logic and control circuitry, 2.) motor and synchronization components and 3.) yarn movement components.

Sartain, Steven (MS, TS): Untitled study of weaving and braiding to include; 1.) a comparison of weaving and braiding structures, processes and mechanisms, 2.) a review of testing systems used on woven and braided structures and 3.) a comparison of the behavioral and tensile properties of woven structures and slitted, tubular braids.

Vickers, Daniel (MS, ME): Untitled study of novel concepts and mechanisms used to accomplish yarn interlacing in a braiding process to include; 1.) an evaluation of various arrangements of moving and stationary yarn carriers, 2.) design and evaluation of various innovative interlacing devices and concepts.

Unidentified Graduate Student: Untitled study of the impact of using the proposed new braiding/weaving process including a cost comparison to conventional weaving.

Completed Undergraduate Student Projects


Unassigned Undergraduate Student Projects

“Solenoid Deflector”; to include; 1.) moving part less than 2 grams (shaft weight not included), 2.) amplitude of oscillation movement about 5 mm, 3.) motion in the vertical plane and 4.) a detailed description of oscillation speed limitations.

“Spool Interchange System Design”; to include; 1.) interchange in 1 second minimum time, 2.) simple design for 4000 yam spools and 3.) motion in the vertical plane.

“Low Profile Yam Spool Design”; to include; 1.) height less than 5 mm, 2.) pointed edge facing approaching yarns, 3.) width less than 1.25 cm, 4.) length less than 15 cm and 5.) yam delivery along the centerline of the length axis.

“Motor and Gear System Design”; to include; 1.) geared center mandrel drive at 1/2 the rpm of outermost rotating yam spools, 2.) use of a concentric shaft arrangement with the outer shaft driving the outermost yam spools and the inner shaft driving the center mandrel, 3.) mandrel should be clear of obstructions to allow fabric take-up, 4.) brake torque should be above 400 ft-lbs in the range of 500
to 1500 rpm and 5.) the motor torque curve should be approximately 1000 ft-lbs at low rpm.

“Variable Diameter Mandrel Design”; to include; 1.) mandrel may be flexible but should be stiff enough to maintain individual yam tension levels at 40 grams minimum during braiding, 2.) air or other non-toxic fluids) may be used to inflate/deflate a hollow flexible mandrel, 3.) mandrel surface should allow fabric structure to slide off easily to take-up device and 4.) the mandrel diameter may be varied mechanically (i.e., by designing a mechanism to smoothly vary the diameter).

Outside Contacts

Visits were made to two braiding machinery companies, Wardwell Braiding Machinery Co. and Composite and Wire Machinery, Inc., to solicit interest in the research. A 16-carrier, rotary braiding machine was donated by Composite and Wire Machinery, Inc. for use in the project. A visit was made to the Systems and Controls Group of A.B. Carter, Inc. to discuss yam carrier design. Two models of a retractable spool carrier were donated by A.B. Carter for consideration and study. Two other companies (WestPoint Foundry and Machinery Co. and Russell Corporation) were invited to participate in an Industry Review Committee that will monitor progress in the project. Another company (Tapistron International, Inc.) has expressed interest in the project and two meetings between Auburn and Tapistron have occurred. Copies of this annual report will be sent to individuals representing these six companies for their review and feedback to the research team.

Fundamentals

Following an introduction to the fundamentals of weaving and braiding for non-textile members of the research team, the team visited Russell Corporation for a first-hand look at current textile processing technology. A further detailed evaluation of the 16-carrier rotary braider in operation coupled with several brainstorming sessions led to the development of the functional requirements for the proposed new weaving process. The new process is referred to as the ‘BS²’ process (Bias Slitted -- aided Structure).

The BS² weaving process:

1. must facilitate interlacing of the two yam systems, desirably with infinite control of the order of interlacing from simple plain weave order to an order limited only by the number of yams involved and the number of yam revolutions in the structure involving the mechanism by which interlacing will be accomplished. Of the two braiding interlacing technologies in use (maypole and rotary), it is felt that rotary principles where only sweeping yams (not packages) from one system have to pass over or under the other systems yam packages is more desirable. It is also desirable to have the ability to change the interlacing pattern quickly without major down-time perhaps using an electronic control system with direct hook-up to a computer aided design system.
2. must have one yam system interlaced at near 90 degrees angular placement to the other yam system. Using current technology in fabric finishing, it may be possible to correct yam angles in the structure.
3. accommodate a wide variety of yam structures and patterns created by different yams (colors, size textures, etc.) within the same system. This aspect of the process should be approached with consideration for quick change.
4. provide for special treatments at the slitted edges (selvages) of the structure.
5. must have independent control of the yam density (compactness) for each of the two yam systems with absolute timing and synchronization between the two independent controlling mechanisms. Although normally the density of a given yam system is uniform, it is desirable to have the ability to alter the density of yams within each system in a predetermined pattern of variable density stripes.
6. accommodate short or long production runs (under 50 yds or up to thousands of yds) with equal ease. This relates to design of the yam spool carriers and the capacity of the spools.
7. cause a very low incident of yam failure, near zero if possible.
8. must have independent control of the tension level exerted on each yam within each yam
system and reasonable control of the range of tension on yarns during operation.

