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DEVELOPMENT OF GENERALIZED 3-D BRAIDING MACHINES FOR COMPOSITE PREFORMS

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ABSTRACT

The development of prototype braiding machines for the production of generalized braid patterns is described. Mechanical operating principles and control strategies are presented for two prototype machines which have been fabricated and evaluated. Both machines represent advances over current fabrication techniques for composite materials by enabling nearly ideal control of fiber orientations within preform structures. They permit optimum design of parts that might be subjected to complex loads or that have complex forms. Further, they overcome both the lack of general control of produced fiber architectures and the complexity of other weaving processes that have been proposed for the same purpose. One prototype, the Farley braider, consists of an array of turntables that can be made to oscillate in 90 degree steps. Yarn ends are transported about the surface formed by the turntables by motorized tractors which are controlled through an optical link with the turntables and powered through electrical contact with the turntables. The necessary relative motions are produced by a series of linear tractor moves combined with a series of turntable rotations. As the tractors move about, they weave the yarn ends into the desired pattern. The second device, the shuttle plate braider, consists of a braiding surface formed by an array of stationary square sections, each separated from its neighbors by a gap. A plate beneath this surface is caused to reciprocate in two perpendicular directions, first in one direction and then in the other. This movement is made possible by openings in the plate that clear short columns supporting the surface segments. Yarn ends are moved about the surface and interwoven by shuttles which engage the reciprocating plate as needed to yield the desired movements. Power and control signals are transmitted to the shuttles through electrical contact with the braiding surface. The shuttle plate is a passively driven prime mover that supplies the power to move all shuttles and the shuttles are simple devices that employ only a solenoid to engage the shuttle plate on command. Each shuttle is assigned a unique identity and is controlled independently. When compared to each other, the Farley braider is felt to have the advantage of speed and the shuttle plate braider, the advantage of simplicity.

INTRODUCTION.

The work reported here was part of a study of the potential for practical 3-D braiding machines having the ability to generate any prescribed relative motions of the braidingyarns. [1-8] Such a braider would afford complete freedom in defining braid structures and would facilitate the design of high-performance composite components. An ideal braider would possess only the mechanical complexity needed to control the braiding pattern, yet be capable of producing generally variable patterns. Most 3-D braiding schemes either achieve simplicity by limiting flexibility or seek flexibility at the expense of complexity. For example, most braiders yield structures having characteristics inherently linked to the process and that cannot be changed, and they therefore have no flexibility at all. Examples are: conventional 2-D mechanical braiders [2,6,7], the Florentine Magnaweave scheme [3,4], and the two-step braider [2,6,7], all of which produce braid patterns that are intrinsic to the process. On the other hand, methods such as the **AYPEX** [8] procedure and the Bluck [1] and Fakuta [5] processes possess the necessary flexibility but suffer from complexity in their implementation. This complexity becomes overwhelming when the processes are scaled up to produce large sections with full flexibility. Even when the size of the product is modest, the flexibility required to produce a variety of structures requires a great deal of redundant capacity.

Two different approaches were examined in detail as part of this study and small prototypes were built. The first machine was based on an idea developed prior to the start of the study by one of the authors (Farley) and is referred to here as the Farley braider. The other was originated during the course of the study and is referred to as the shuttle plate braider. Four general requirements were set initially and were principal influences on the detailed design of the prototypes. These were as follows:

- A completely general braiding capability was to be attained which would permit any particular yarn end to be moved from any position on the braiding surface to any other position by any prescribed path.
- The mechanical construction and control requirements had to be practically feasible in machines of large size.
- A large number of non-braiding, axial yarns were to be accommodated.
- The physical dimensions of the braiding surface were to be minimized, ideally no greater than needed to allow the use of yarn packages of one inch diameter.

