DESIGN OF MICHELIN CALENDER 800

QUICK PACE CHANGE ASSEMBLY

by

Jayakumar Gurusamy

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degrees of

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and

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at the

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ABSTRACT

The calender 800 produces metallic tissue that is used as steel belts in Michelin tires. The capacity of the calender 800s in North America does not meet the requirements of production. Any improvement in the output of this machine would increase the production capacity of tires. One area of the machine that has been identified for improvement is the pace change area. Most of the changeover time of the calender 800 from one type of metallic tissue to another is dedicated to this area; changeover of the area, known as a pace change, consumes between 30 to 90 minutes of time.

The objective of this project is to design a system to allow operators to perform a pace change more quickly. Three concepts are formulated and studied to reduce the pace change time. Concept 3, which uses a one-axis robot to reset the positions of cables that are imbedded in the metallic tissue, is most promising. In addition to saving time, the concept improves on operator safety and eye strain which are also of concern in the existing pace change area.

Thesis Supervisor: Professor Igor Paul
Title: Associate Professor of Mechanical Engineering

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TABLE OF CONTENTS

Abstract. 2
Acknowledgments. 3
Table of Contents. 4
List of Figures. 6
List of Tables. 7

Chapter 1. Introduction. 8
1.1 Objectives
1.2 Motivation for Project
1.3 Background
- 1.3.1 Calender 800 Operation
- 1.3.2 Operation of Pace Change Area
  - 1.3.2.1 Pace Change Area Structure
  - 1.3.2.2 Pace Change Procedure
- 1.3.3 Variables in a Pace Change
- 1.3.4 Problems with Present Pace Change Procedure
- 1.3.5 Goals of Project
- 1.3.6 Constraints

Chapter 2. Design Approach. 23
2.1 Introduction
2.2 The Design Process
- 2.2.1 The Creative Process
- 2.2.2 The Analytical Process

2.3 Reducing Equipment Setup Time

Chapter 3. Simplification of Existing Equipment. . . . 29
3.1 Need for Simplification
3.2 Approach to Simplification
3.3 Simplification of the Pace Change Area

Chapter 4. Concept 1. 34
4.1 Need for New Technology
4.2 Basic Idea
4.3 Concept Variations
4.4 The Pace-Changing Mechanism
4.5 Background
- 4.5.1 The Elastic Element
- 4.5.2 Wear

4.6 Development of Concept 1
4.7 Reason for Failure

Chapter 5. Concept 2. 44
5.1 Introduction
5.2 Design Layout
5.3 Pace Change Procedure
5.4 Concept Development
5.4.1 Special Component Requirements
5.4.2 Component Designs
5.4.2.1 Adjuster Assembly
5.4.2.2 Storage Unit
5.4.2.3 Guide Box Assembly
5.5 Control Layout
5.6 Conclusions

Chapter 6. Concept 3. 62
6.1 Introduction
6.2 Design Layout
6.3 Pace Change Procedure
6.4 Component Designs
6.4.1 Adjuster Assembly
6.4.2 Half-Pace Roller Assembly
6.4.3 Full-Pace Roller Assembly
6.4.4 Cable-Holding Bar
6.4.5 Transfer Clamps
6.4.6 Temporary Storage Tray
6.5 Adjuster Control System
6.5.1 Control Layout
6.5.2 Motor Size

Chapter 7. Conclusions & Recommendations. . . . 87
7.1 Conclusions
7.2 Recommendations for Future Work

Appendix A. Present Pace Change Procedure. . . . 89
Appendix B. Algorithm for a Pace Change. 90
Selected Bibliography. 95

LIST OF FIGURES

Figure 1.1. Side View of Calender 800 Assembly. . . . 10
Figure 1.2. Side View of Pace Change Area. 12
Figure 1.3. Typical Profile of Half-Nappe Roller Grooves. . . 14
Figure 1.4. Full-Pace Roller Delivery System. 16
Figure 1.5. A Typical Comb. 18
Figure 2.1. Primary Design Domains. 25
Figure 2.2. The Design Loop. 25
Figure 3.1. New Layout of Pace Change Area. . . . 32
Figure 4.1. Layout of Concept 1. 35
Figure 4.2. The Stack. 39
Figure 4.3. Pace Change Using the Stack. 39
Figure 4.4. Layout of Lift-and-Shift System. 42
Figure 5.1. Concept 2 Area Layout. 46
Figure 5.2. Top View of Half-Pace Subassembly. . . . 47
Figure 5.3. Components of Concept 2. 49
Figure 5.4. Adjuster Assembly. 53
Figure 5.5. Cable Unit. 55
Figure 5.6. Storage Unit. 56
Figure 5.7. Guide Box Assembly. 58
Figure 5.8. Control System Layout for Both Adjusters. . . 60
Figure 6.1. Main Assemblies of Concept 3. 63
Figure 6.2. Some Parts of Pace Change Area. 66
Figure 6.3. Typical Cable Block. 68
Figure 6.4. Cable Block in Slot. 68
Figure 6.5. Moving a Cable Block. 70
Figure 6.6. Overlapping Cable Blocks at 2.2 m m Spacing. . . 70
Figure 6.7. Adjuster Assembly. 72
Figure 6.8. Positioner Extended "Forward". 73
Figure 6.9. Half-Pace Assembly. 75

Figure 6.10. Full-Pace Roller Assembly. 77
Figure 6.11. Pneumatic Circuit for Full-Pace Roller Assembly. . 78
Figure 6.12. Cable-Holding Bar & Fixed Support. . . . 80
Figure 6.13. An Assembled Transfer Clamp. 80
Figure 6.14. Temporary Storage Tray. 82
Figure 6.15. Control Circuits for Adjusters. 84
Figure 6.16. Bond Graph Model of Adjuster. 85

LIST OF TABLES

Table 4.1. Main Advantages & Disadvantages of Concept Variations. 37
Table 6.1. Bond Graph Symbols. 85

Chapter 1.
Introduction

1.1 Objectives

The objective of this thesis is to design a system to allow operators of the Michelin calender 800 machine to perform a pace change more quickly. In addition, the design should simplify the procedure, improving safety and reducing eye strain.

1.2 Motivation for Project

The calender 800 produces metallic tissue which eventually is placed into tires as steel belts. Of course, for various tire lines, unique metallic tissue is required. Presently, the total output of the calender 800s in North America is below the required amount. The time required to accomplish a changeover, known as a pace change, from one type of metallic tissue to another ranges from 30 to 90 minutes. A reduction in this time will directly increase the metallic tissue output of the calender 800 and the production capacity of Michelin manufacturing facilities. This improvement in capacity is the main motivation for this project.

In addition, two other concerns motivate this study. One is operator safety. During a pace change, operators place themselves in awkward positions that have a great potential for injury. The second concern is eye strain. The metallic tissue produced by the calender can contain up to 800 steel cables; during a pace change, the cables are moved individually by operators to new positions. Since only a few millimeters separate each cable, operators must strain their eyes to locate each cable and its new position.

1.3 Background

1.3.1 Calender 800 Operation

The calender 800 produces metallic tissue (two rubber sheets that sandwich steel cables). The cables run parallel to one another and are equally

spaced; the spacing (pace) can range from 1.1 mm to 3.15 mm. To accomplish this task, the calender 800 utilizes four major subassemblies: the block creel, the pace change area, the rubber feeding mechanisms, and the finishing operations. Shown in figure 1.1 is a side view of most of the calender 800 (only part of the block creel is shown). The machine is very large with numerous components and requires three full-time operators to perform various tasks throughout the process of producing metallic tissue.

The block creel is a large storage unit for the bobbins of cable that feed into the rubber sheets. The bobbins are placed onto pegs and the cables are guided through a series of pulleys. The cables are made of steel with a brass coating. In addition, in the block creel contains a tension-setting mechanism for each cable. When the tension in a cable becomes too high or too low, the mechanism triggers a lever which stops the calender; the cable tension can range between 3 and 24.5 newtons. Finally, the cables leave the block creel on six separate planes as shown in figure 1.1. The six levels are required for proper separation between the cables when using the present design for guides.

From the block creel, the cables flow into the pace change area. In this area, two main objectives are accomplished. The primary task of this area is to set the spacing or the pace between the cables that are to be imbedded between rubber sheets. In addition, any additional cables that are not being used in the product being run are removed and stored. When these stored cables are needed in a product, they are tied back into the system. Since the pace change area is the primary focus of this thesis, section 1.3.2 provides a detailed description of this area and of how the tasks are presently completed.

Once the pace and the number of cables are carefully set in the pace change area, the cables flow into the rubber feeding mechanism. Here, two large metal cylinders, called boles, rotate in opposite directions, each cylinder guiding a sheet a rubber. The cables are first pressed onto one of these rubber sheets. Next, the two large cylinders meet at a point as shown in figure 1.1. As

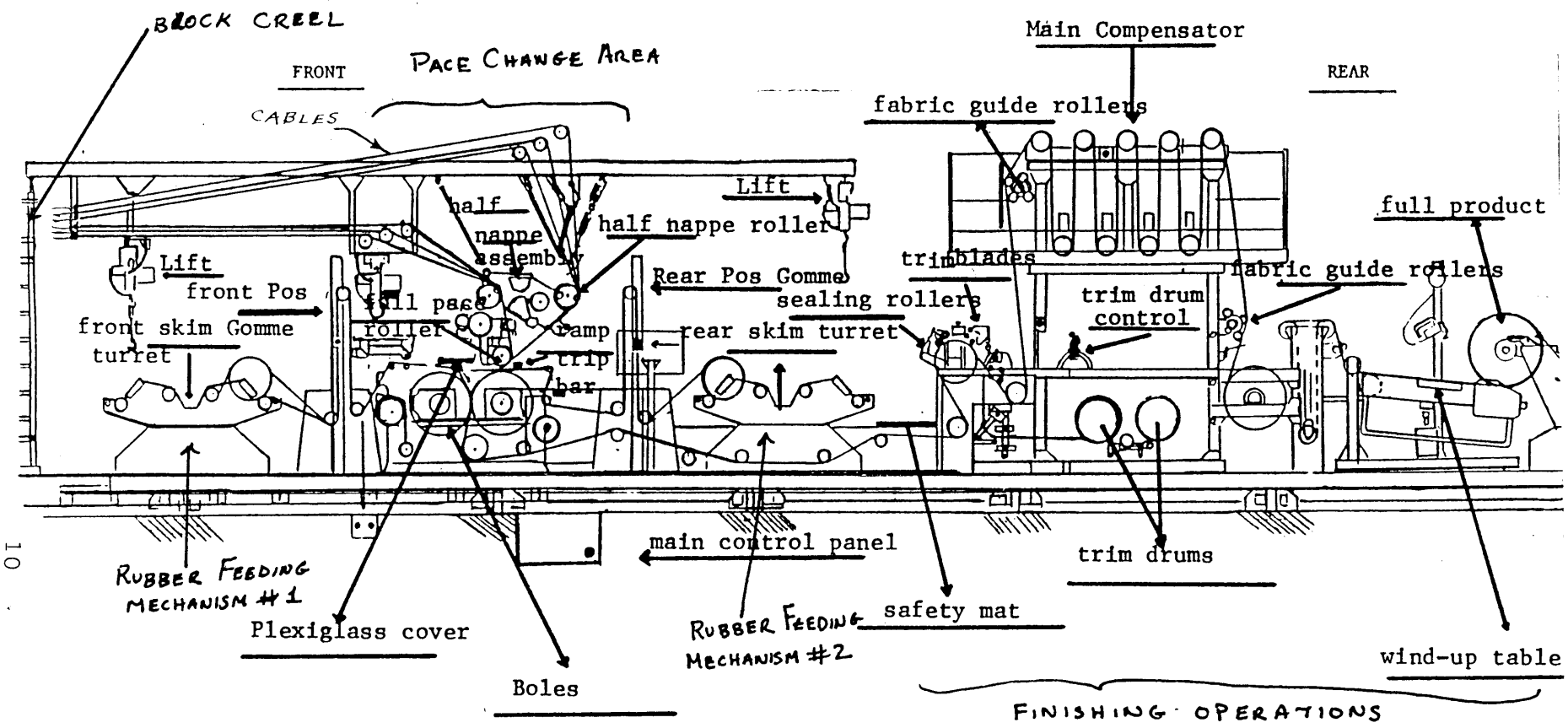

Figure 1.1. Side View of Calender 800 Assembly.

a result, the cables become embedded between the two rubber sheets. The tackiness of the rubber permanently holds this laminated metallic tissue together.

The finishing operations are accomplished using several machines, each performing a unique task. Once the metallic tissue leaves the boles, it arrives at the trimming machine; this machine determines the amount of excess rubber at the edges of the product and cuts this excess off. Next, the product enters a compensator which eliminates slack in the product that results from any difference in speed between the drives that pull the rubber product through the machine. If this compensator fills with product or empties, the calender is stopped automatically. Finally, the product reaches a wind-up so that it can be wound into rolls and sent to the 10/30 cutter, which converts the metallic tissue into steel belts.

1.3.2 Operation of Pace Change Area

1.3.2.1 Pace Change Area Structure

In the pace change area, the number of cables and the spacing between those cables are set. The existing design is comprised of numerous parts that make this part of the calender extremely congested.

The numerous parts in the pace change area can be grouped into four subassemblies. In figure 1.2 is shown a side view of the area with key components labeled. Notice that the first units with which the cables come into contact are the guide boxes. Six levels of guide boxes maintain the same six levels of cables that arrive from the block creel. The purpose of the guide boxes is to keep the cables separated so that they do not rub against other cables and so that operators can easily find the desired cable. On each level are seven to eight guide boxes that can slide on a shaft; each guide box contains 15 grooves made on the outer surface of a hollow steel cylinder that rotates on two bearings. Through each of these grooves a cable is placed; the grooves rotate so that the cables do not slide on any surface.

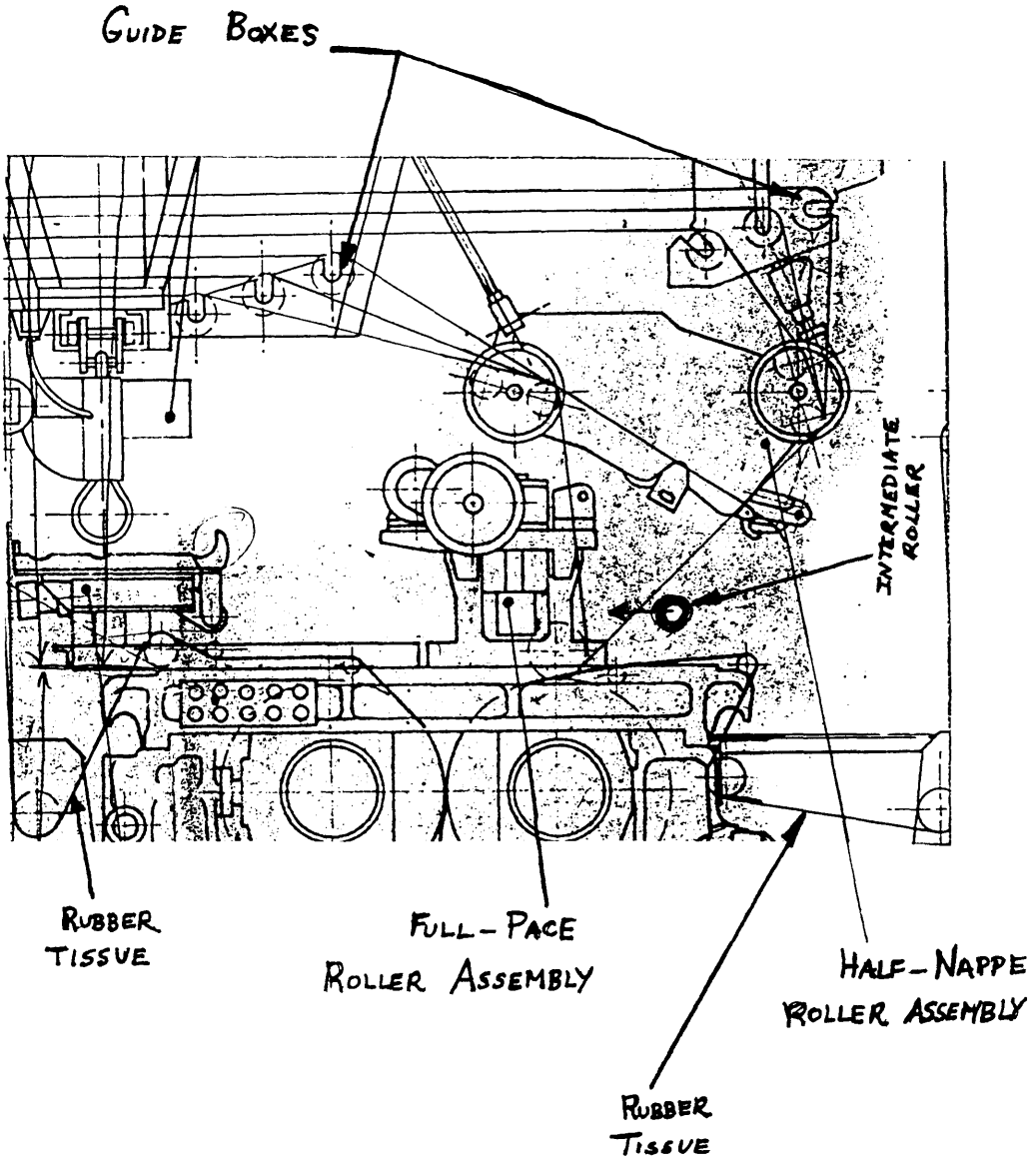

Figure 1.2. Side View of Pace Change Area.