9. must be contained within a reasonable floor space. This also involves the design of yam spool carriers, their physical size, and the configuration of the drive mechanism and track for yarn carriers.

10. must include consideration for slitting of the tubular braid either as a second, off-line process or as an integral part of the proposed process. Slitting technology already exists for tubular goods.

11. should incorporate a concept of automation to include yarn replenishment and slitting. Existing yarn winding, splicing and package transport and exchange technologies may be refined for the proposed process.

12. must give consideration to the physical properties and stability of slitted, tubular braids.

Further work by some team members has led to the development of mathematical relationships among the proposed machine parameters and the braid structure geometry.

### Machine Parameters

General braiding relationships are developed here for important fabric geometric characteristics and production rates in the \((BS)^2\) process. Certain machine parameters determine geometry of the fabric. These machine parameters are:

- \(N_x\): total number of carriers on the two tracks.
- \(D_m\): diameter of the mandrel.
- \(s_m\): circumference of the mandrel.
- \(x\): absolute value of carrier angular velocity.
- \(V_t\): linear take up speed or rate at which the tubular braid is pulled up the mandrel axis from point of formation.

### Braid Geometry

Braid geometry is described by the following variables (all quantities subscripted with a "1" indicate measures resulting from 1 complete revolution of the carriers):

- \(P_1\): height of fabric tube along the mandrel axis for one complete rotation of the yarn carriers.
- \(L_1\): yam length along the helical slit, for one rotation.
- \(w\): slitted fabric width.
- \(D_y\): yarn thickness.
- \(D_m\): diameter of the braided tube on the mandrel (for balanced crimp and equal warp and weft yam sizes, actual braid diameter would be \(D_m + 4D_y\), but because fabric thickness is usually very small, braid diameter is approximated the same as the mandrel diameter).
- \(a\): braid angle, i.e. angle between the two sets of strands of a braid. In these calculations braid angle \(a\) will be fixed at 90 degrees, which is desired in woven fabric.
- \(Y\): percent yam occupation factor, the percent of the fabric area that is covered by the yams of both systems, warp and weft.
- \(A_1\): area of fabric produced in one rotation of carriers.

The concepts and terminology presented in Figures 1 and 2 are applicable to rotary and geared braiders with two sets of spools on carriers and traveling in opposite directions while braiding onto a mandrel. Figure 1 reveals how the tubular fabric is slit along one of the yam paths (on the bias) for one complete revolution of all carriers. Figure 2 is presented to visualize the geometry, and shows the flat unwrapped helix. Each thread of length \(L_1\), forms the hypotenuse of a right triangle with leg lengths \(p_1\) and \(s_m\).
Machine/Braid Relationships

Braid geometric relations are defined and/or developed for percent yarn occupation factor \((Y)\), yarn length along the helical slit \((L)\), width of the slitted, flat structure \((W)\), and area of fabric produced \((A)\). Each relation can be written as functions of yarn thickness, \(D\), mandrel diameter, \(D_m\) and other machine variables.

Restricting braid angle, \(a\), to an ideal 90 degrees simplifies the derivation of the braid geometry relations. Square construction and equal size yarns are also specified. For example, the fabric width, \(W\), in Figure 2 is:

\[
W = \frac{\pi D_m}{\sqrt{2}}
\]  (1)

The length of slitted fabric produced by one revolution of the braiding machine, \(L\), is twice the fabric width, \(W\), or:

\[
L = \frac{2\pi D_m}{\sqrt{2}} = 2W
\]  (2)

The area of fabric, \(A\), produced during one revolution of all carriers on the braiding machine is:

\[
A = \pi^2 D_m^2 = L W
\]  (3)