THE FARLEY BRAIDER

The braiding surface of the Farley braider consists of an array of turntables that can be made to oscillate in 90° steps. Yarn ends are transported about the surface by motorized tractors which are controlled through an optical link with the turntables and powered through electrical contact with the turntables. The tractors are guided by track segments mounted on the turntables and are propelled by small motors driving through a gear train against a rack incorporated into the track segments. The necessary relative motions are produced by a series of linear tractor moves combined with a series of turntable rotations. With the turntables oriented in one direction, the track segments become aligned and form a continuous path in one direction for the tractors. When oriented in the other direction (rotated 90°), the track segments again form a continuous path but in a direction perpendicular to the first orientation. A proper combination of turntable rotations accompanied by appropriate tractor moves along the paths formed by the track segments weaves the yarn ends into the desired pattern. Stationary axial yarns, if needed, would pass through the braider surface in the space between the turntables. The basic concept is illustrated in Figure 1.

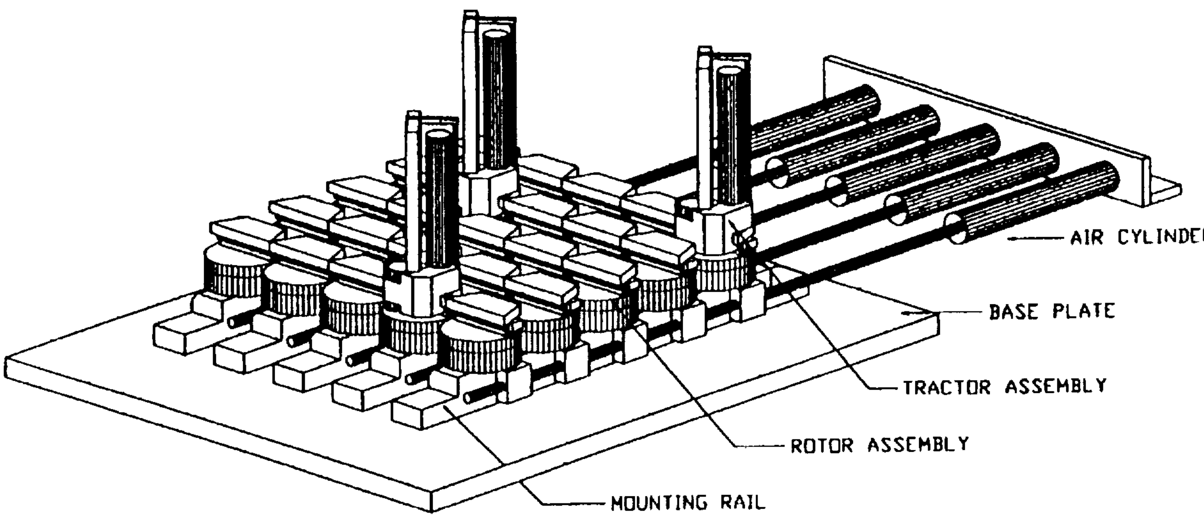

Figure 1-- Prototype Farley Braider Showing Basic Components of the System

As originally conceived, the Farley braider would consist of a large array of independently controlled rotating turntables. Such independent control of the turntables is desirable but would require an immense number of actively controlled devices when implemented on a practical scale. Consequently, in the prototypes, and likely in a practical implementation, the turntables were made to operate in unison and were actuated by a single actively controlled prime mover. The switching action of the turntable array is controlled by a computer with each rotation occurring after a complete set of tractor moves along a given axis. For example, with the turntables set in the X-axis, the tractors are moved as necessary in the X-direction. After each tractor reaches its current destination, the turntables are switched to the Y-axis. The next set of moves of the tractors, all in the Y-direction, then take place. The turntables are then returned to the X-axis orientation, and another set of tractor moves occurs. The switching back and forth of the turntables continues in this alternating manner until the entire braiding program has been executed.

Each of the tractors incorporates an electronic control circuit and a small d.c. motor and gear train. Power is conveyed to the tractors through contact with electrically isolated conductors incorporated into the turntables. Control signals are transmitted by frequency modulated optical signals through emitter-detector pairs mounted in the turntables and in the tractors. Signals are directed to specific turntables in the array. Directional start signals are transmitted to the locations occupied by the tractors. Stop signals are erected at the destinations of the tractors. The tractors, once set in motion, continue in motion until they encounter the stop signals. When all tractors have completed moving, the turntables are commanded to rotate a quarter-turn to align with the opposite coordinate axis. In the current prototype, this rotation is accomplished via solenoid controlled valves and pneumatic cylinders. After the rotation has occurred, the next set of instructions is sent to the tractors and the appropriate moves are accomplished as before. The sequence of operations continues, alternating between tractor moves and turntable rotations, until the desired braided shape is completed.