Any significant amount of sliding contact that a cable makes with a surface results in two severe problems. The sliding contact makes the cable curl. This curl in the cable does not allow the metallic tissue to lie completely flat, causing quality problems in steel belts of tires. Secondly, the cable will cut through material that it slides across. Although the rate of wear is not significant on glass nor on steel, the cable has been known to completely cut through aluminum rollers. For these reasons, most surfaces to which the cables come into contact are made to roll in the direction of cable path.

From the guide boxes, the cables are run into two separate rollers; the top three levels of cable feed into one roller while the bottom three levels feed into another. This area labeled in figure 1.2 is called the half-nappe (or half-pace) assembly; this entire assembly is suspended from the top I-beam using three turnbuckle supports. The two rollers shown in this assembly, known as half-nappe rollers, contain 3 mm deep grooves (typical profile shown in figure 1.3). The number of grooves on each of these rollers is equal to one-half the number of cables that will be in the metallic tissue being produced. The grooves are equally spaced apart with the spacing determined by the pace of the product being run. In addition, the groove pattern is symmetrical about the center of the cylinder so that the cables will be centered on the rubber. The ends of these rollers are placed in roller-bearing mounts so that they rotate with the motion of the cables. Finally, each half-nappe roller is on a turret that allows operators to position a new roller while the calender is running.

Next, the cables run into the full-pace roller assembly, converging to this roller from the two half-nappe rollers as shown in figure 1.2. The purpose of the full-pace roller is to place the cables onto the rubber product. The number of grooves in this roller is equal to two times the number of grooves in a half-nappe roller. The maximum length covered by grooves is 800 millimeters on both the half-nappe and the full-pace rollers. The groove depth on the full-pace rollers is less than the diameter of the cables; as a

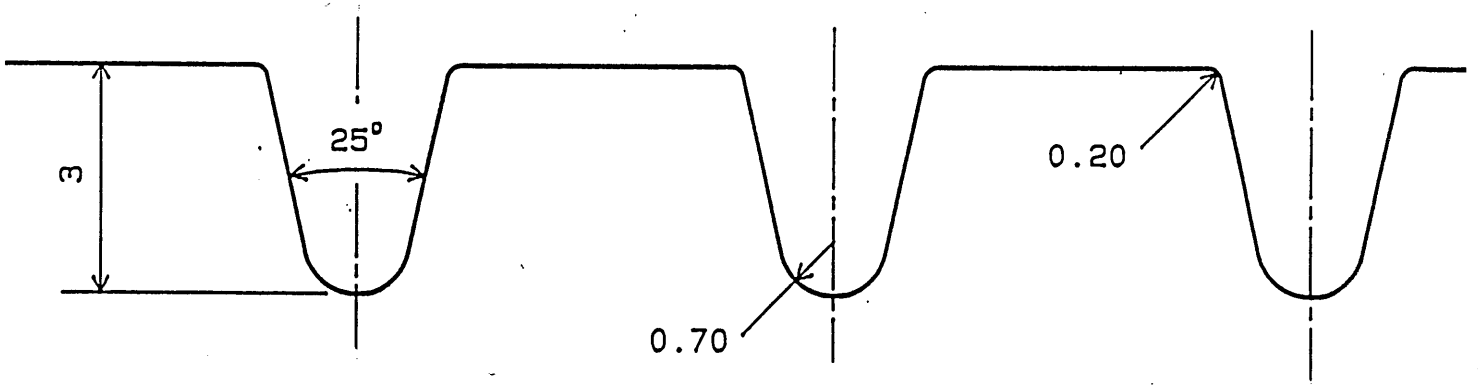

Figure 1.3. Typical Profile of Half-Nappe Roller Grooves.

result, a portion of all cables protrude from the roller, allowing them to be pressed onto the rubber product. The full-pace roller is on a turret that contains a total of two rollers; this turret allows the operators to insert a full-pace roller into the "waiting" position while the calender is running. To bring the new roller into the working position, the operators force the entire turret to lift off of the rubber product, rotate 180 degrees, and then return back down onto the rubber product.

The final subassembly in the pace change area is the full-pace roller delivery system. This system's functions are to bring a new roller from storage to the turret and to move a used roller from the turret to storage. This subassembly is shown in figure 1.4; as shown in the figure, the system is composed of two parts, the hoist and the carriage. The hoist travels between the storage area and the carriage, while the carriage travels from the hoist to the turret. The carriage contains a pneumatic actuator that is used to pick up the roller in the "waiting" position of the turret. Then, the operators roll the carriage back to the hoist. The hoist picks up the roller and moves it to storage and brings a new roller from storage. Once the hoist places this new roller onto the carriage, the carriage moves forward and pushes the roller into the turret. It is important to note here that the carriage and the full-pace roller assembly sit on the rubber feeding unit that contains the two large cylinders that press the two sheets of rubber together.

1.3.2.2. Pace Change Procedure

A pace change is performed by three operators when a different metallic tissue is to be produced on the calender 800. The change of pace in the steel belts of tires has a dramatic impact on tire performance. In addition, using less cable for tires not specified for high performance applications (i.e. car racing) saves Michelin a substantial sum of money. For these reasons, a pace change must be performed carefully to ensure that cables are placed in the proper positions.

Before the calender is stopped, the "new" full-pace roller and the

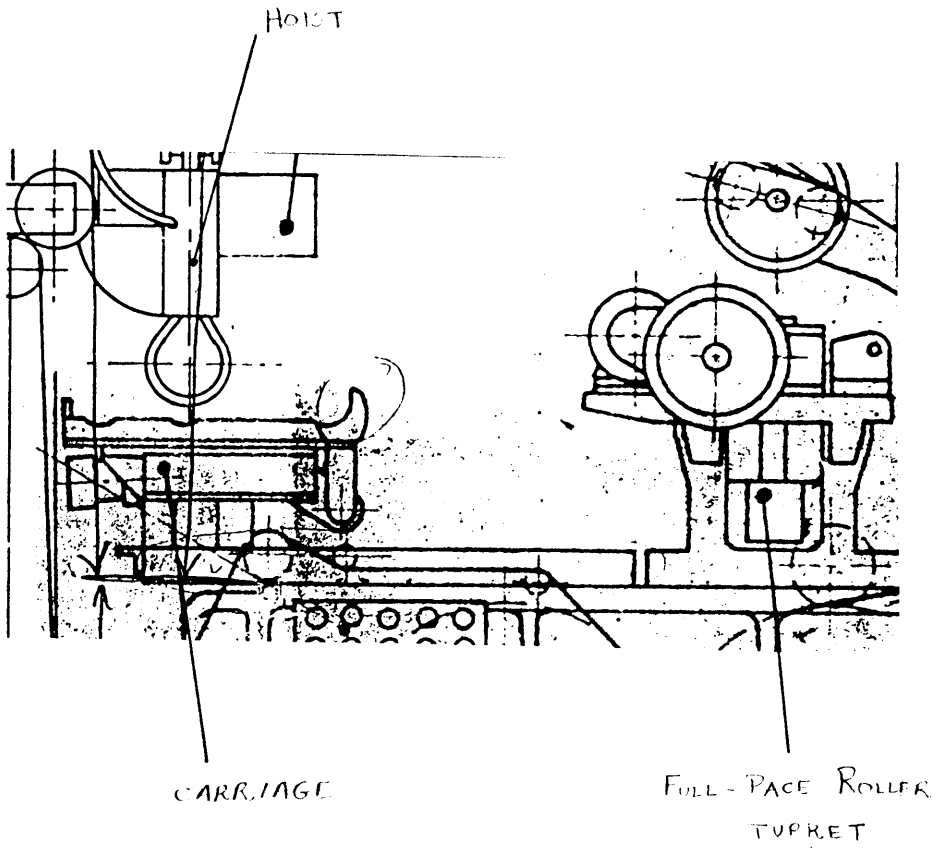

Figure 1.4. Full-Pace Roller Delivery System.

"new" half-nappe rollers are placed in their respective turrets. In addition, the required tooling to accomplish the pace change is obtained from storage and brought to the pace change area. In this section is given a description of the main steps in the procedure; for a full step-by-step procedure, refer to appendix A.

Once the calender is stopped, the half-nappe turrets are rotated to bring the new half-nappe rollers into their working positions. Next, the operators place each cable individually into its groove on the half-nappe rollers. In addition, the operators remove or add cables into the system as necessary. To remove cables from the system, the cables are simply cut and tied to stationary rods. When these cables need to be added back into the system, they are untied from the rods and tied onto cables already in the system; when the calender is run forward, the added cables are pulled into the product allowing them to be placed into the half-nappe roller grooves. This step of placing cables and of changing the number of cables is the most time consuming and tedious step in the pace change.

Once the cables are properly placed in the half-nappe rollers, the new full-pace roller is brought into position and a tool known as a comb is used to move the cables from the half-nappe rollers onto the full pace roller while maintaining the spacing established in the half-nappe rollers. Figure 1.5 shows a typical comb; a different comb is used for the various cable paces. Once the comb is moved from one half-nappe roller to the full-pace roller, the calender is slowly run forward for a few seconds so that the cables move onto the grooves on the full-pace roller (this process is known as jogging). Then the comb is removed and used to repeat the procedure with the other half-nappe roller.

Finally, the operators place an intermediate roller into position as shown in figure 1.2. The function of the intermediate roller is to force the front set of cables back onto the full-pace roller so that a greater area of contact between the full-pace roller and the cables is created. This greater area

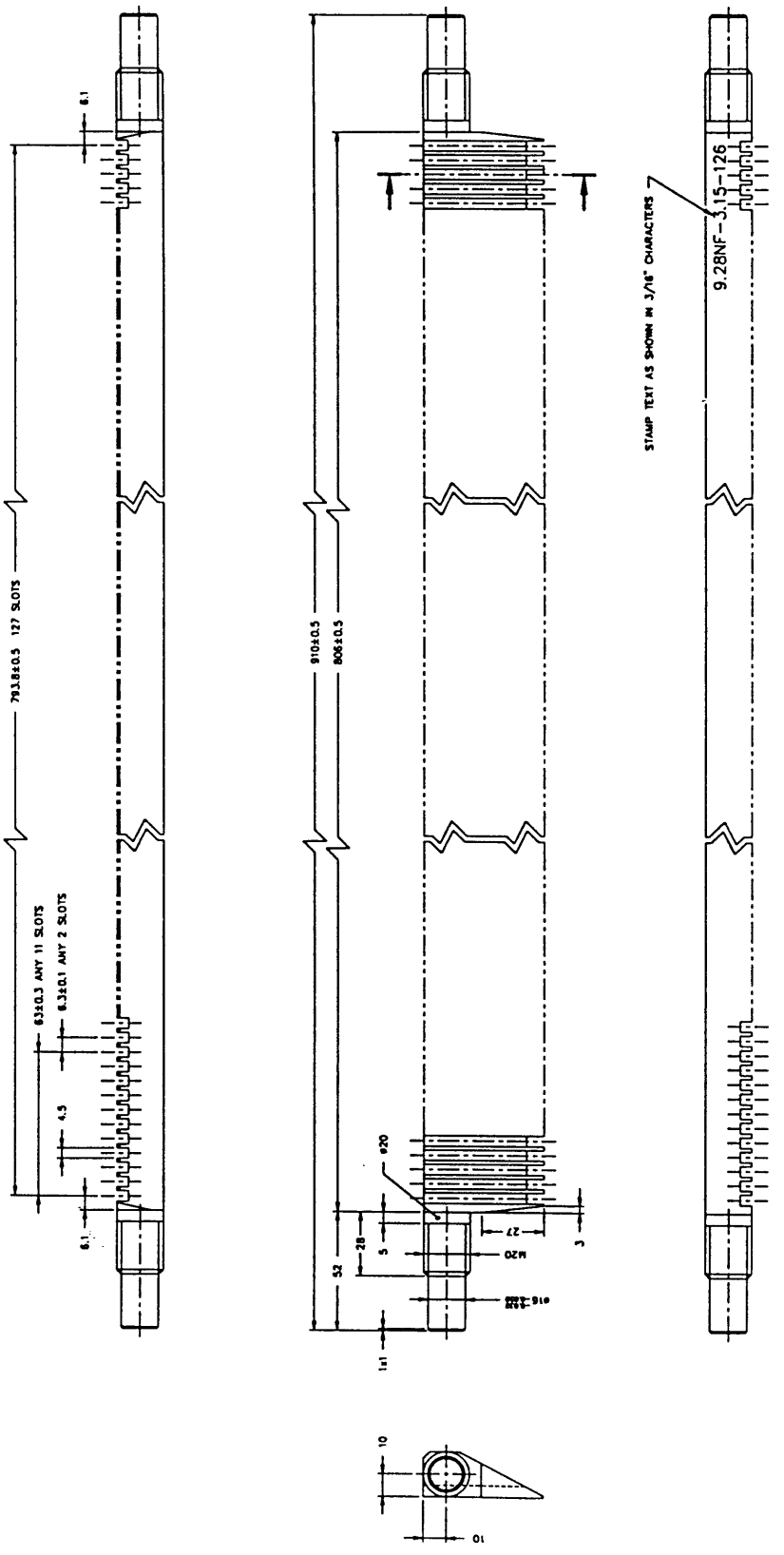

Figure 1.5. A Typical Comb.

ensures that the cables do not jump out of the grooves in the full-pace roller.

Before starting the calender, the distance of the full-pace roller and the rubber product is checked by running a metal bar underneath the full-pace roller and measuring the thickness of the resulting bar with a micrometer. If the measured thickness is not at the desired value, the full-pace roller turret is moved vertically until the correct thickness is achieved. Once achieved, the calender is started to produce the new metallic tissue. Of course, if cables were tied into the system, the first few yards of product must be discarded.

1.3.3. Variables in a Pace Change

Several factors vary in different qualities of metallic tissue produced by the calender 800. These factors and the range they cover are critical to any new design of a pace change procedure. The factors and each factor's associated range include:

- Pace (1.1 mm - 3.15 mm)
- Cable Diameters (.6, .8, and 1.0 mm)
- Number of Cables (Up to 800 cables)
- Rubber Quality (thickness & composition)

The pace is the spacing of cables in the metallic tissue and is equal to the groove spacing on the full-pace roller; however, the spacing on the half-nappe rollers is twice the pace. Therefore, the spacing of the half-nappe roller grooves can range between 2.2 mm and 6.3 mm. The cable used in metallic tissue is made of steel with a brass coating. The 3 cable diameters listed are the ones used presently at Michelin's US1 manufacturing facility; however, other cable types have been used in the past and could be used in the future. Although not presently being used, fretted cable have been used in the past. Fretted cable has a separate wire that wraps around the cable in a helix.

1.3.4 Problems With Present Pace Change Procedure

The present procedure to accomplish a pace change has been used for

decades in both North America and in France. When the calender was first designed and used to produce metallic tissue, the calender's production rate was well above some of the other processes in producing tires. Over the years, as capacities of the other processes have been improved, the calender 800 has gradually gained attention as it no longer enjoys the luxury of being one of the faster processes. Presently, the calender 800 is one of the bottlenecks in the manufacturing process of tires at Michelin.

Presently, production of metallic tissue is carefully planned and monitored to ensure that necessary qualities are produced when needed. However, the calender 800 is expected to become a major problem in the coming years as it further falls behind in production. As a result, in recent years, Michelin has reviewed the calender 800 process to determine possible ways to increase its production rate of metallic tissue. It has been determined that a large amount of downtime occurs for a pace change; generally, a pace change consumes anywhere from 30 to 90 minutes to complete depending on several factors including the magnitude of the pace change, number of cables to be removed or inserted, and on the experience of operators. Recently, a search has been made to shorten the time required; nevertheless, the search has proven fruitless. As a result, the pace change time remains the main concern associated with the calender 800.

Although the change time is the main concern, several other problems exist in the calender 800 that deserve attention. Operator safety in the pace change area needs careful study. When cables are placed into half-nappe roller grooves, when cables are added/removed from the system, and when cables are combed into the full-pace roller, operators climb into the machinery high above the shop floor to gain access to the equipment. This procedure has a great potential for injury; operators can bump their heads or fall from the machinery. This risky condition is a result of the numerous parts in the pace change area, making the area highly congested, obstructing operator access.