From its definition, the percent yarn occupation factor, \(Y\), is represented as:

\[
Y = \frac{(A - A_{ol})}{A} 100
\]  (4)

where \(A\), is total yarn area on the braid as a result of one rotation. \(A_{ol}\) is the total area of the many braid overlaps (of which a typical overlap is shown in Figure 1), which must be subtracted from the total yarn area to form the total projected area in the numerator. \(A_{ol}\), in terms of machine variables is:

\[
A_{ol} = N_{ol} A_d
\]  (5)
where \( N_{U} \) is the “number of intersections” (or yam overlaps) in one rotation and \( A_d \) is the area of each square of overlap created by a single intersection of Figure 1. Figure 3 illustrates that a six carrier braider creates 18 intersections in one rotation, and in general:

\[
N_{U} = \frac{N_c^2}{2}
\]  

(6)

Figure 3. Intersections Made by a 6 Carrier Braid By One Rotation of Each Carrier Around the Track.

\( A_d \) can be shown to be:

\[
A_d = D_y^2
\]  

(7)

\( A_m \) is the product of the diameter and length of each yam, times the total number of yarns or carriers. Figure 2 can be used to visualize one half of \( A_m \), from half the carriers and yarns of length \( L_i \). Had the cross yams (weft) been cut along their bias, they too would have the same length \( L_y \), so,

\[
A_m = N_i L_y D_y
\]  

(8)

Combining and substituting Equations 2, 3, and 5 through 8 into Equation 4, \( Y \) can be expressed as:

\[
Y = \frac{N_i D_y^2}{\pi D_m} \left( \sqrt{2 \frac{N_i D_y^2}{2\pi D_m}} \right) 100
\]  

(9)
Requiring \( \alpha = 90^\circ \) and referring to Figure 2, the rotational thread velocity around the mandrel must equal the take up rate \( V \):

\[
V_t = \frac{\omega_D}{2}
\]  

(10)

Hence to maintain \( \alpha \) at 90 degrees, the linear relation between machine rotational speed and take up speed in Equation 10 must be satisfied.

Production Rate

Production rates of traditional weaving machines are typically compared using one of two measures, length of fabric per unit of time or consumption of weft yam per unit of time. For comparison of production rate for the proposed BS \(^2\) process and conventional looms, the following terminology is developed:

\[
\begin{align*}
\text{LPR}_L & : \text{linear production rate for the loom} \\
\text{LPR}_e & : \text{linear production rate for the BS}^2 \text{ process}
\end{align*}
\]

Linear production rate of a loom in meters per hour (m/h) is:

\[
\text{LPR}_L(m/h) = \frac{\text{PPM}}{\text{PPC}} 60 \frac{100}{}
\]

(11)

Where PPM is picks per minute and PPC is the number of picks \textit{per} centimeter. From Equation 2 and now measuring mandrel diameter \( D_m \) in centimeters, the linear production rate of a braider is:

\[
\text{LPR}_B(m/h) = \sqrt{2} \pi D_m \text{RPM} 60 \frac{100}{}
\]

(12)

Where RPM is the absolute value of the angular velocity of either set of carriers, in carrier rotations per minute (rpm).

\[
\begin{align*}
\text{WCR}_L & : \text{weft consumption rate for the loom} \\
\text{WCR}_e & : \text{weft consumption rate for the BS}^2 \text{ process}
\end{align*}
\]

Weft consumption rate for a loom in meters per hour (m/h) is:

\[
\text{WCR}_L(m/h) = W 60 \frac{100}{\text{PPM}}
\]

(13)

with \( W \) measured in centimeters. The weft consumption rate for the braider is \( N/2 \) times the linear production rate, or:

\[
\text{WCR}_B(m/h) = N_c \pi D_m \text{RPM} 60 \frac{100}{}
\]

(14)

The speed of the loom, expressed in picks per minute \((\text{pm})\) and the speed of the braider, expressed in carrier rotations per minute \((\text{rpm})\) could be considered as comparable; but it may be useful to look at another measure of production, the rate at which intersections are produced in intersections per second (denoted IPS). This follows the earlier redefinition of the basic unit of a fabric as a yam intersection rather than one pick cycle. This concept is appropriate for fabrics produced on a typical loom or on a braiding machine and brings up the need for these new measures:
IPS<sub>L</sub>: intersections per second for the loom  
IPS<sub>B</sub>: intersections per second for the braider

The yarn intersection rate for a loom is:

\[ IPS_L = \frac{N_w \times PPM}{60} \quad (15) \]