THE SHUTTLE PLATE BRAIDER

The shuttle plate braider consists of a braiding surface formed by an array of stationary square sections, each separated from its neighbors by a gap (Figure 2). A flat plate beneath this surface is caused to reciprocate in two perpendicular directions, first in one direction and then in the other. This movement is made possible by openings in the plate that clear short columns supporting the surface segments. Yarn ends are moved about the surface and interwoven by shuttles which engage the reciprocating plate as needed to yield the desired movements. An operating sequence is illustrated schematically in Figure 3.

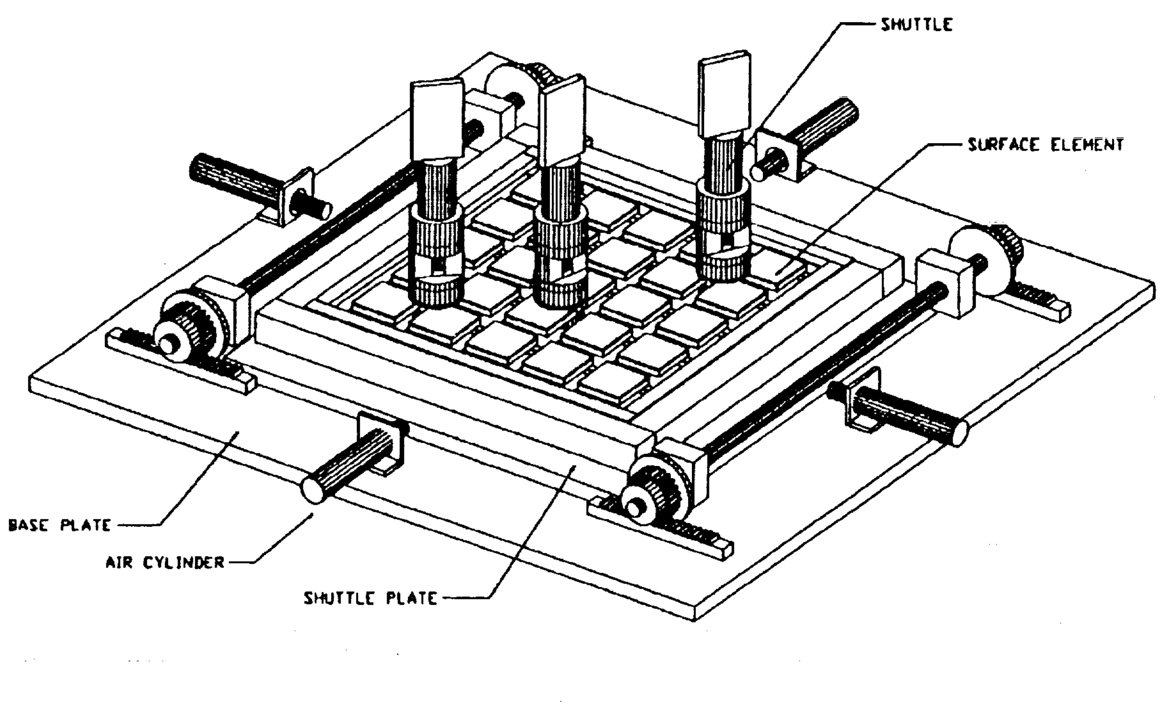

Figure 2-- Prototype Shuttle Plate Braider

In the current version, both power and control signals are transmitted to the shuttles through electrical contact with the braiding surface. The shuttle plate is a passively driven prime mover that supplies the power to move all shuttles. The shuttles themselves are very simple devices that employ