Another safety concern in this area is heavy eye strain. When operators must place the cables in half-nappe roller grooves, operators must continually locate the correct cable that goes into a specific groove from the numerous cables in the system. Since the cables are extremely close to one another, the task of locating cables is extremely tedious and strains the eyes of operators.

Knots placed in cables pose another problem to the operation of the calender 800. In a procedure called a bobbin change, bobbins in the block creel are replaced with new bobbins of cable. The cable from the new bobbin is simply tied to the cable from the old bobbin that is already in the system using a double knot. When these knots reach the half-nappe rollers, some cables jump out of their grooves; generally, 50-60 cables jump out. These out-of-pace cables must be placed back into their grooves by the operators. Since this is done with the calender stopped, repositioning out-of-pace cables results in loss of production.

The full-pace roller assembly is another area that could be improved. Presently, the roller is placed at a set distance from the bole carrying the rubber product. Within any given rubber quality, however, the thickness of the rubber can vary; when this occurs, the cables are imbedded into the rubber at different depths. It is more desirable, however, to set the cables into the rubber product at the same depth throughout the roll of rubber tissue. If this could be done, the cables would be centered when sandwiched between the two rubber sheets resulting in a higher quality metallic tissue. Placement of cables at the same depth, however, is not possible with the existing full-pace roller assembly.

1.3.5 Goals of Project

Some existing problems with the calender 800 are discussed in section 1.3.4. The specific objectives for this design thesis are as follows.

A. *Reduce pace change time.* On the calender 800, a pace change requires 30 to 90 minutes to complete. The primary objective of the project is to significantly reduce the amount of time to accomplish a change.

B. *Improve operator safety.* Operators place themselves in awkward and dangerous positions during the pace change, largely resulting from a lack of accessibility. Greater accessibility is desired.

C. *Reduce operator eye strain.* Operators presently must strain their eyes to locate and move each cable.

D. *Incorporate a pressure-driven full-pace roller.* To imbed cables into the rubber sheet at a constant depth, it has been suggested that constant pressure be placed on the roller. When the rubber thickness changes, the roller would rise and fall as needed.

E. *Eliminate out-of-pace cables resulting from knots.* Knots placed in cables result in cables jumping out of the grooves in the half-nappe rollers. A solution is needed to eliminate the time required to reposition these cables.

1.3.6. Constraints

To produce a usable solution, cost of the design needs to be kept to a minimum without sacrificing performance. To minimize cost, two constraints should be followed. First, the tooling used in a pace change should not be changed significantly. The existing tooling is expensive and numerous; separate tooling (rollers, combs, etc.) is used for the various values of pace; replacement of this tooling would make the cost of any design prohibitively high. Second, a design should be sought to impact a minimal number of assemblies in the calender without sacrificing the functional independence of these assemblies. Using this approach, the number of components needing redesign is kept minimal.

Chapter 2.
Design Approach

2.1 Introduction

Since this project involves existing machinery, the design process utilized to find a workable solution becomes somewhat constrained. The calender 800 is a large system of several subassemblies performing various functions necessary to create metallic tissue. As a result, any modifications made to one area of the calender must not compromise the functionality of the other subassemblies. This constraint placed on the design by the assemblies on the periphery of the pace change area demands that a careful design procedure be followed.

The first step in the design process is to gain a thorough understanding of the entire system. Without a good understanding of all machinery involved, the designer can not determine how a proposed solution impacts other assemblies. It is possible, as described in section 2.2, for a proposed solution to make the calender 800 a coupled system; if this occurs, the calender would no longer be usable. Therefore, when studying a system, each component's function and its influence on the other components must be determined.

Once the entire system is understood, the objectives of the project must be determined from the customer attributes (Suh 1990, 34). Often, this step is accomplished using a quality function of deployment (QFD). In a QFD, the customer attributes are mapped into functional requirements; the functional requirements are customer attributes converted into engineering terms. Functional requirements state the desired outcome in terms of *measurable* quantities; the perceived needs should be satisfied with a minimal set of functional requirements (Suh 1990, 28).

Determining the constraints placed on the solution is just as important as determining the functional requirements because the constraints provide the boundary of acceptable solutions. Generally, constraints impact multiple

areas of a design. For example, a cost constraint impacts all components in a design. As long as a proposed design does not exceed the imposed constraints, the design is acceptable.

2.2 The Design Process

Once the top-level functional requirements (FRs) are determined from the customer attributes, the designer can begin determining how to fulfill these FRs. Figure 2.1 shows the 3 primary design domains: the functional domain, the physical domain, and the process domain. The functional domain contains the set of functional requirements established by the designer, while the physical domain contains the tangible embodiment that satisfies the FRs (Suh 1990, 26). The process domain includes the manner in which the items in the physical domain will be manufactured. The determination of design parameters (DPs) to satisfy functional requirements (FRs) and of process variables (PVs) to satisfy DPs is known as mapping. Mapping is a nonunique process in that multiple solution sets are possible for a given problem definition.

Figure 2.2 illustrates the design process utilized to determine the design parameters in the physical domain (Wilson 1980). The illustration includes a marketplace loop that could be replaced in manufacturing equipment design by the department requesting the design. The step of formalizing the needs is discussed in section 2.1. Once established, engineering creativity must be utilized to synthesize a solution; analysis and tests are then performed to determine if the solution properly satisfies the functional requirements. As shown, the mapping process involves two distinct phases: the creative stage and the analysis stage. The creative process yields solutions and the analytical process determines their worthiness.

2.2.1 The Creative Process

To generate potential design solutions, engineers can employ numerous techniques that boost creativity. Although the mechanisms of

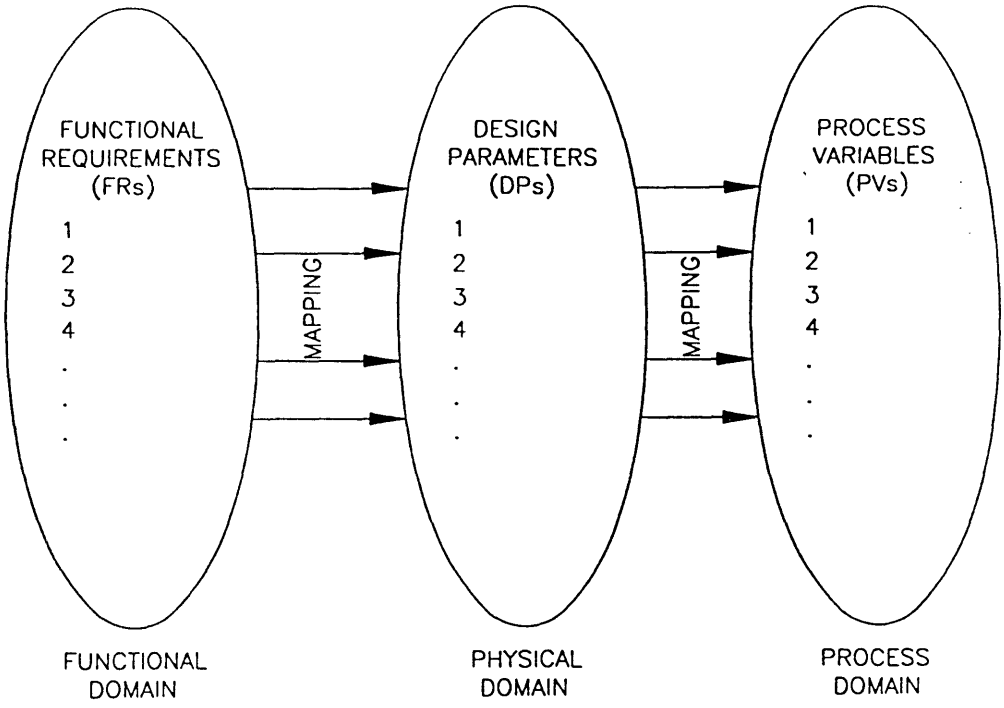

Figure 2.1. Primary design domains.

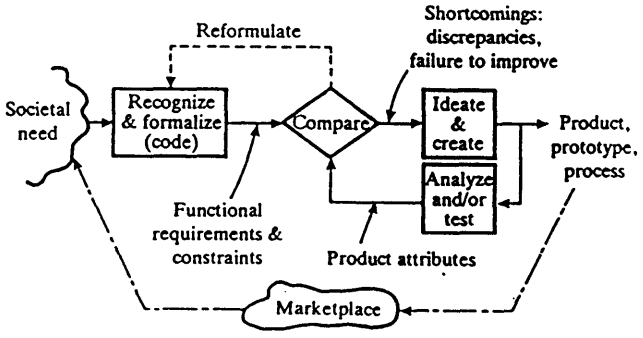

Figure 2.2. The design loop. (From Wilson, 1980.)

creativity are not nearly as well understood as techniques of analysis, some methods have been found to stimulate the imagination. It is important to note that all new ideas involve some degree of risk; a good designer is one who is willing to accept failures in the search for a winning solution (Suh 1990, 29). The analytical process helps to reduce this risk by allowing the designer to identify solutions that contain fundamental flaws and that are doomed to failure before large monetary amounts are spent on pursuing those solutions.

One effective approach to creativity is building on metaphors. Metaphors allow comparisons to be made between the meaning and qualities of one thing and those of another. In this technique, something that is not understood is compared to things that are understood; the comparisons lead to new ideas by allowing the mind to see the problem in different ways (Hanks and Parry 1983, 69). With the understanding of the unknown gained from the metaphor, other metaphors can be created to further increase knowledge of the unknown, leading to additional ideas.

Another useful technique to promote creativity is visual brainstorming (Hanks and Parry 1983, 80). In visual brainstorming, ideas are sketched on paper as they come to mind; these sketches make the abstract notions more concrete, allowing those ideas to stimulate new ideas. The sketches also reveal any gaps in thinking, forcing the mind to see the problem in a different light. When visual brainstorming, ideas should not be judged. All thoughts that come to mind should be put on paper, allowing the mind to freely make connections between the thoughts. Judgments should be made only after the process is completed.

2.2.2 The Analytical Process

The analytical process involves the use of engineering know-how and judgment to assess the ideas obtained from the creative process. The design axioms help to facilitate this process. In this section, a brief summary of the axioms and their implications to machine design are given.

The axioms can be stated in several forms; the procedural form can be stated as (Suh 1990, 391):

Axiom 1 *The Independence Axiom*
Maintain the independence of FRs.

Axiom 2 *The Information Axiom*
Minimize the information content.

The independence axiom declares that when a design parameter (DP) is perturbed, only one functional requirement (FR) should be affected. If one DP influences more than one FR, the performance of the system becomes extremely difficult and often impossible to control; this type of design is known as coupled. The information axiom deals with the complexity of the design; basically, the statement declares that the design should be made as simple as possible. Designs that maintain functional independence should first be sought and then the information axiom should be utilized to choose the best of these designs. Although the axioms seem at first to be obvious and simple, designers without a good understanding of these axioms often violate them leading to excessive time spent in pursuing a bad idea. Numerous corollaries and theorems, which can be used as more specific design rules, can be derived from the axioms (Suh 1990, 391). Of course, the designer must also have a solid grasp of engineering fundamentals to effectively apply the axioms of design.

2.3 Reducing Equipment Setup Time

To reduce the changeover time on industrial equipment, several specific areas in the setup process should be studied and modified (Hay 1984). Hay, in his paper, suggests that any setup time can be reduced by 75% no matter how complex the machinery or the changeover. Although he strongly recommends against redesigning equipment as the primary approach to setup time reduction, when a redesign is deemed necessary, some of his suggestions can be extremely useful to a designer.

Identification of internal and external steps in the setup is of primary importance (Hay 1984). Internal steps are those that can only be performed while the machine is stopped. External steps are those that can be done while the machinery is running; methods must be found to accomplish these steps before the machine is stopped or after it is restarted.

A second category of changes is classified as adjustments. One type of adjustment occurs when equipment is made to be infinitely adjustable over a specified range. Usually, infinite adjustment is provided because the exact use of the equipment is not known at time of design. However, in use, many times only a few points in the range are utilized. If such a situation is identified, it is usually possible to add some form of stops at those points to eliminate the need for measurement. Such a change will dramatically reduce the time involved to reposition equipment from one point in the adjustable range to another point.

Clamping should be preferred to bolts for holding items together when the items must be released during a changeover. Of course, this can be done only when sufficient space is available and when clamps can provide the necessary holding force. Bolts and other threaded components consume a tremendous amount of time to fasten and unfasten; in addition, they usually require tooling that can be lost. Clamps generally require only one or two motions to be activated or inactivated.

A final area to look for time reduction can be classified as problems (Hay 1984). A problem is anything that interferes with a quick, trouble-free setup. The correct approach is to eliminate the root cause of the problem and not to find ways to reduce the setup time despite the problem.

Hay suggests the above four key categories as sources for time reduction on existing designs. Nevertheless, the suggestions should be kept in mind to avoid introducing items from these categories into a design.

Chapter 3.
Simplification of Existing Equipment

3.1 Need for Simplification

The calender 800 pace change area as described in section 1.3.2 is highly congested. Numerous parts make this area very difficult to enter when performing a pace change. The lack of accessibility presents several problems to the operators. As explained in section 1.3, a key concern is safety; often, operators hang from the equipment during a pace change. This potential for injury can be addressed by simplifying the equipment to improve operator access. Increased working space would also allow operators to perform the steps in a pace change more quickly. For example, greater access would allow operators to more easily align the comb with the cables when transferring the cables from the half-pace rollers to the full-pace roller.

Simplification of the pace change area would also provide the room necessary to add any new equipment. Presently, as shown in figure 1.2, only a small amount of space is available between the half-pace and full-pace rollers to add any new devices or to modify significantly the existing equipment. The lack of space tightly constrains design options; therefore, by increasing the available space, design solutions become more numerous.

Finally, reducing the number of parts without compromising functional independence decreases the number of replacement parts that must be stocked. Reducing the number of stocked parts provides several key benefits. The effort necessary to ensure that parts taken from stock are replaced is lessened. In addition, the cost of storage space is minimized with fewer, smaller parts.

3.2. Approach to Simplification

To simplify the existing equipment, it is important to follow a careful procedure. The first step is to thoroughly understand the system and the functions performed by each subassembly. In addition, it is necessary to

identify if any subassemblies influence the performance of the other subassemblies (functional coupling). Only with such an understanding can a designer determine how an assembly can be simplified or which parts can be eliminated entirely.

The second step is to creatively find potential modifications to the existing equipment that improve accessibility or reduce the number of parts without compromising the functionality of each subassembly. To find these potential solutions, the engineer can employ numerous methods including those identified in section 2.2.1. Once the designer has found some possible solutions, each solution's acceptability must be determined; a solution is acceptable if it satisfies all of the functional requirements of the original design without violating the independence axiom discussed in section 2.2.2.

3.3 Simplification of the Pace Change Area

The functions of each subassembly and the effects of each subassembly on other subassemblies is given in 1.3.2. In the search for simplifying options, two other concerns are addressed. The first is the incorporation of a pressure-driven full-pace roller; to force the roller with pressure, pneumatic cylinders could be built into the end supports of the roller. The cylinders could lift the roller from the rubber product to allow a new roller to be inserted; also, the pressure input into the cylinders could be adjusted to apply the desired pressure to the various product qualities. The size of pneumatic cylinder selected determines the maximum force that can be applied to the roller using the 80 psi available in the plant. The ability to set the speed with which the roller is raised or lowered can be provided in the pneumatic control design.

The second concern addressed in the simplification process is the full-pace roller carriage. Operators have complained that the carriage that delivers the full-pace roller from the hoist to the full-pace is difficult to use. The carriage shown in figure 1.4 contains a pneumatic lift that is supposed to position the roller into the turret; often, the lift fails to properly locate the

roller into the turret. As a result, operators use a steel rod to force the roller into position; this process consumes valuable time and much effort.

An effective solution to the carriage problem is to eliminate the need for a carriage altogether. If the pneumatic assembly that sets the roller onto the rubber product could be designed to travel to the hoist, the hoist could place the new roller directly into this assembly; such a design performs the function of moving the roller into position, the function performed by the carriage in the existing design.

To address these concerns as well as the desires to increase space and reduce number of parts, the layout shown in figure 3.1 is best suited. The cables run from the guide boxes into two half-pace rollers; from the half-nappe rollers, the cables converge onto a full-pace roller. Both the half-pace and full-pace rollers are on linear slides that permit the rollers to be moved into their change positions. At the change positions, the rollers can be replaced with new ones. Notice that for the half-pace rollers, two levels of rollers are provided so that a new roller can be inserted while the calender is running. The full-pace roller is shown with pneumatic cylinders; the roller slides back to the hoist so that the full-pace roller can be replaced, eliminating the need for a separate carriage.