Where PPM represents loom production rate in ppm and \( N_w \) is the number of warp yams. Whereas for a braiding machine, the IPS is \( N_M \) from Equation 7 times rotational speed:

\[ IPS_B = \left( \frac{N_M}{2} \right) \times \frac{RPM}{60} \quad (16) \]

Equations 1, 4 and 11 through 16 are now used to compare existing loom and braider production rates for a fabric of the following characteristics:

- Fabric Width \( W = 152.4 \text{ cm} \) (60 inches)
- Fabric Construction:
  - weft density = 19.685 ppc (50 ppi)
  - warp density = 19.685 epc (50 epi)
- Loom speed = 600 ppm

From Equation 1, the given fabric width requires a mandrel with 68.6 cm diameter. The fabric width times the warp construction density means 3000 warp yarns are required for both loom and braid, and hence \( N_w \) is 6000. Assuming each carrier on the track requires 7.62 cm (3 inches) of track length, each track is then 228.6 meters long. Based upon a carrier velocity of 4.572 m/s (15 f/s), then machine RPM can conservatively be taken as 1 rpm. Table 1 reveals that all three fabric production rate measures are 10 times greater if performed on the braider.

**TABLE I. Fabric production rate comparison between loom and braider.**

<table>
<thead>
<tr>
<th></th>
<th>LPR (m/h)</th>
<th>WCR (m/h)</th>
<th>IPS (intersections per s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Looms</td>
<td>18.29</td>
<td>54864.</td>
<td>30000.</td>
</tr>
<tr>
<td>Braiders</td>
<td>182.87</td>
<td>548640.</td>
<td>300000.</td>
</tr>
</tbody>
</table>

The graphic representation of Equation 9 is given in Figure 4 for a typical yam with \( D_y = 0.2 \text{ mm} \) (.008 inches). The plot reveals how changing mandrel size (and hence affecting production rate through Equations 12 and 14) can affect the fabric construction, while maintaining a equal to 90 degrees. This relationship is presented for various number of carriers, where the percent yam occupation factor \( Y \) (100% minus the fabric interstices) is plotted as a function of mandrel diameter. \( Y \) is very sensitive to \( D_m \) for small numbers of carriers and small mandrel diameters, indicating that it may be difficult to achieve an invariable \( Y \) and production rate. Whereas for large numbers of carriers and small mandrel diameters this sensitivity is much reduced. Figure 4 also reveals that a distinct minimum mandrel diameter exists for a given number of packages and 100% yam occupation factor. This indicates that braiding with too small a mandrel diameter can corrupt the braid structure.
Prior work has been devoted to exploration of innovative machine design concepts, many of which have been fully developed with AUTOCAD drawings and/or hand sketches. Consideration has been given to various drives, cam mechanisms, pneumatic or magnetic levitation and pneumatic or linear motors. Technology related to the BS² process includes existing technology in many instances and includes design opportunities in several key areas as follows:

Floor Space Requirement

Since the proposed process would involve a large number of yarn packages (thousands), it is necessary to conceive a yarn carrier design and a yarn carrier track configuration that minimizes the space required. Configuring a track in a traditional fashion using typical yarn carriers would require too large an area negating the production advantage over traditional weaving machines.

Two approaches are being considered to solve this problem. First, redesigning the shape and therefore the space required for each package of yarn. The length of warp yarn normally supplied to conventional weaving machines is in thousands of yards. The length of cloth roll desired by purchasers of this material is normally in the hundreds of yards. Very small single-end packages or several multi-end packages can provide several hundreds of yards of yarn for the proposed BS² System. It is felt that the physical dimensions of these yarn creels can be designed to accommodate the function of the proposed system using very little space per yarn end. Also, consideration is being given to the impact that a frequent yarn replenishment cycle would have on quick response to market demands (a short cycle may be desirable). The second approach involves configuration of the yarn carrier tracks in some design other than circular and flat. Whether this will be necessary or the degree of downsizing that may be required has not been determined at this point. Several ideas have been discussed such as the use of thin yarn spool cassettes spacing yarns at $1/2$ to 1 inch apart, and the use of various 3-D track configurations.