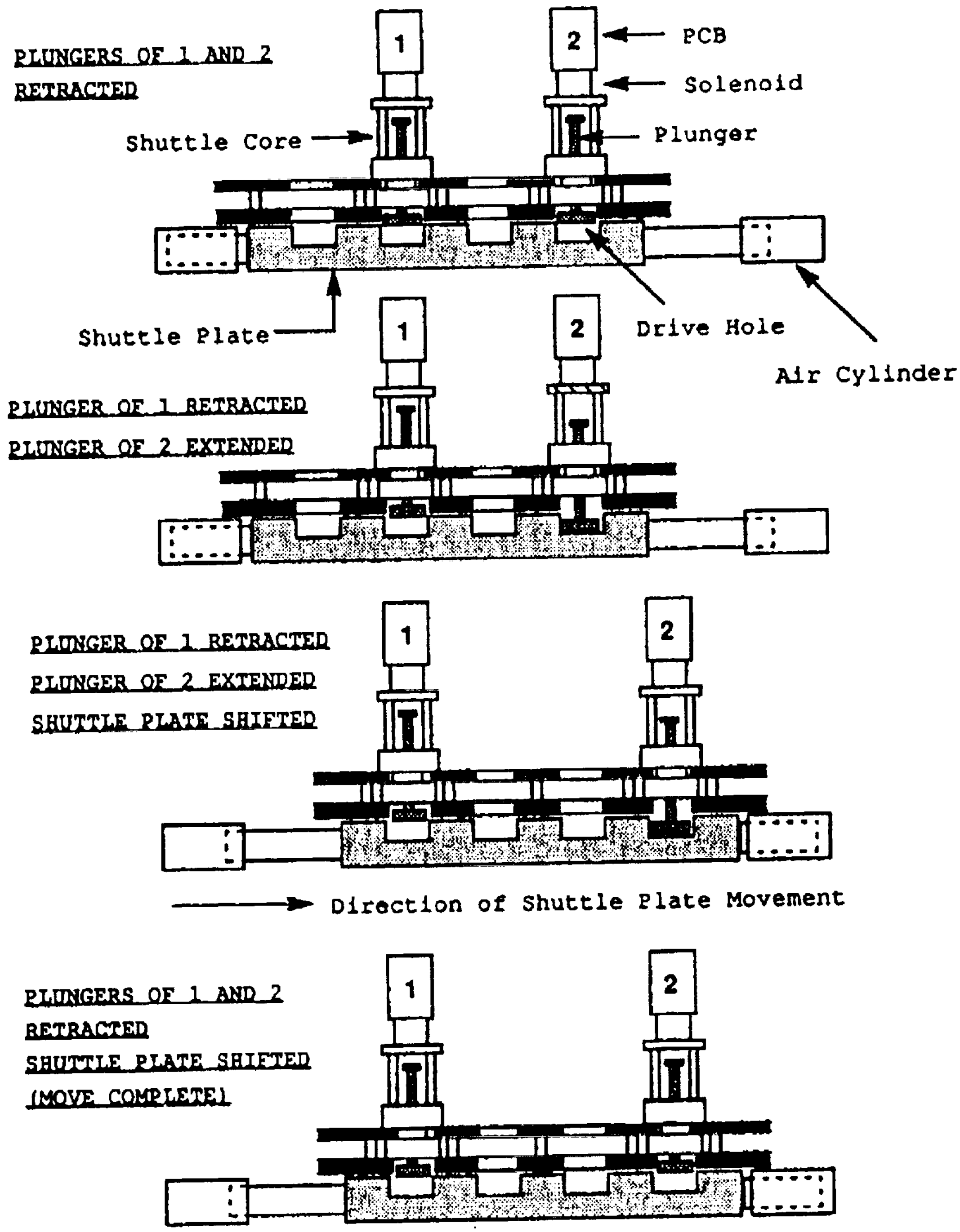

Figure 3-- Schematic Representation of Shuttle Plate Operating Sequence.

only solenoids to extend a plunger that engages the shuttle plate on command. Each shuttle is assigned a unique identity and is controlled independently by directing commands to particular addresses.

The shuttle plate approach was originated after identifying two additional attributes likely to be found in an ideal braiding machine. These attributes were as follows:

- The braiding action should require the minimum of actively and independently controlled devices required be reduced to an absolute minimum. Assuming simultaneous and independent control of all braiding yarns, this minimum would equal the number of braiding yarn ends.