The proposed layout has several important advantages over the existing pace change area. The most important benefit is the reduction of space consumed by the assemblies. Compared to the existing design shown in figure 1.2, the proposed design is much less congested, providing the room necessary to add any new devices. In addition, operators have a greater amount of room in which to work; the two operator work areas are labeled in figure 3.1. As a result, the operators need not place themselves in awkward positions during a pace change. Finally, the proposed design contains far fewer parts than does the present pace change area. As a result, fewer replacement parts need to be stocked, reducing inventory costs.

One other key modification has been incorporated into the proposed

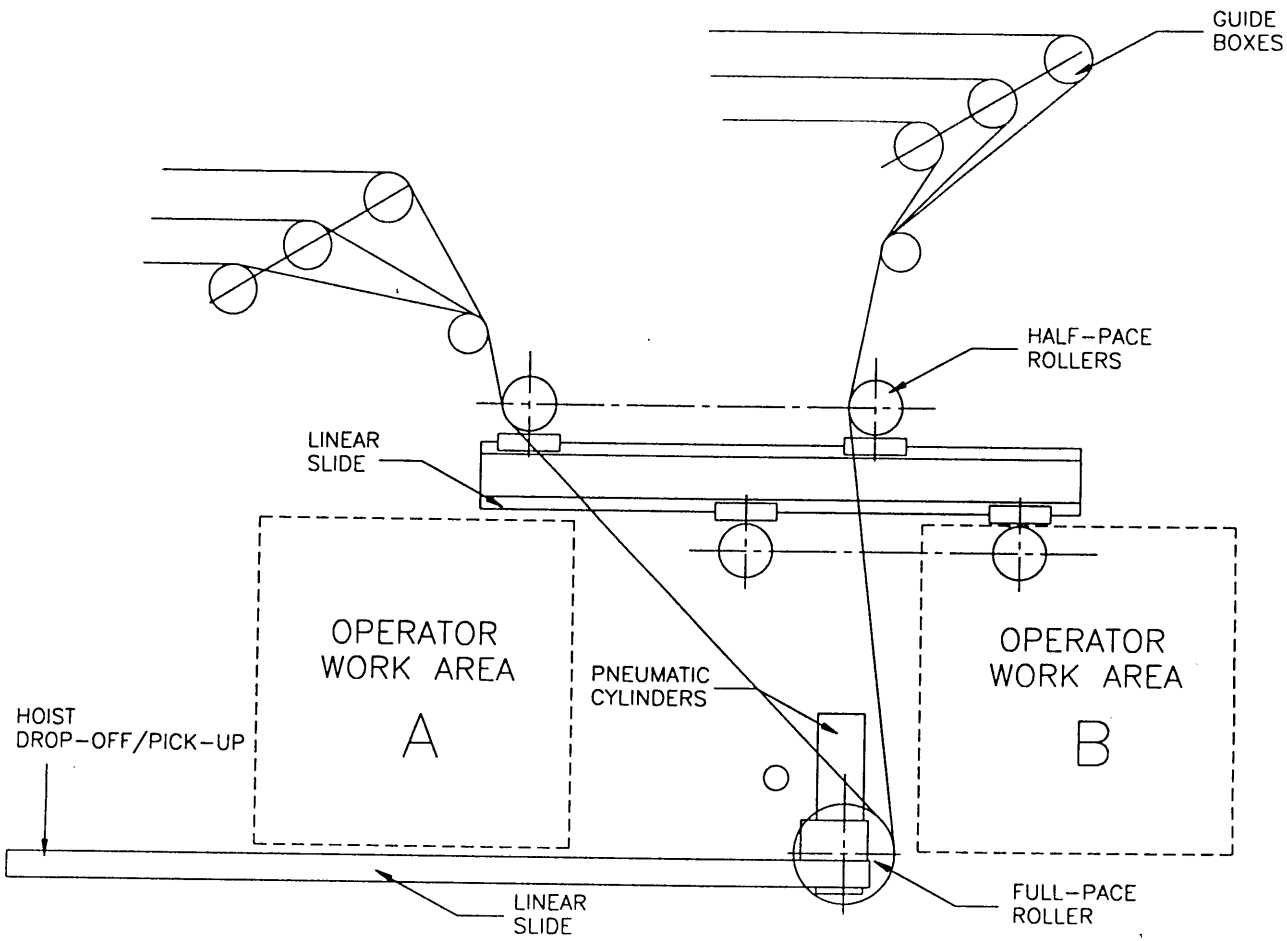

Figure 3.1. New Layout of Pace Change Area.

design. During a pace change, an intermediate roller is placed into position as the final step. The intermediate roller forces the cables from one of the half-pace rollers back onto the full-pace roller. The intermediate roller ensures that the cables stay in the grooves of the full-pace roller. However, the intermediate roller is needed only for the half-pace roller that guides the cables from in front of the full-pace roller as shown in figure 1.2. When both half-pace rollers are placed behind the full-pace roller as shown in figure 3.1, the need for an intermediate roller is eliminated. Placement of an intermediate roller consumes 5 to 10 minutes during the pace change. The changed cable path proposed reduces the pace change time by 5 to 10 minutes.

Chapter 4.
Concept 1

4.1 Need for New Technology

As discussed in chapter 1, most steps in the present pace change procedure are completed by the three operators. Ideas suggested in section 2.3 can be applied to the area to reduce the setup time. However, without the application of any new technology, such modifications would only reduce the time by a small amount.

Two steps in the present procedure consume the majority of the pace change time. The placement of cables into the half-pace rollers requires the greatest amount of time; since operators must locate each cable and its proper position by hand, the task is extremely repetitive and slow. The process of removing cables from the system or adding cables to the system is the next most time consuming step; again, this is a result of having to locate the correct cable and the position in which to store it. As long as these two steps remain manual operations, the pace change time can not be greatly reduced. As a result, it is appropriate to incorporate new technology to automate some of these time consuming operations.

4.2 Basic Idea

To automate the steps of placing cables into half-pace rollers and of moving cables to and from storage, concept 1 attempts to pick up all the cables at once from the half-pace rollers, change the pace between the cables and then place the cables onto the new half-pace rollers. Since cables are spaced at a certain pace between the half-pace and full-pace rollers, the cables run parallel in this region; as a result, it is possible for a pace-changing device to locate these cables. Throughout this thesis, such a pace-changing device is called an adjuster.

In addition to changing the pace, the adjuster performs the task of removing or adding cables as necessary. Figure 4.1 shows the proposed layout

of concept 1; the actual operation of the device is discussed in section 4.4. In this layout the main mechanism changes the pace; on the sides, is the device (storage unit) which determines which cables to remove or add and then inserts or deletes those cables. For example, if 50 cables were to be removed, each storage unit would cut out 25 cables and clamp them.

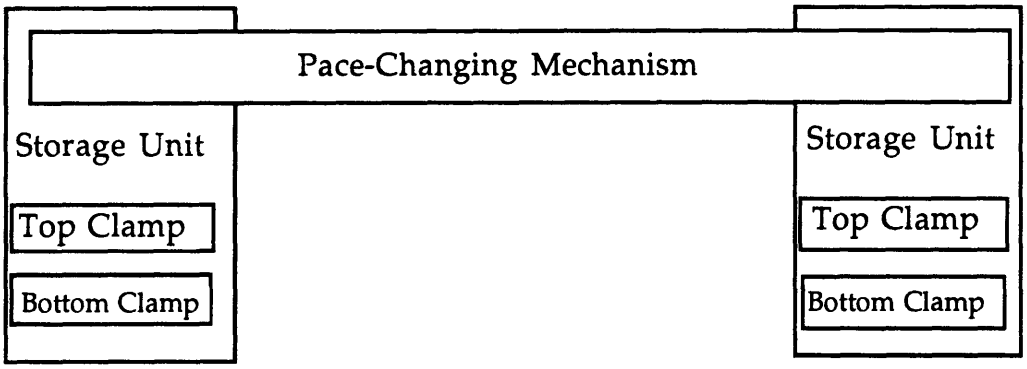

Figure 4.1. Proposed Layout of Concept 1.

Notice that within each storage unit are two clamps; two clamps are necessary so that cables already in storage can be held while other cables are brought into storage. When new cables are to be placed in storage, the top clamp opens to allow entry while the bottom clamp stays closed to hold onto the cables already in storage. Once all cables not needed in the new roller are brought into storage, the top clamp closes, locking onto all cables in storage. At this point, an operator cuts out these new cables from the rubber tissue using a pair of scissors. The bottom clamp opens to accept these new cables and then closes. The storage unit "knows" which cables to remove by

determining the distance from the center of the adjuster covered by cables to be placed into the new half-pace roller. This distance is simply the product of the pace and one-half the number of cables to be kept in the system; this distance is the same on both sides of the adjuster since all half-pace rollers are symmetric. By performing the two most time-consuming operations in a pace change, the concept 1 adjuster reduces the pace-change time from 30-90 minutes to 10-15 minutes.

4.3 Concept Variations

To accomplish the functions described in section 4.2, three approaches are possible, each with its advantages and disadvantages. One approach is to create a hand-held tool that operators can position to perform a pace change and then remove once the change is completed. Another approach is to create a new half-pace roller which also acts as an adjuster when a pace change is necessary; such a roller would change the spacing between the cables and storage units would remove or add cables. The third approach incorporates the adjuster assemblies into the pace area; the adjuster is this case would be separate from the half-pace rollers. The half-pace rollers would hold the cables when the calender is running, while the adjuster would receive the cables from the rollers only to perform a pace change and return the cables to the new half-pace rollers.

Some advantages and disadvantages of each approach are listed in table 4.1. The hand-held device would be too large and heavy to be effectively handled by operators. Although a pace-changing half-pace roller would perform a pace change most quickly, creating such a cylinder would be extremely difficult and expensive. Such a cylinder would have to absorb the constant vibration and wear from the cables. For these reasons, a device built into the calender that picks up the cables from the rollers and then changes the pace is the best choice to pursue; this device is listed in table 4.1 as the lift-and-shift device.

Table 4.1. Main Advantages & Disadvantages of Concept Variations.

	ADVANTAGES	DISADVANTAGES
HAND-HELD DEVICE	1. Operator maintains complete control over alignment. 2. Does not become another part in pace-change area. (does not congest area) 3. Does not experience heavy load from cable tension.	1. Large & Heavy 2. Great chance for serious damage to operator and device if dropped.
LIFT-AND-SHIFT DEVICE	1. No heavy strain placed on operator. 2. A fast procedure. 3. Does not experience wear of sliding cables.	1. Requires several modifications to the structure of the pace change area.
VARIABLE HALF-PACE ROLLER	1. No alignment required, providing easy control to the operator. 2. Fastest of 3 options. 3. Maintains contact with cables at all times. This ensures that cables will not become out-of-pace.	1. Experiences constant wear from moving cables. 2. Must be very large to accept a heavy load and vibration from cables.

4.4 The Pace-Changing Mechanism

Inside the adjuster, a mechanism, called the stack, changes the pace between the cables. Figure 4.2 shows the components that make up the stack; only two unique components make up the stack: the cable block and the elastic element. The function of each cable block is to hold a cable in place, while the elastic elements maintains equal spacing between the cable blocks. The cable block should be designed to accept all three cable types used by the calender. The amount of deflection that the elastic element can experience without plastically deforming determines the amount of the pace change range that the stack can cover.

When a pace change is to be performed, the cable blocks in the stack receive the cables from the half-pace roller. Once the cables are in the blocks, two actuators begin to change the pace. If a greater pace is desired, the two actuators move outward, allowing the entire stack to expand. If a reduced pace is desired, the two actuators move inward, compressing the entire stack. Since each elastic element is identical to the others, equal separation is maintained in both cases. Both cases are shown in figure 4.3.

4.5 Background

Two problems must be addressed for concept 1 to work effectively. The first problem is finding a suitable elastic element that is compact and has a large range of compression; a large compression range is necessary to cover the half-pace separation range of 2.2 mm to 6.3 mm. The second problem is wear. The stack must be held in place by a structure; when a pace change is performed, the elements of the stack slide on the surfaces of the supporting structure. The wear between the sliding surfaces should be kept minimal so that each elastic element displays consistent performance throughout its specified life.

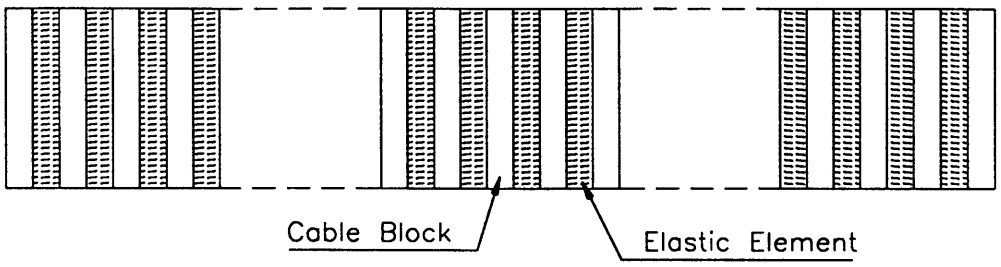

Figure 4.2. The Stack.

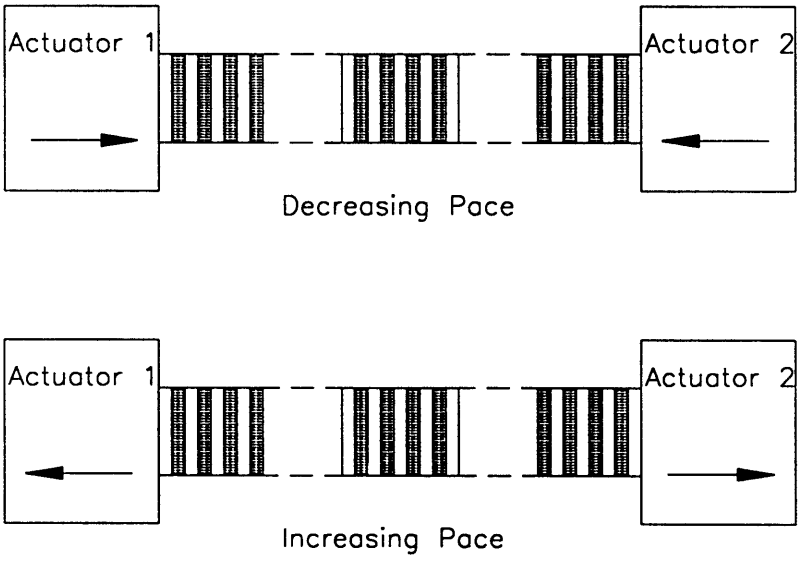

Figure 4.3. Pace Change Using the Stack.

4.5.1 The Elastic Element

From the numerous elastic elements available in the market, a compact elastic element with a large compression range must be chosen. Compression springs available from many manufacturers are too long to fit in the available space and do not compress to achieve the separation of 2.2 mm. However, many other possibilities exist, including bellows, belleville springs, disc springs, rubber sandwiches, and cantilevered springs (Chironis 1961).

Each possibility has its own unique qualities that determine its range of application. For the stack, the best choice for the elastic element is the disc spring. Disc springs are extremely compact and can compress significantly; in addition, by placing the disc springs either in series or parallel, it is possible to achieve various load-deflection characteristics that are predictable.

4.5.2 Wear

The sliding contact between the stack and the supporting structure experiences friction and wear. The most widely accepted theory on wear between two solid surfaces is the adhesion theory (Rabinowicz 1965). According to this theory, the points of contact between the two surfaces stick to one another; as a result, these bonds must be broken when sliding is initiated, leading to deterioration of the surfaces.

Two approaches can be taken to greatly reduce the opposition to motion that results from the adhesive force and the destruction of material that results from wear. One approach is to make one sliding surface of a hard material and the other of a soft material, so that at the points of contact, the harder material will easily break free of the softer material. The second approach is to use a lubricant between the two surfaces to isolate the points of contact between the two sliding elements; the separation created by the lubricant eliminates the possibility of one surface adhering to the other.

4.6 Development of Concept 1

Figure 4.4 shows the layout of the lift and shift system, including the two actuators, the storage unit, the stack, and a back plate. To obtain precise positioning, the two linear actuators are ball-screw drives that are available from many manufacturers. These ball-screw actuators are modules that contain a motor and guides; they have a positioning tolerance to within +/- 0.001".

Disc springs are used to separate the cable blocks in the stack. The disc springs and cable blocks are guided by a shaft. In addition, the springs and blocks are supported by a back plate. The back plate absorbs the load placed on the stack by the tension in the cables; without the back plate, the stack and the shaft would deflect considerably, compromising the performance of the system. To minimize the effects of wear, both the back plate and the guiding shaft are covered with a hard-coat lubricant. The lubricant forms a barrier between the two sliding surfaces making it difficult for adhesion to occur. The solid lubricant coating is very thin and is cleaner than an oil or a grease.