Even if the proposed machine cannot be downsized significantly, the possibility still exists that the speed of the yarn carriers can be achieved above 15 feet per second (the current operating speed of rotary braiders) gaining a production advantage greater than ten times current weaving rates. Also, the possibilities of application to certain fabric markets may make the proposed system feasible even with a large floor space requirement.
A normal braided structure has balanced yarn densities, since both yarn systems are driven by the same source at the same speed relative to fabric take-up speed. It is proposed to separate the drives for the two yarn systems to control independently the yarn spacings of the two yarns, warp and weft. Several alternatives are being studied; rotating both yarn systems (as is currently done in braiding), rotating only one yarn system and rotating the fabric structure to obtain angular displacement of the non-rotating yarns in the structure. Primary control of yarn spacing for the yarn systems would be controlled by speed ratios relative to take-up speed. Secondary control for both yarn system spacings might be necessary and could be accomplished by controlling the mandrel diameter size (actual fabric tube diameter at the point of cloth formation). It is felt this could be done with adjustable control rings inserted as yarn guides or with a tapered mandrel and control ring assembly.

Weave Pattern Control

Current technology used in rotary braiders involves passing the yarns from outer system packages over or under the inner system packages. The normal path of these "sweeping" outer yarns is under the inner packages with a fixed deflector used to cause some yarns to go over the inner packages. This system requires a “double drive bar” driving system for the inner packages such that the two drive bars of a given inner package are alternately lowered by a cam system to “miss” the sweeping outer yarns. Actually though these drive bars move at every ensuing outer yarn, they only need to jump the outer yarns that are coming under the package. A system using current rotary braiding technology has been considered, tested briefly and eliminated from consideration.

Currently, consideration is being given to two new concepts of yarn interlacing. One involves a "slip" device that might be incorporated in future braiding machines as well as in the proposed new weaving process. This concept captures the fact that a sweeping yarn can successfully pass between an ensuing package and its support without removing the package from its support. Several designs incorporating this slip concept are being considered. The system envisioned would have a set of moving (sweeping) outer yarn carriers slipping past a set of stationary inner yarn carriers with a rotating fabric mandrel. The second interlacing concept involves the use of a “slotted” track for yarn shed formation with multiple moving weft insertion devices. Many component design ideas have been suggested, debated and abandoned in favor of more promising ideas. Full drawings have been made and some partial models have been built. The ideas with the most potential are being protected purposely at this point to allow time for refinement and the filing of patent disclosures. A mechanical system prototype for fixed weave patterns is being constructed as a demonstration model. The use of an electronic control system to allow production of any weave pattern is a part of the electrical design considerations.

Electrical Design Considerations

The electrical system can be broken up into three subsystems: logic and control circuitry, motor and synchronization components, and yarn movement components. The yarn movement components are in a separate category since it appears they will be the limiting factor in machine operation. Motor and synchronization components are grouped together because all other activities must be coordinated to the angular displacement and speed of the motor. Finally, the logic and control circuits are the controlling devices to ensure correct operation.

Data acquisition and control boards for use in a standard PC have already been purchased which should satisfy the prototype machine requirements. Each data acquisition board has 96 individual input/output lines, each of which can be used to control a yarn movement device. The output line logic resides on the board, is under software control by the PC, and is fully programmable to handle any variety of scenarios. Each output line will be connected to either a solid-state or electro-mechanical relay which will connect the yarn movement device to its power supply. The solid-state relay is the preferred choice due to lower cost and faster reaction time; however, the electro-mechanical relay might have to be used since it can handle higher currents. One area that needs further study is the ability to synchronize the data acquisition board’s internal timer to the rest of the
Currently, electromagnetic coils are being considered to control yarn movement. The force required to move the deflection device is proportional to the device mass, operating distance, and inversely proportional to the square of the activation time. For the prototype machine of 300 warp and weft yarns with an effective rotation speed of 5 rpm there will be 1500 decisions/min. This translates to a 40 millisecond window in which the device will have to fully respond, wait for the yarn to pass, and then return to the neutral position. Depending on the accuracy of predicting where the yarn will be in this 40 millisecond window will determine the amount of time available to activate the mechanism. Assuming the yam will always be within the middle 20 milliseconds of the window, there will be 20 milliseconds in which to activate and retract the movement device, which allows for 10 milliseconds of travel time in each direction. This translates to a constant acceleration of 167 ft/sec² for a 0.1” full range move, and a force of 0.324 lb. needed for a one ounce deflection device. Coils that can provide this force are commercially available. The goal is to find a deflection device that has a ferromagnetic core, weighs about one ounce, and can survive the repeated stress from the moving yarns.