- Actively controlled actions should be mechanically uncomplicated.

The shuttle plate device possesses both of these attributes. The move commands are transmitted directly to the shuttles and the controlled action is a simple on/off command to actuate a solenoid. Such simplicity is in stark contrast to other methods that require control of actuators, direction control devices, and the like at each point on a braiding surface that could be occupied by a yarn end. For example, the Bluck [1] and Fakuta [5] braiders and the **AYPEX** [8] process, as originally proposed, require an x-y grid of actuators, all independently controlled and quite complicated in their function. A 100*100 braiding grid would require ten thousand such actuators, even when only a few hundred or perhaps a few dozen yarn ends are being controlled. With the shuttle plate approach, the size of the braiding grid has no effect on the number of required controlled devices.

It is possible to make the shuttle plate itself a completely passive device by driving it alternately in one direction, then the other at a constant frequency. However, the braiding process can be sped up by independently driving the plate in the two axes in a fashion tocontrolled eliminate wasted moves when possible. Such control adds one element to the number of controlled devices and promises substantial speed increases for certain braid patterns.

THE PROTOTYPE MACHINES

Both braiding approaches have been reduced to practice in the form of small devices consisting of a 5*5 braiding grid with three shuttles. Both work well. However, the greater mechanical complexity of the Farley braider rendered it much more temperamental and difficult to make reliable. The shuttle plate braider works with hardly a hitch. The prototypes are shown in the photographs of Figures 4-6.

COMPARISON OF THE TWO APPROACHES

The two braiders discussed both accomplish generalized braiding, both in theory and as reduced to practice, in that they are both capable of moving any yarn end from any endpoint to any other endpoint by any path specified by the programmer. To the investigators' knowledge, this has not been practically achieved before.

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BLACK AND WHITE PHOTOGRAPH

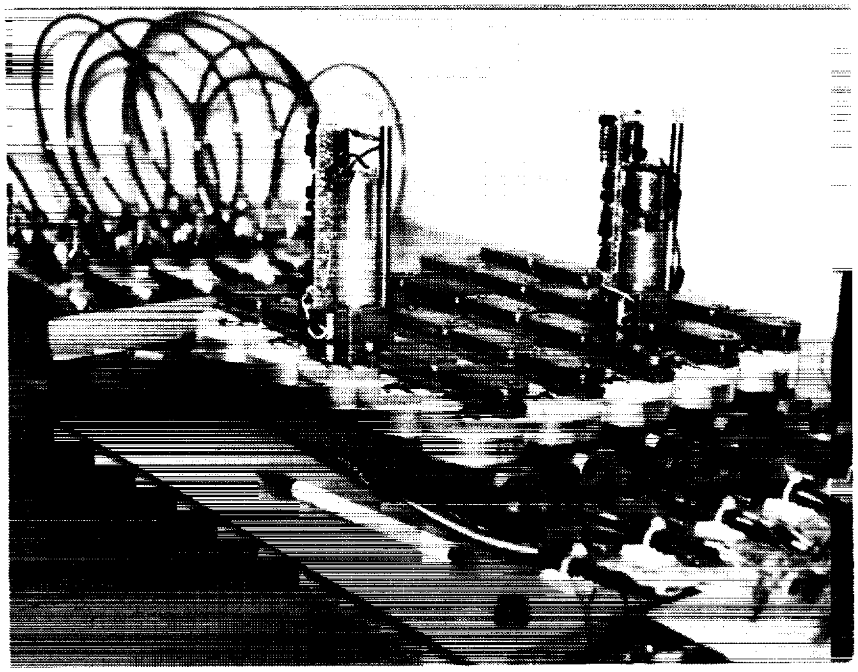

Figure 4-- Photograph of Prototype Farley Braider Showing Two Yarn Carriers and with Track Segments Oriented along the X-Axis