4.7 Reason for Failure

Using available components, concept 1 proves to have a flaw. The problem is one of tolerance buildup. When the concept was first conceived, it was hoped that although the spring constant of the elastic elements would not all be identical, they would be within a tight enough tolerance to match the tolerance specified for the half-pace rollers. If such tight spring constants could be achieved, the independence axiom presented in section 2.2.2 would be satisfied.

Even disc springs, with the most precise and predictable load-deflection curves, differ slightly in the amount of deflection from spring to spring for any specified force input. In the worst case scenario, this variation between the springs can build up to exceed the tolerance specified for the last groove location on the half-pace rollers (+/- 0.05 mm). This variation in springs

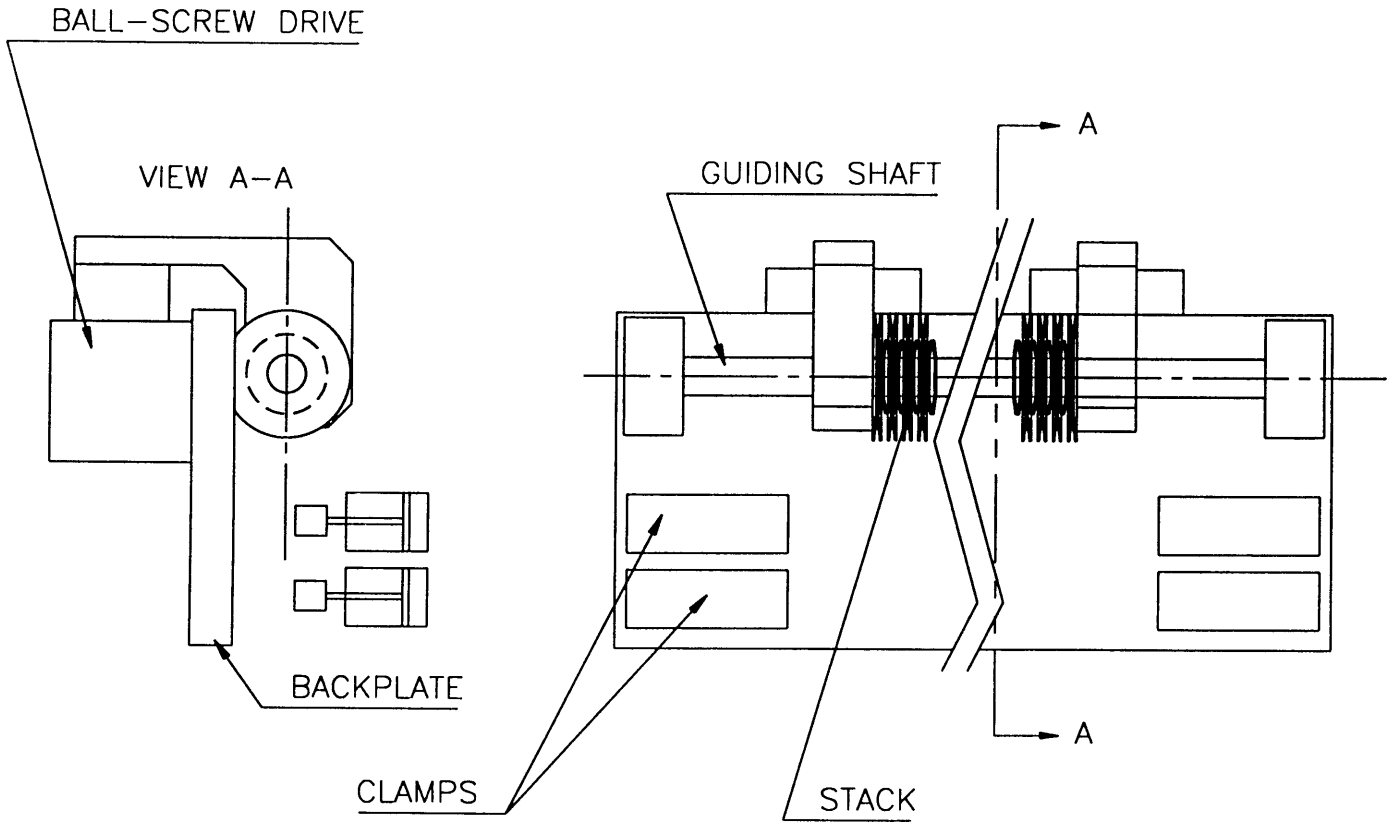

Figure 4.4. Layout of Lift–and–Shift System.

leads to a coupled design. If the springs had turned out to be more precise (within allowable tolerance), the only functional requirement for the adjuster would have been:

FR1: Compress/Expand the Stack.

However, since each spring constant is different (above acceptable tolerance), compression of each spring must be controlled separately; as a result, the number of functional requirements is equal to the number of springs in the stack. In the presented design, only 2 design parameters are available (the 2 linear actuators). Since the number of design parameters available is less than the number of functional requirements, the design is coupled (Suh 1990).

Once a coupled design is identified, two approaches can be taken. One approach is to decouple the design by adding new design parameters; the other approach is to scrap the design and formulate a new set of functional requirements. Since controlling 400 springs independently would be extremely expensive and difficult in the available space constraint, a new set of functional requirements should be created and a new concept sought.

Chapter 5.
Concept 2

5.1 Introduction

In concept 1, the objective is to pickup all the cables at once and change the pace in one quick step. However, the springs in the mechanism can not reliably maintain a constant separation between all cables. To avoid the problems associated with moving all cables at one, the objective of concept 2 is to pickup and move one cable at a time from its position on one half-pace roller to its position on the new half-pace roller.

Concept 2 attempts to duplicate the movements of operators in the existing pace change procedure. Presently, operators place each cable in its proper groove on the half-pace roller. This task involves 3 steps: (1) locating the cable, (2) locating the groove location, and (3) moving the cable into the groove location. To automate these steps requires a multifunctional manipulator that can be programmed to perform a pace change properly depending on the pace and number of cables. A multifunctional and reprogrammable manipulator, or a robot, can perform dull, repetitive operations more quickly than human workers (Ullrich 1983). Since the present tasks of placing cables into grooves and of moving cables not needed into storage are highly repetitive and mathematically definable, a robot is well suited for this application.

A robot has several advantages over a human operator that allow the robot to complete repetitive tasks more quickly. Often, during a pace change, operators become tired when moving numerous cables; such a problem will not arise with a robot. In addition, a robot's cycle time, or time needed to move each cable, is dependent on components used and the movements those components perform. As a result, the time involved to move each cable is predictable and consistent throughout the pace change process. Finally, a robot allows operators to perform other necessary tasks while it moves cables; such parallel operations further reduce the pace change time.

To create such a robot and to allow it to perform effectively, all components in the pace change area must be analyzed and designed to meet requirements placed by a robot. Unlike a human operator who can easily adjust to changes such as varying locations of cables, a robot in this case would have to be programmed to pickup and place cables at precise locations. If the cables are not where they are expected by the robot, pickup of the correct cable would not occur. This chapter describes the development of the robot and the pace change area.

5.2 Design Layout

Shown in figure 5.1 is the side view of the pace change area for concept 2 with main subassemblies labeled; in figure 5.2 is given the top view of the half-pace subassembly, which sets the pace and the number of cables. This concept includes new guide-box assembly that is more compact and more suitable to following the movements made by the robot. Throughout this chapter, this robot which moves cables will be called an adjuster.

In figure 5.1 is shown two levels of half-pace rollers; when the calender is producing product, one set is forward in the active position with cables in its grooves. The other set is back in the change position where half-pace rollers can be replaced with rollers needed for the next pace change. The two sets perform an essential function in this design. In the existing pace change area, when a new half-pace roller is brought into position by rotating the turret (see figure 1.2), cables are released from the old roller and then come into contact with the new roller. When this occurs, the cables move from their groove locations; as a result, the precise location of each cable becomes unknown. An operator has little problem with finding cables in such a situation; however, even robots designed with elaborate sensory systems would have great difficulty locating these cables. Using two levels of half-pace rollers solves this problem. With the cables in the grooves of active half-pace rollers, the new set of half-pace rollers can be brought forward with the

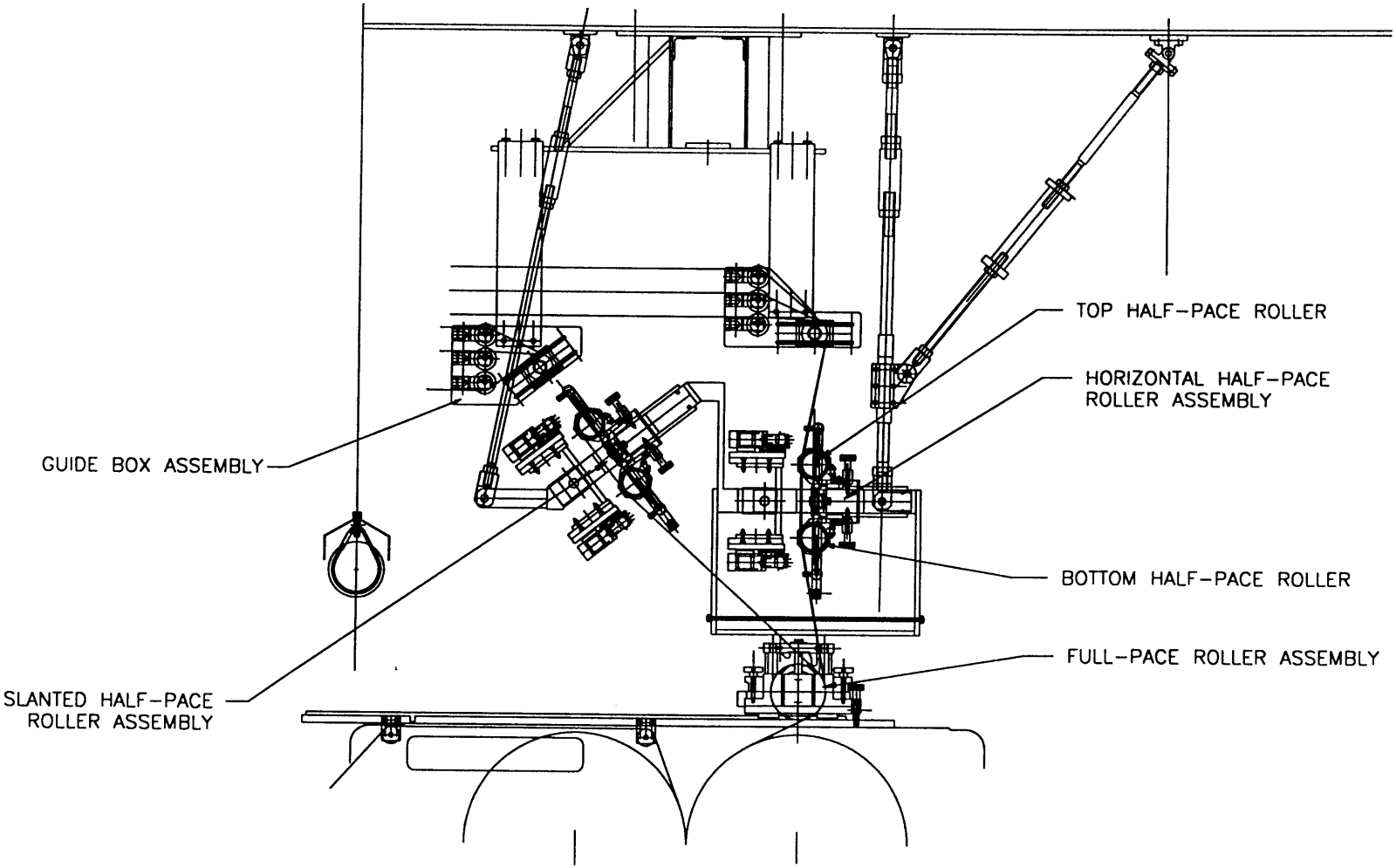

Figure 5.1. Concept 2 Area Layout.

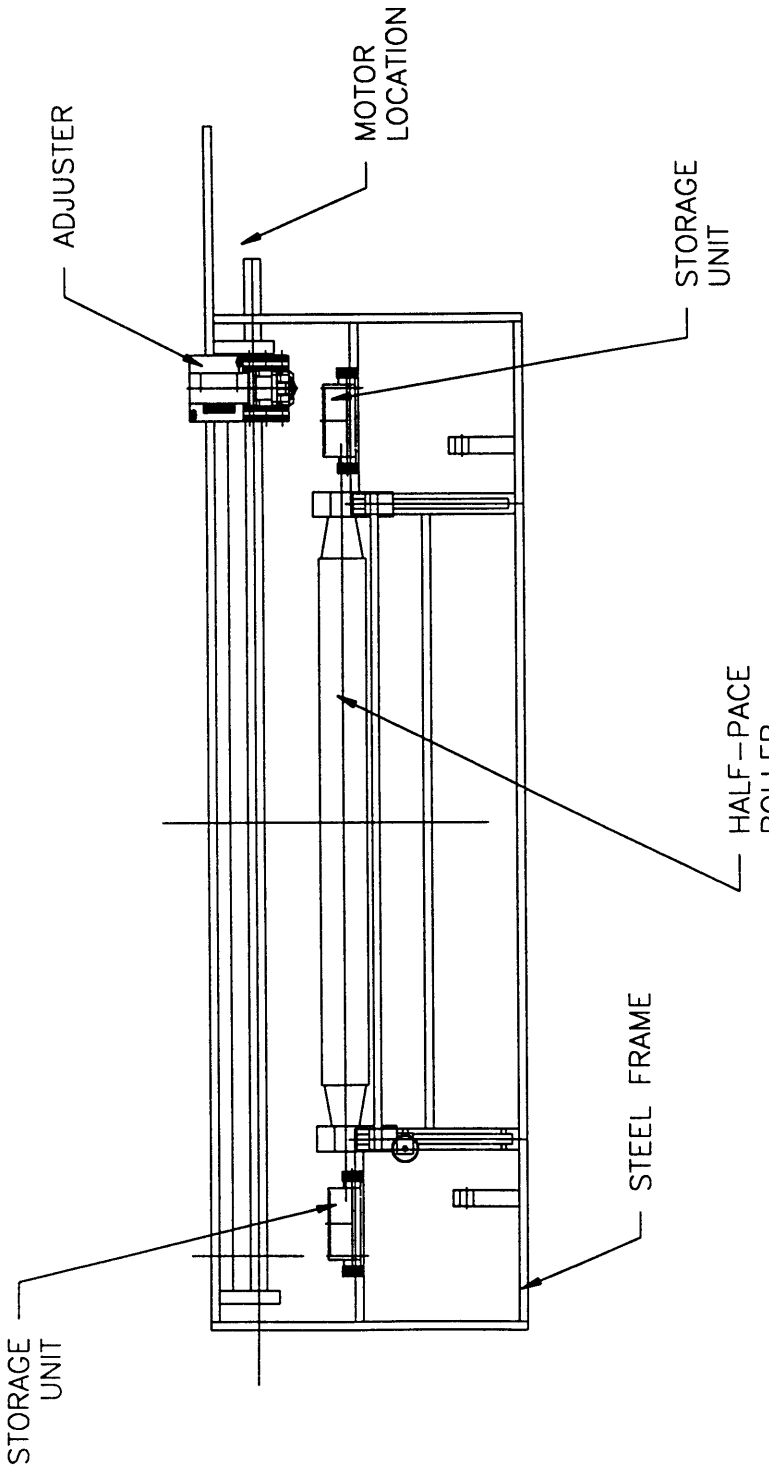

Figure 5.2. Top View of Half-Pace Subassembly

calender stopped. When both sets are in their active positions, the cables are in the grooves of the old half-pace roller and simply resting on the surface of the new rollers. The old set maintains a "memory" of the cable locations and the new set provides the groove locations to which the cables are to be moved. The "memory" maintained by the old set allows the adjuster to easily locate the cables to be moved.

In the half-pace assembly shown in figure 5.1, one half-pace roller subassembly is horizontal with respect to the shop floor while the other is angled at 38 degrees. This slant is the result of the angle created by the cables between the guide boxes and the full-pace roller. For the horizontal subassembly, the cable angle is not nearly as extreme as that of the slanted subassembly. If both subassemblies were kept horizontal, the two subassemblies would require unique designs to meet different requirements. However, with the slant, both units become identical, permitting the same adjuster design. Having the same design for both units allows the use of the same operating procedure for both subassemblies. In addition, the number of spare parts that must be stocked is reduced significantly.

5.3 Pace Change Procedure

In this section, a description of the procedure to accomplish a pace change for concept 2 is given. In figure 5.3, components discussed in the procedure are labeled.