The last area of concern is the motor and synchronization devices. Since the machine must work correctly under all transient and steady-state conditions it must be best to coordinate all electrical activities to the motor’s angular displacement or position. This will enable changing the machine operating speed by only changing one control, the motor speed adjustment. Current plans are to use a circular bus bar, with alternating areas of conducting and non-conducting material with two accurately placed position sensors to provide feedback to the logic controllers on the motor position. When the motor is in position for the deflection device to extend, one of the position sensors will be on a conducting portion of the bus bar enabling an interrupt signal to be sent to the data acquisition board. Similarly, when the motor is in position for the deflection devices to retract, the other position sensor will be on a conducting portion of the bus enabling another interrupt signal to be sent to the board. In this way, independent of motor speed, the logic circuits will operate at the correct time, and will be based on actual motor position. The physical contact system like a bus bar is thought to be better than an optical device since the anticipated operating environment could be quite dirty, and the alignment of a bus bar should be easier to maintain. Controlling the motor speed is fairly easy, since there are plenty of commercial devices available for this task. Once some of the mechanical aspects of the machine have been built in a prototype, several of the assumptions will be tested and modifications made where necessary.

Fabric Slitting and Yarn Winding

Slitting of tubular fabric has been around since the mid 1920’s and several systems are available to accomplish this aspect of the proposed new process. It is felt that slitting of the tubular fabric on line as part of the new weaving machine may be possible. Since the proposed system may incorporate a rotating mandrel, it is conceivable that the fabric could be slit by a stationary device with the flat fabric roll rotating much the same as with knitted fabric take-up systems. If slitting cannot be incorporated as part of the process, it certainly can be done off-line.

Accurate yarn winding to produce not only near perfect yarn but also near perfect yarn packages may be a critical aspect to the efficiency of the proposed process. Given the likelihood of small packages that have to be refilled frequently and the complexity of repairing broken yarns, it may be necessary to utilize the latest technology in splicing, winding and yarn package transport systems to fully automate the proposed system to include yarn winding, automatic replenishment, weaving and slitting.

Fabric Stability and Performance

Since the proposed system would produce the fabric in a tubular form, it is likely that the slitted flat fabric will have a tendency to torque or curl back into its original coiled shape. It is felt that this problem will be dealt with much the same as is currently done with knitted fabrics that curl or woven fabrics that torque (twills). Currently these stability problems are addressed in finishing where fabrics are “corrected” or finished to minimize the
instability. Various techniques already being used will probably work for this new fabric as well. It may be possible to address some part of the instability problem by changing yam angles during forming to offset anticipated effects.

Performance of the new fabric with respect to tensile properties and shrinkage will be evaluated as part of the ongoing research comparing the slitted, braided structure to regular woven goods. The task of producing braided samples for testing has been initiated. Four different yarns (cotton-medium to coarse count, cotton/polyester-medium to fine count, **nylon/carpet-coarse** count and polypropylene/tape-l/4 inch) were wound onto spools and carried to North Carolina State’s Textile School for braiding on a 192 carrier braider. A special winding device was built for this purpose. All yam samples did not braid successfully, but several tubular braids of different diameter were produced from the nylon/carpet and polypropylene/tape yarns. It is not anticipated that the new form of fabric will perform significantly different, but with this new approach, the option to produce fabrics with engineered yarn angles to give performance characteristics unique to an end use requirement would be available.

**System Reliability**

The proposed system would be complex to say the least and may present additional design opportunities related to:

1. Lubrication (current technology should suffice)
2. General maintenance (depends on number of moving parts, etc.)
3. Response frequency of interlacing device (computerized)
4. Repairing broken yarns (with appropriate stop motions)
5. Tension control (current technology should suffice)
6. Selvage design (current technology should suffice)
7. Energy requirements (should be no less energy efficient than conventional weaving machines depending on the type drive system employed, ie. geared belt, linear motors, etc.)

These seven and other considerations are felt to be minor compared to those already discussed.

**Publications and Presentations to Date**

Walker, R.P.; “The Use of Narrow Fabric Technology to Revolutionize Wide Fabric Weaving”; Narrow Fabrics Conference; Clemson University; Myrtle Beach, SC; March, 1992.

Walker, R.P.; “The Second Loom - Will Slashing be Eliminated”; Slashing Conference; Auburn University; Auburn, AL; September, 1992.

Walker, R.P.; “Development of Machine Design Specifications to Produce Traditional Flat Woven Structures by Bias Slitting a Tubular Braid”; A Plenary Presentation to the National Textile Center First Annual Forum; Auburn AL; February, 1993.

Beale, et.al; “Maximizing Production Rate of Woven Fabrics Using Braiding Principles”; Submitted to *Textile Research Journal*; 23 pages; March, 1993. (Publication rejected, currently being revised)