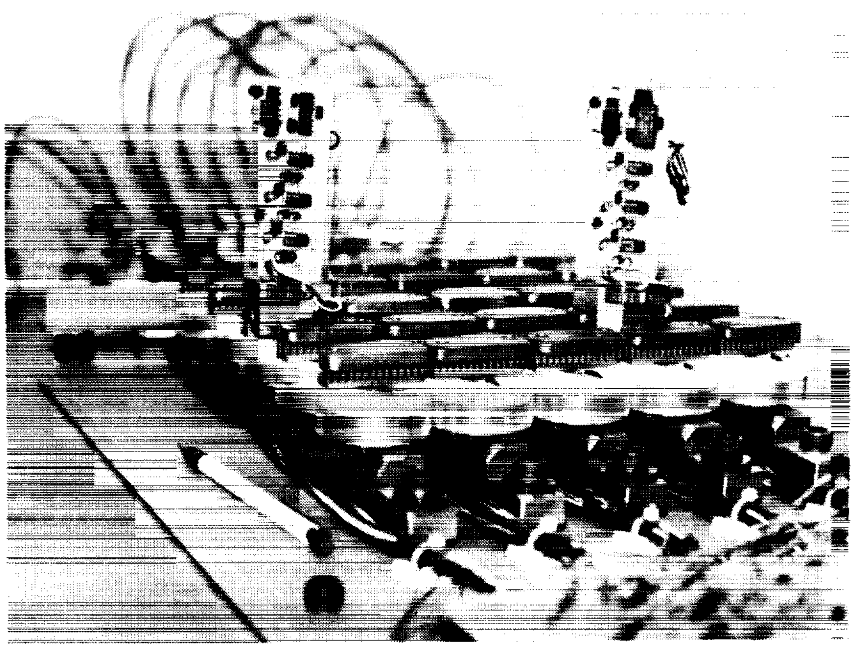

Figure 5-- Photograph of Prototype Farley Braider with Track Segments Rotated to Align with the Y-Axis