When a pace change is to be performed, new half-pace rollers are placed into the half-pace roller change positions and a full-pace roller is brought from storage into the temporary storage tray. The storage tray provides two locations to store full-pace rollers at the pace change area. In addition, the operators initialize the adjuster by providing it with information about the pace change, including the starting and ending pace, the starting and ending number of cables, and if the new set of half-pace rollers are on the top or the bottom level. Once the operators have obtained

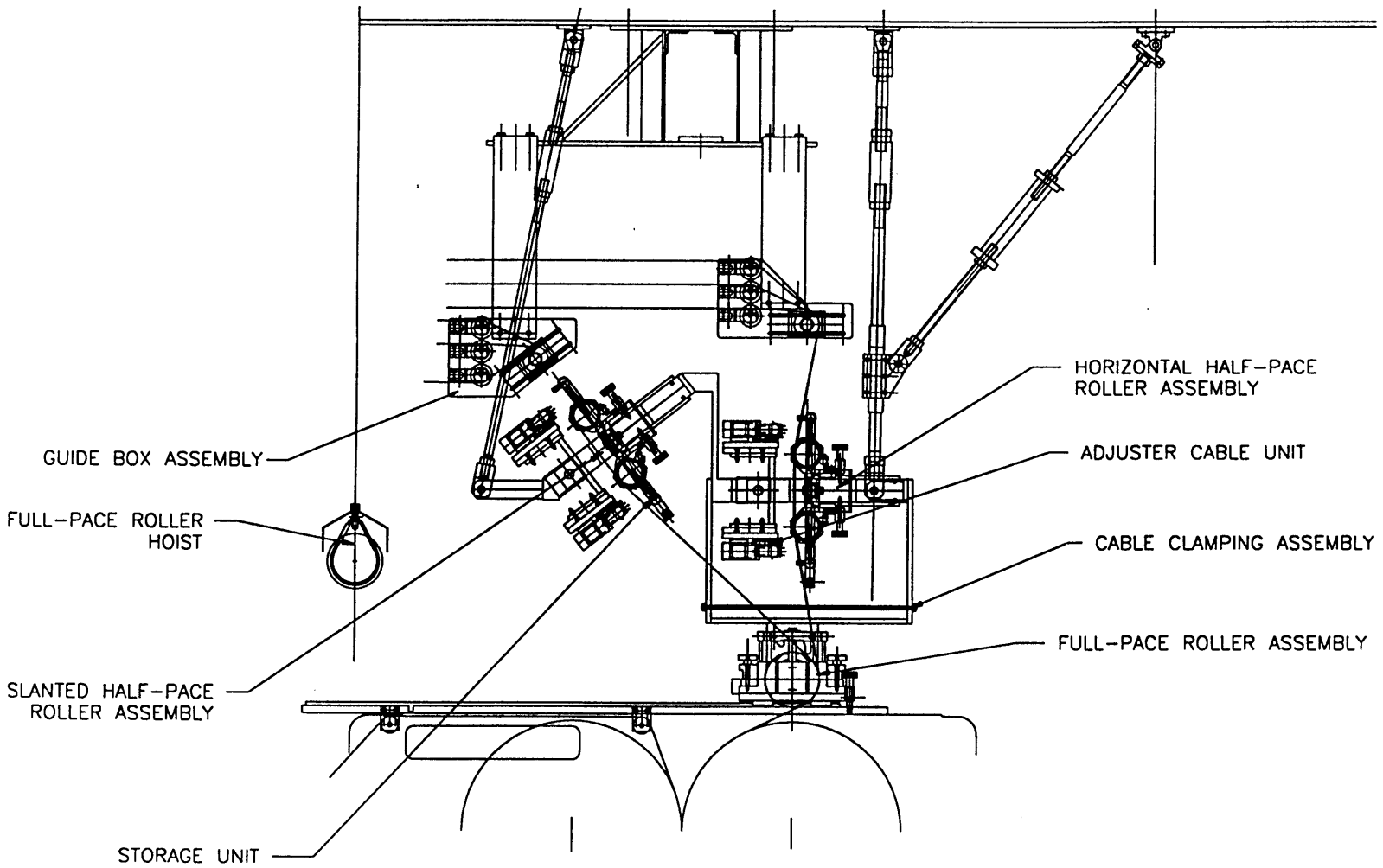

Figure 5.3. Components of Concept 2.

all the necessary tooling (clamps, combs, etc.), the calender is stopped to perform the changeover.

In the changeover process, the new set of half-pace rollers are brought forward into their active positions. Then, as described in section 5.2, the adjuster moves the cables from the grooves on the old half-pace roller to those on the new half-pace roller. Also, the adjuster moves cables to and from the storage units shown in figure 5.2 as needed.

While the adjuster performs, the operators clamp the cables in place near the full-pace roller so that the full-pace roller assembly can be moved to its change position beneath the hoist. Here, the full-pace roller is replaced by moving the old roller to the storage tray with the hoist and then moving the new roller from the storage tray to the full-pace roller assembly. Once securely in place, the new full-pace roller is moved forward into its active position.

Once the adjuster has completed moving all cables as necessary, operators deal with cables moved to or from storage units. If cables were moved to a storage unit, the operator uses a pair of scissors to cut those cables from the rubber product and attach them to the tie rod. If cables were moved from the storage units, operators release those cables from the tie rod and fasten them to cables already running into the rubber tissue. By running the calender slowly, the fastened cables are pulled into the rubber tissue. Before running the calender, however, the clamps holding the cables are released.

Next, the old set of half-pace rollers are moved to their change positions, leaving the cables in the grooves of the new set of half-pace rollers. Finally, the cables can be combed into the full-pace roller from the half-pace rollers. Once completed, the calender can start to produce product at the new pace.

5.4 Concept Development

5.4.1 Special Component Requirements

Concept 2 places new functional requirements on the guide box assembly that creates the path for cables from the block creel to the pace change area. The existing guide boxes, shown in figure 1.2, also determine the angles at which the cables enter into the grooves of the half-pace rollers. In concept 2, the guide boxes must be more compact to fit in the space that will provide the necessary cable angles. The guide boxes, each of which holds up to 15 cables, must also be able to follow the movement of cables made by the adjuster; for example, if cables in a certain guide box were moved to the storage area by the adjuster, the angle created by the cables in tension should force that guide box to move in the direction of the storage unit to reduce the angle generated in the cables. Finally, the angles of all cables leaving each guide box assembly and entering the half-pace rollers should be the same. Presently, each guide box assembly contains 3 levels of guide boxes as shown in figure 1.2; each level of cables creates its own angle with the half-pace rollers, making it very difficult for the adjuster to pickup cables.

The storage unit for cables not needed at a given pace has several requirements. The storage unit must provide the adjuster with access to deliver cables and to pickup cables. For cables to enter the storage unit properly, cables delivered by the adjuster must run parallel with the grooves in the storage unit. For the adjuster to pickup cables from the storage unit, the storage unit must make the cables parallel to the adjuster. In either case, if the cables were at an angle, neither the adjuster nor the storage unit would be able to accept cables. Finally, the storage unit must maintain the cables at locations "known" to the adjuster, so that when cables are to be removed from storage, the adjuster can locate these cables.

5.4.2 Component Designs

Although numerous design changes are made to the pace change area to incorporate the ideas developed for concept 2, in this section is given only the design of the most critical components: (1) the adjuster assembly, (2) the storage units, and (3) the guide box assembly. Other changes to the area are

discussed in chapter 6 with concept 3.

5.4.2.1 Adjuster Assembly

In figure 5.4 appears the top view of the adjuster assembly. The adjuster performs several functions that are necessary to properly set the pace and number of cables in the half-pace rollers. One requirement of the adjuster is to locate precisely the center of each half-pace roller. Since the grooves on the rollers are dimensioned and toleranced from roller centers, the location of the centers is essential to properly locating cable pickup and drop-off points. Secondly, the adjuster moves cables from pickup to drop-off points on the rollers. This step needs to be accomplished very quickly for each cable since the amount of time the adjuster consumes is the sum of the amount of time to move each cable; in this application, the addition of even a fraction of a second to move each cable adds minutes to the downtime of the calender. Finally, the adjuster moves cables to and from the storage units as needed in each changeover.

The adjuster is shown in figure 5.2 in relation to the half-pace rollers and the storage units. The adjuster is made up of 5 main components: 1 linear actuator, 2 photoelectric sensors, 1 cable unit, and 1 magnetic linear encoder. The linear actuator presented in figure 5.4 is similar to a ball-screw actuator; by turning the shaft with a motor, the cable unit is moved along the length of the shaft. However, unlike the ball-screw actuator, the linear actuator used contains no threads on the shaft; the provided block that travels along the shaft is held to the shaft by a special arrangement of bearings. These actuators are rated at maximum speeds that are much greater than those of ball-screw actuators. In addition, the linear actuator in the design requires only a small fraction of the time required by ball-screw or belt-driven drives to accelerate and decelerate.

One photoelectric sensor determines the location of the top half-pace roller while the other sensor establishes the location of the bottom half-pace roller. Both rollers have a black line at a known distance from its center; by

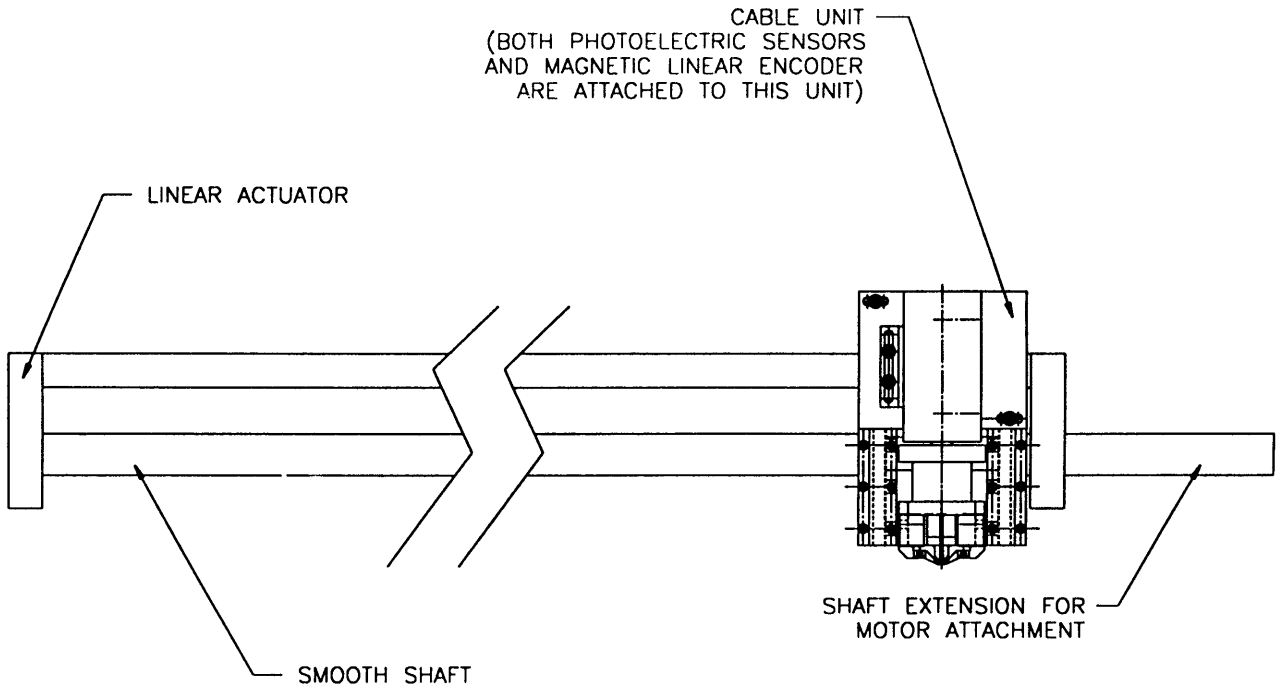

Figure 5.4. Adjuster Assembly.

sensing this line, the center point of the roller can be computed. The magnetic linear encoder provides the closed-loop position feedback that is necessary to precisely position the cable unit.

The cable unit, shown in figure 5.5, travels with the linear actuator; the function of the cable unit is to pickup and release cables. The cable unit grabs onto a cable at two points so that in between theses two points the cable will remain parallel. By keeping the cable parallel in this region, the cable unit can properly insert the cable into a groove on a roller or on a storage unit. To pickup the cable at each of these points requires two actuators, a pneumatic cylinder and a pneumatic gripper. The pneumatic cylinder thrusts the gripper forward to reach the cable. Then, the gripper closes its "fingers" around the cable.

To move a cable from one location to another, the following sequence of steps occur in the adjuster. The linear actuator moves the cable unit to the pickup location. The pneumatic cylinders move the two grippers forward, allowing the grippers to lock onto the cable. Then, the cylinders retract, pulling the cable away from the roller. The linear actuator moves the cable unit to the correct groove location of the other roller. Once at the drop-off location, the cylinder moves the gripper forward once more. The gripper opens its fingers; the fingers are designed to allow the tension in the cable to easily pull the cable out of the gripper and into the groove. Finally, the cylinder retracts and the next cycle can begin.

5.4.2.2 Storage Unit

Shown in figure 5.6 is the design for the storage unit utilized to hold extra cables until they are needed in a half-pace roller. Each of these storage units can hold up to 50 cables; when each cable is brought to the unit by the adjuster, the cable enters two grooves. Both grooves are located between the two points on the cable unit in which the cable is held. Only in this region can a cable properly enter a groove. Outside this region, the cable forms an angle that will not allow it to move across the groove openings.

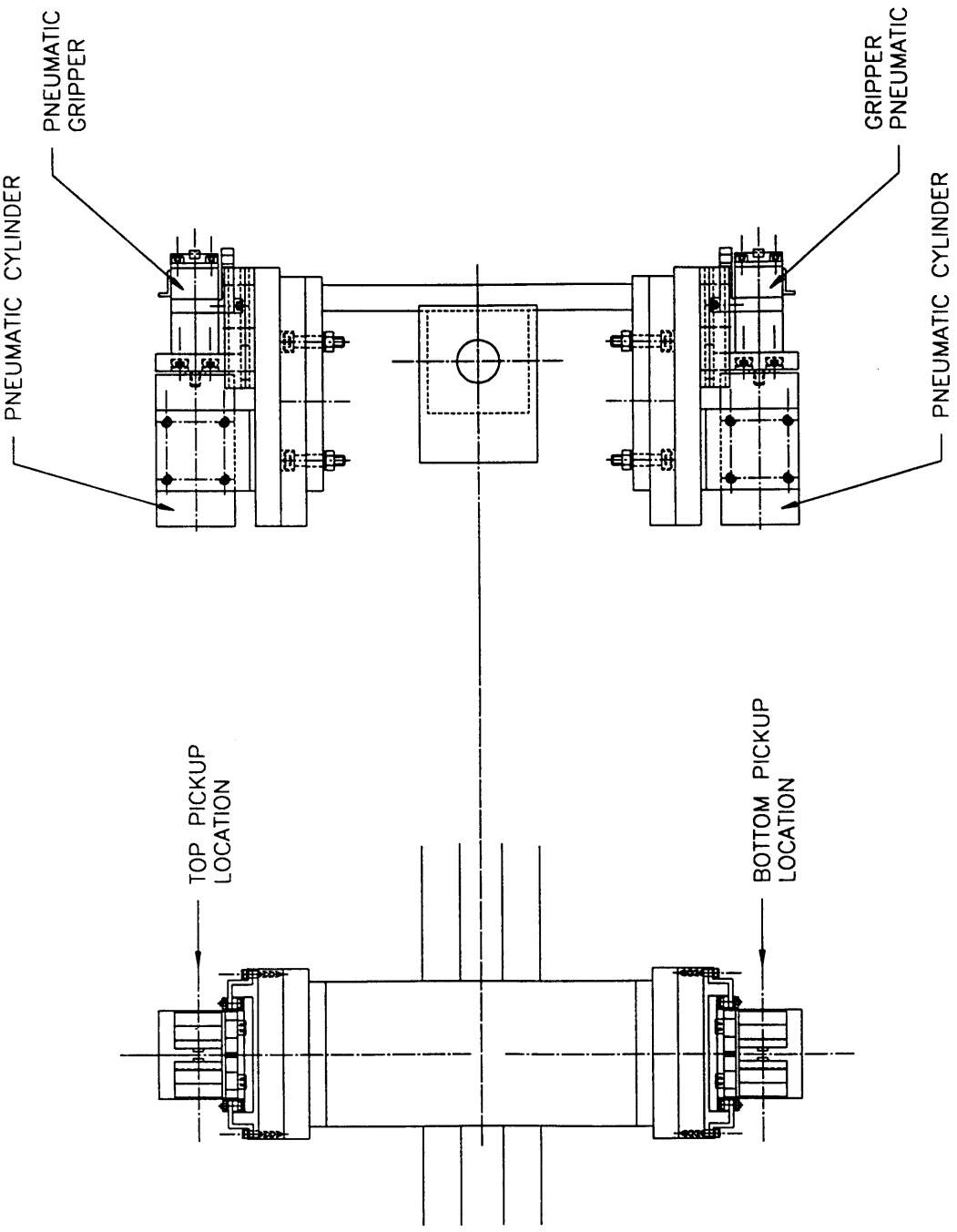

Figure 5.5. Cable Unit.

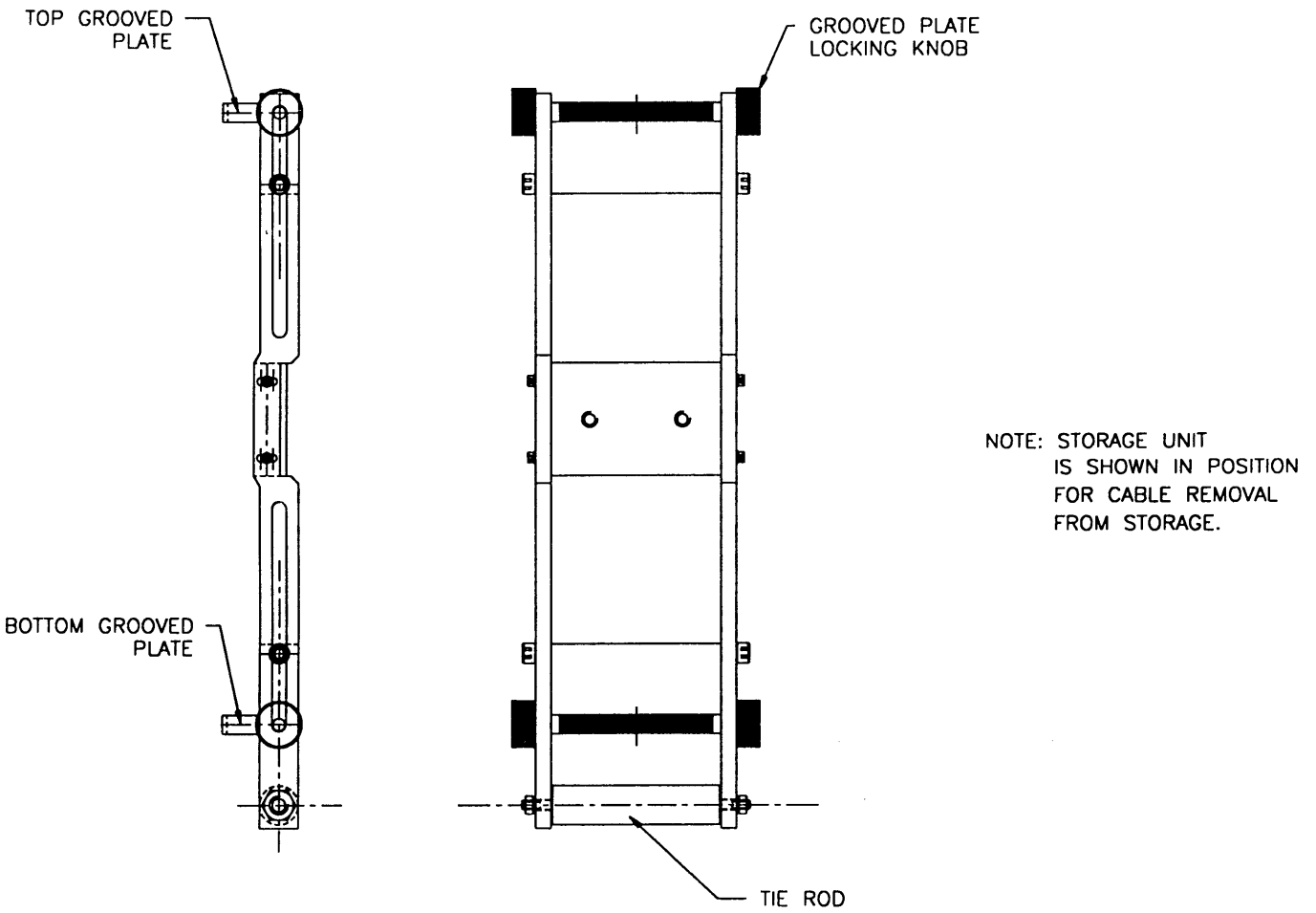

Figure 5.6. Storage Unit.

When cable is to be removed from the storage unit by the adjuster, the same situation must arise in the reverse direction. The adjuster must collect a cable from storage between the two groove locations. However, having the adjuster change its two pickup points each time it moves a cable from a storage unit to a half-pace roller would lead to a slow, complicated mechanism. However, if the groove locations change to lengthen the range beyond the two adjuster pickup points, the adjuster would not have to change at all. Before the calender is stopped for a pace change, the two groove locations are changed by the operators when the new half-pace rollers require a greater number of cables than the rollers they are replacing. To accomplish this task, operators simply loosen the two knobs locking each grooved plate of a storage unit in place and move the two plates away from one another, lengthening the range in which the cables are parallel. When cables are to be brought to the storage unit in a later changeover, the grooved plates are returned to their initial positions. This design allows the change to be made while the calender is running and requires the change to be done only once per product changeover.

5.4.2.3 Guide Box Assembly

The design for the guide box assembly displayed in figure 5.7 meets all of the functional requirements discussed in section 5.4.1. Cables from the block creel enter guide boxes that are miniature versions of the existing guide boxes on the calender. However, unlike the existing guide boxes that are all simply supported by a shaft, the new guide boxes are free to travel along the length of a linear guide. Each guide box is fixed on its own sliding block so that it can travel independently of the other guide boxes on the same slide. These linear guides and blocks are inexpensive and readily available from manufacturers. In addition to the low friction that permits easy travel between the blocks and the slide, each slide is rated to carry high loads, making it suitable to support the force exerted by the tension in the cables.

Also included in the guide box assembly is a mechanism called an

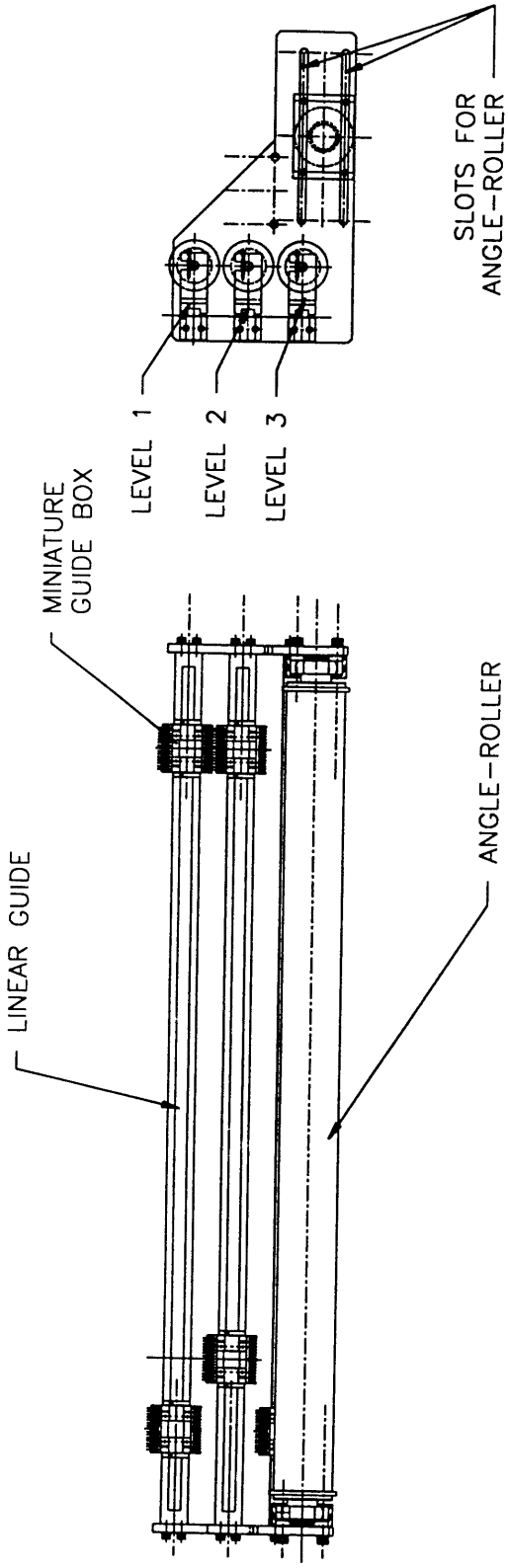

Figure 5.7. Guide Box Assembly.

angle-roller. The function of the angle-roller is to ensure that all cables leaving the guide box assembly are at the same angle before entering the half-pace roller. The angle-roller spans the entire length of the assembly and supports the cables in tension. The location of the angle-roller is adjustable at its ends so that desired cable angle can be obtained.

5.5 Control Layout

The components in figure 5.8 form the "brain" of the adjuster by controlling the pneumatic and mechanical actuators that perform the pace change. The linear actuator of the adjuster is connected to an AC-servo motor. The motion controller which contains the algorithm for performing a pace change prompts the operators for initial information about the pace change and obtains closed-loop feedback from the linear encoders and the photoelectric sensors. The motion controller uses these initial inputs and outputs from the feedback devices to properly actuate the pneumatic control valves that direct air flow to the pneumatic cylinders and grippers and to instruct the motor drives that formulate the velocity profiles for each desired move of the linear actuators.

5.6 Conclusions

A primary consideration in this project is total time required to accomplish a pace change. For concept 2, the total time is greatly influenced by the adjuster's cycle time, or time consumed in moving 1 cable. The components in the adjuster have clear performance characteristics provided by the manufacturers. From these specifications, an estimate of time necessary to perform each movement can be made. Combining the sum of these estimates with estimates of processing time leads to a total cycle time of 1.5 seconds. Moving the maximum 360 cables for each half-pace roller would require a total time of 540 seconds (9 minutes). The total pace change time also includes the time required for the operators to perform the other steps

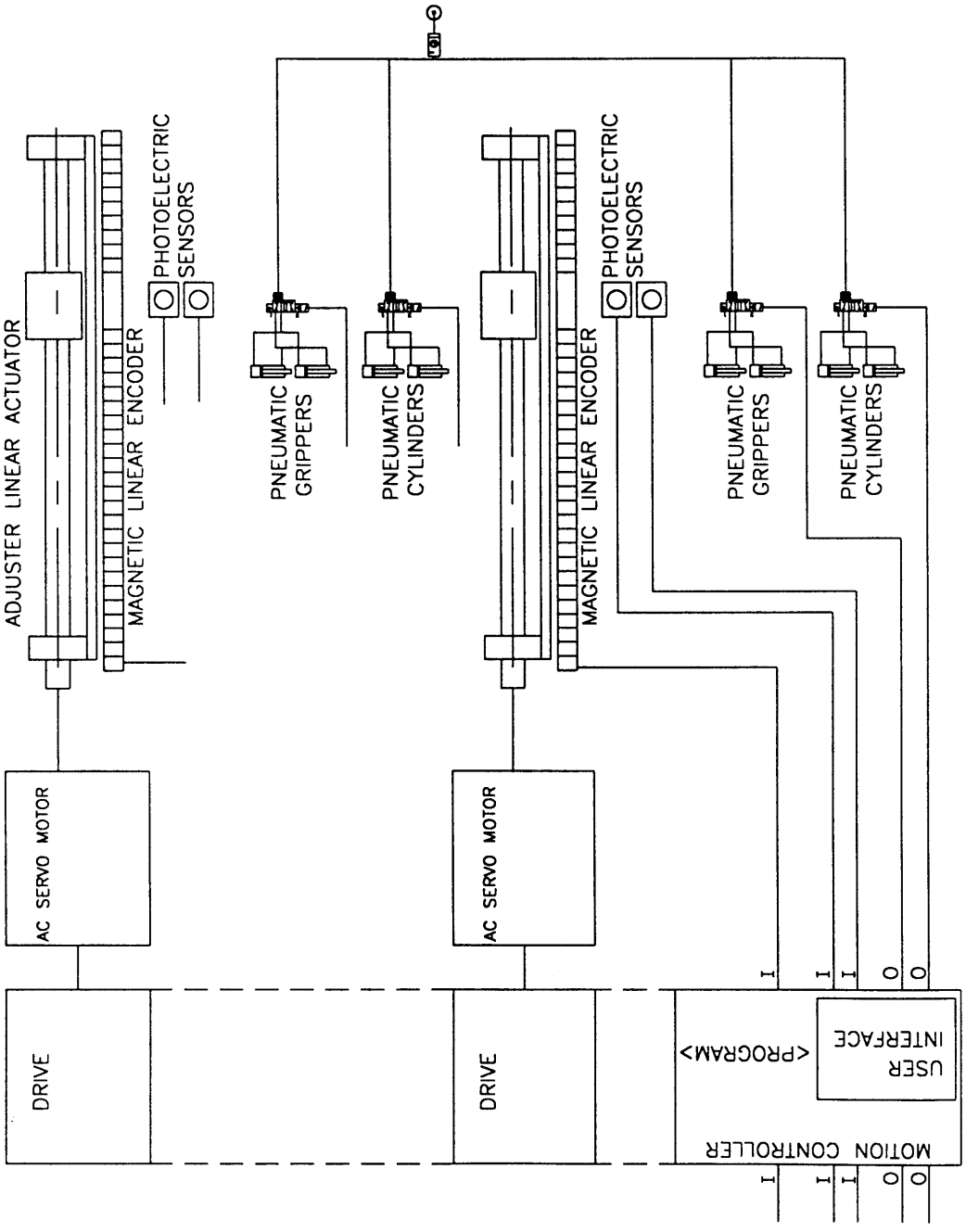

Figure 5.8. Control System Layout for Both Adjusters.

discussed in section 5.3. For concept 2, the total changeover time would range from 15 to 20 minutes, a dramatic improvement from the present changeover time: 30 to 90 minutes.

Concept 2 succeeds in avoiding the tolerance buildup problem of concept 1 by moving one cable at a time. However, the design of concept 2 led to numerous modifications of the pace change area, as can be seen from figure 5.1. These modifications and additions make the incorporation of concept 2 expensive. Nevertheless, the significant reduction in changeover time on such a critical machine may be worth this expense.

Chapter 6.
Concept 3

6.1 Introduction

To accomplish a pace change quickly, concept 3 provides an alternative approach to concept 2. Concept 3 attempts to combine the ideas developed in both concepts 1 and 2. In concept 1, the goal is to pickup all cables at once and change the pace between all of these cables in one motion. In concept 2, the goal is to pickup one cable at a time and to move it to its position on the new half-pace roller. In concept 3, the objective is to pickup all cables at once, but to move cables one at a time to their new positions.

Although concept 2 succeeds in significantly reducing pace change time, merging ideas of concept 2 with those of concept 1 takes advantage of the desirable qualities of both while eliminating some of the negative characteristics. Concept 1 fails because of the inconsistent performance of springs in the stack; nevertheless, subassemblies of this concept require far less physical space than those of concept 2. It is the movement of one cable at a time that makes concept 2 succeed; however, concept 2 adds numerous components to the pace change area and requires modification of several existing assemblies. Concept 3 attempts to achieve the compactness and simplicity of concept 1, while utilizing the successful idea of repositioning one cable at a time determined in concept 2.

6.2 Design Layout

Figure 6.1 shows the side view of the pace change area with the incorporation of concept 3 assemblies. It is clear from the figure that concept 3 requires fewer assemblies than does concept 2, providing greater access to the area while reducing the number of assemblies that need to be kept as spare parts.

Many of the components in concept 3 are the same as those in concept 2; however, the critical components that change the pace and number of

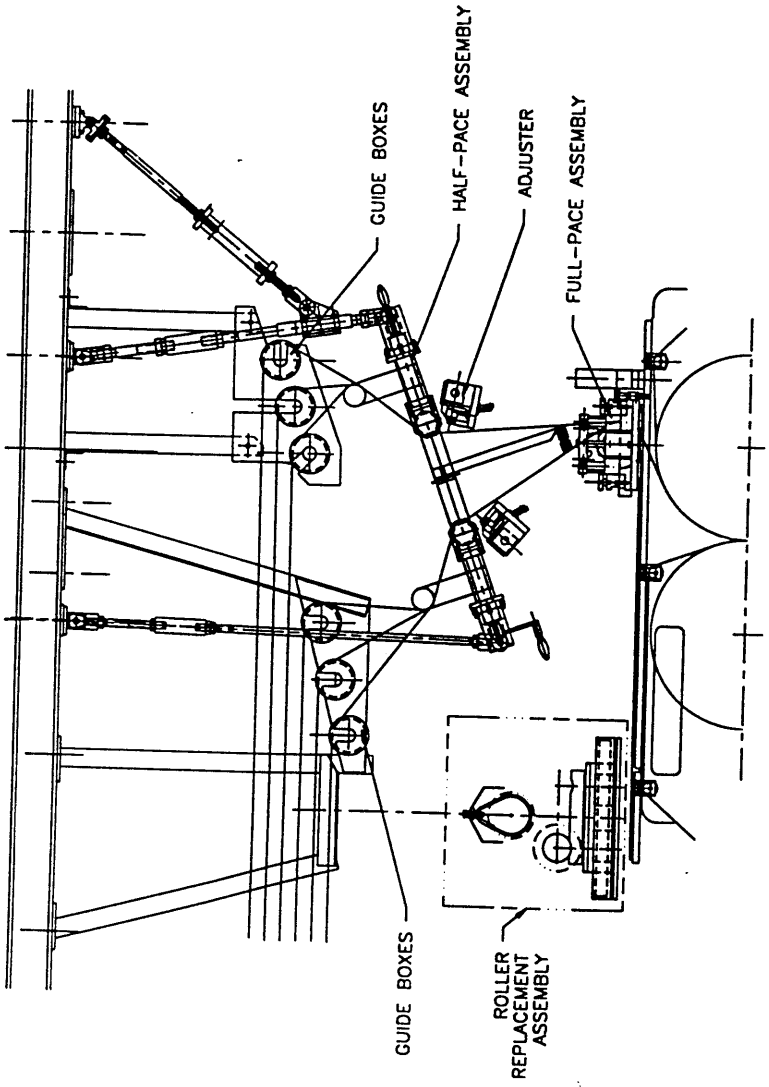

Figure 6.1. Main Assemblies of Concept 3.

cables are different. Labeled in the figure are the main assemblies: (1) the adjuster, (2) the half-pace assembly, (3) the full-pace assembly, (4) the roller replacement assembly, and (5) the guide boxes. The functions of the adjuster in concept 3 are to change the pace between cables and to move unnecessary cables into storage. The adjuster accepts the cables from the half-pace roller, changes the pace between the cables, and then allows cables to be picked up by the new half-pace roller.