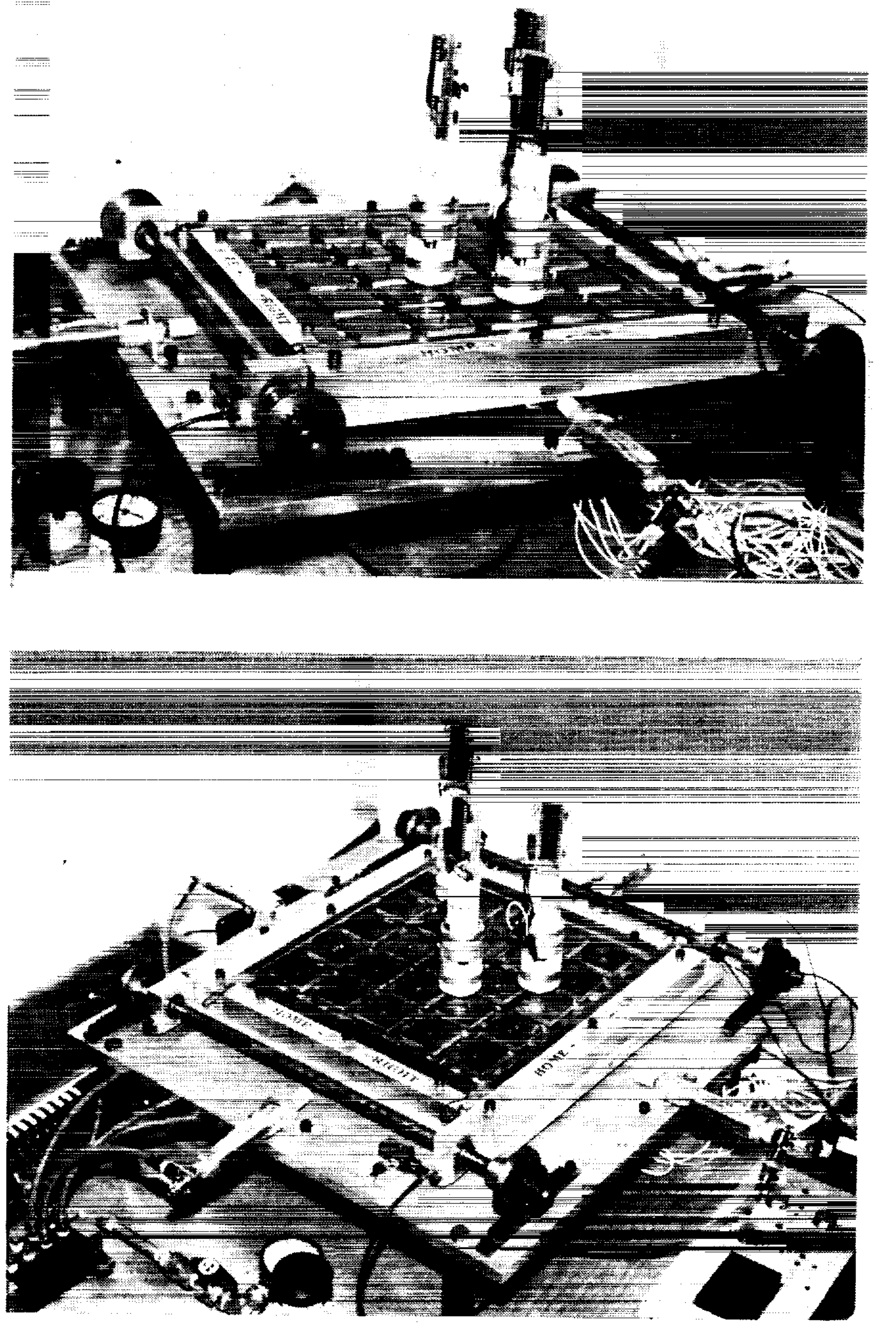

Figure 6 Photographs Showing Prototype shuttle plate Braider

Comparing the two braiders against each other, as opposed to comparing against other braiding techniques, the following advantages and disadvantages have been determined through operation of the two prototypes in the laboratory. The shuttle plate braider is a very simple design from a mechanical viewpoint, and its control requirements are as simple as they can be made, since all that is required are simple on/off commands. Further, all the power needed to move the shuttles is derived from the shuttle plate, and thus little power is needed for the shuttles themselves. The modified Farley braider does not have this simplicity, but it does have the advantage of speed for braiding patterns which require numerous long moves of the yarn carriers. In addition, while at any given time all the yarn carriers of the modified Farley braider must move along a given axis, some can be moving in the forward direction while others are moving in the reverse direction. Of course, this speed advantage diminishes as the average move length of a yarn end becomes shorter in complex patterns.

For the Farley braider the timing and synchronization of moves between yarn carriers become an issue of concern, especially as the number of carriers increases. This concern could force the use of more complicated devices, such as stepper motors, and neighbor proximity detectors. The shuttle plate braider does not have this timing difficulty, since all shuttle moves are automatically synchronized by the driving plate.

Although both braiders transmit power to the yarn carriers via the braiding surface, the need for such power is significantly different in kind. The shuttle plate braider needs power on the surface to engage the solenoid in each shuttle. As currently implemented, this power is held continually to maintain engagement. If several solenoids are activated at the same time, this would require high currents on the surface. However, there are numerous ways to overcome this difficulty in a scaled up version of the shuttle plate braider. These include such options as using mechanical latching and momentary currents to engage the latch. For the Farley braider, the motors must be powered continually. Thus the current, of necessity, must increase as the number of moving yarn carriers increases. There is no simple solution to this dilemma. Finally, as the size of the braiders is scaled up to practical applications, addition difference would be evident. The shuttle plate braider scales up readily, since the control problem remains the same no matter the size of the braider. The Farley braider might more easily be implemented on an upwardly curved surface. Use of such a surface would reduce the size of the braiding surface needed to control braid angles. However, such an approach would complicate the design significantly. For example, the turntables of the modified Farley braider would have to be of unequal size or rotate through unequal angles, depending upon location on the curved surface. Finally, set up and operation of the shuttle plate braider is much easier and more reliable, as discovered in operations to date.

SUMMARY

A successful attempt to develop and implement generalized, three dimensional braiding has been accomplished and two practical schemes for implementation have been designed, built, and tested. Both schemes, as implemented, produce the motions necessary to generate any desired braiding pattern. Each scheme has its advantages and disadvantages. However, the shuttle plate braider offers the greater immediate promise because of its mechanical simplicity and ease of control, especially when scaled up to practical dimensions.

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