The half-pace assembly contains the two half-pace rollers. By turning a crank on this assembly, operators can move each half-pace roller to its change position. The full-pace assembly holds the full-pace roller in place by applying a force at the two ends of the roller with pneumatic cylinders. In addition, the full-pace assembly slides on two parallel tracks to the full-pace replacement assembly. The roller replacement assembly includes two components, the hoist and a temporary storage tray. The hoist moves the old roller to the tray and then moves the new roller to the full-pace assembly from the tray.

Finally, as shown in figure 6.1, the guide boxes used in this concept are the same as those that already exist on the calender. The guide boxes are simply moved to new positions. Unlike concept 2, concept 3 does not need the guide boxes to closely follow the movements of the adjuster. As a result, the design described in chapter 5 is unnecessary for concept 3.

6.3 Pace Change Procedure

In this section, the procedure for a pace change in concept 3 is given. A discussion of how each mechanism mentioned performs its function is provided in section 6.4.

Before the calender is stopped to perform a pace change, the operators complete the following tasks. First, the operators move the new full-pace roller to the temporary storage tray using the hoist. Second, the operators acquire the necessary tooling to perform the pace change, including combs,

half-pace rollers, and a pair of scissors. Finally, the operators initialize the adjuster by providing it with necessary information about the pace change, including the new pace and the new number of cables.

Once the above tasks are completed, the operators stop the calender and begin the pace change. Operators turn two cranks on the half-pace assembly to slowly move the rollers into their change positions as shown in figure 6.2. As the rollers move toward their change positions, the adjusters pickup the cables in the region between the half-pace and full-pace rollers. In this region, the cables are parallel and are at the pace set in the previous pace change. As a result, the cables are received by the adjuster at these known positions.

With the cables securely in the adjusters, operators must decouple the full-pace roller assembly from the cables. In order to be able to move the full-pace roller assembly to its change position underneath the hoist, the cables that are held in tension against the full-pace roller must be held in place. To do this, operators slide a bar between the cables and the full-pace roller; they then clamp this bar in place. This cable-holding bar maintains the position of the cables, allowing the full-pace roller to be released and exchanged.

After the full-pace roller assembly is moved to its change position, two parallel procedures are initiated. The adjusters begin to change the pace between the cables, adding or subtracting cables from storage as necessary. At the same time, operators replace the full-pace roller. First, the old roller is moved to the storage tray with the hoist. Then, the hoist is used to move the new roller from the storage tray to the full-pace roller assembly. Finally, the assembly is moved back into its active position and clamped in place.

Once the adjuster completes its function of changing the pace, the cable-holding bar is removed so that cables are once again forced against the full-pace roller. Operators comb the cables from the two adjusters onto the half-pace rollers as the cranks are rotated to bring the half-pace rollers to their active positions. With the cables in the grooves of the half-pace rollers, operators comb the cables onto the full-pace roller and jog the calender

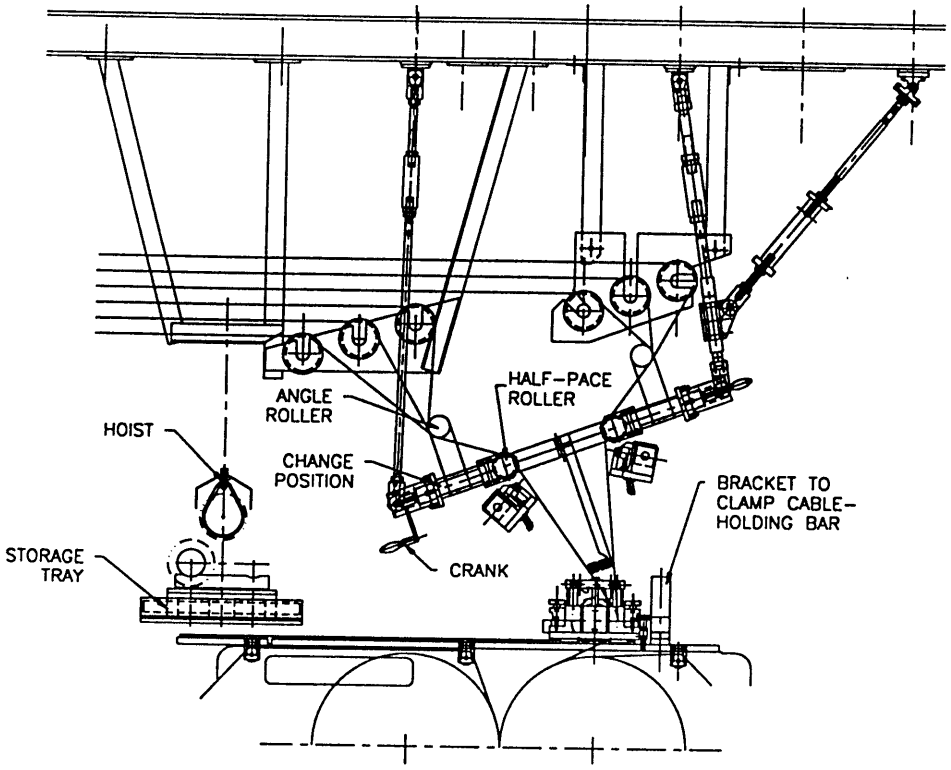

Figure 6.2. Some Parts of Pace Change Area.

forward to allow cables to enter the grooves. Finally, the calender is restarted to produce product at the new pace.

6.4 Component Designs

In this section, the designs of the main assemblies for the pace change area are described. With these designs is described how these assemblies perform the functions noted in section 6.3.

6.4.1 Adjuster Assembly

The concept 3 adjuster completes the two main tasks involved with a pace change in one unit. The adjuster moves cables to the pace needed and moves cables to and from storage as required. Each cable is positioned within the adjuster in its own grooved steel holder; these steel holders are called cable blocks throughout this chapter.

A typical cable block is shown in figure 6.3; each cable block consists of 3 parts: a grooved unit, a disc spring, and a hex nut. The cable block grips the two surfaces of a slot as shown in figure 6.4. When the cable block is first assembled in the slot, the nut is rotated until the compressed disc spring exerts a force of 50 newtons. The spring exerts the 50 N on the nut and on the interior wall as shown. The load on the nut leads to two results. First, the load on the nut keeps the nut from rotating once the cable block is assembled. Second, the nut forces the grooved unit of the cable block onto the exterior wall by pulling against the thread of the unit.

The exterior and interior walls onto which the cable block grips have different properties. The exterior wall is made of steel; the static coefficient of friction between the steel cable block and this wall is approximately 0.8. The interior wall is coated with a dry-film lubricant; the static coefficient of friction between the disc spring and this lubricated surface is expected to be approximately 0.1. A dry-film lubricant is used to achieve the low coefficient instead of oils or greases for two reasons. The dry-film lubricant is described by the manufacturer to be permanent; this quality allows a long interval of

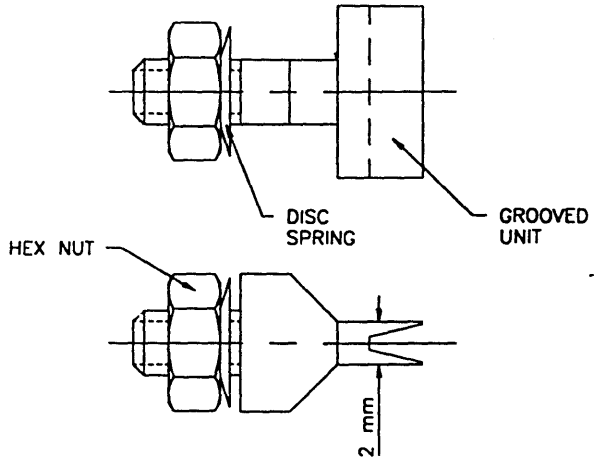

Figure 6.3. Typical Cable Block.

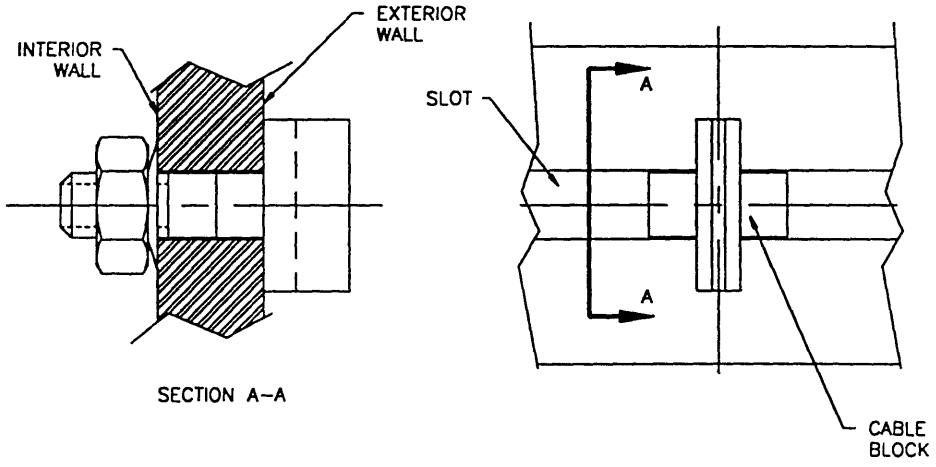

Figure 6.4. Cable Block in Slot.

time before a new coat of lubricant needs to be applied. In addition, unlike oils and greases, the dry-film lubricant will not easily spread onto the cable blocks or onto other surfaces. A grease or an oil could contaminate the exterior wall, compromising the high frictional coefficient that is desired.

To move a cable block from one location along the length of the slot to another, only a few short operations are necessary. When a force of greater than 50 newtons is applied to the end of the cable block, the disc spring compresses further, exerting a greater normal force against the interior wall. At the same time, the cable block lifts off of the exterior wall. The force is applied to the cable by a steel bar, resulting in a static coefficient of friction between the cable block and the steel bar of approximately 0.8. The steel bar slides the cable block on the low-friction interior wall to its new position. The cable block will not slip against the steel bar surface because the greater frictional force at this junction. Figure 6.5 displays how a cable block is moved.

Once the cable block reaches its new position along the slot, the steel bar releases the cable block. The cable block once again engages with the high-friction exterior wall; this locks the block in place. The high friction maintains the position of the cable block, making it not susceptible to the force exerted by the cable.

For each cable in the half-pace rollers, a separate cable block is needed to receive the cable and to move the cable to its new position. Cable spacing can range from 2.2 mm to 6.3 mm; this means that each cable block can not exceed a width of 2.2 mm. However, such a small block can not be created for two reasons. First, no disc spring is available at that width. Second, such a thin cable block would not be strong enough to carry the forces exerted on it. To solve this problem, 3 slots are used. The 3 slots run parallel and their centerlines are separated by 9 mm.

With the multiple slots, greater widths for the cable blocks can be used. The grooved portion of the cable block that protrudes from the exterior wall

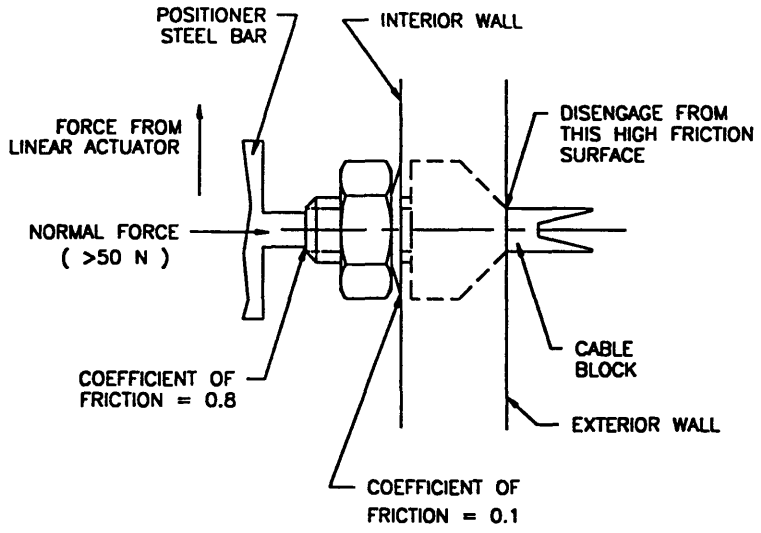

Figure 6.5. Moving a Cable Block.

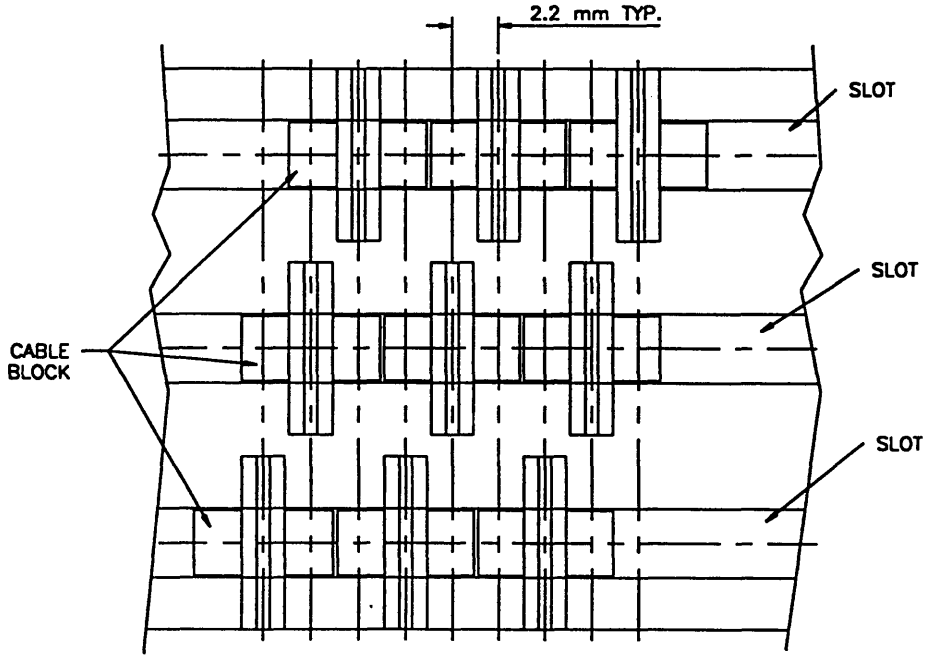

Figure 6.6. Overlapping Cable Blocks at 2.2 mm Spacing.

which receives the cable is the only portion of the block that must now be less that 2.2 mm. The rest of the cable block can be as wide as 6.6 mm. At a short cable spacing, say 2.2 mm, the grooved portions of the cable blocks, designed with a width of 2 mm, are only separated by 0.2 mm. The rest of the cable block can afford to be wider than 2.2 mm because the two blocks adjacent to it are in the other 2 slots, making it possible for the blocks to overlap along the length of the adjuster without coming into contact. Figure 6.6 shows the positioning of the cable blocks that allows them to overlap as described. Having multiple slot levels is the key idea that makes this concept possible.

The adjuster assembly is shown in figure 6.7. In this assembly are five main components: (1) a linear actuator, (2) a positioner, (3) a cable block unit, (4) a linear guide, and (5) a magnetic linear encoder. The linear actuator moves the positioner along the length of the adjuster. A servo motor rotates the shaft of the linear actuator, forcing the actuator's block to travel along the shaft. This actuator's block is connected with a bracket to the linear guide; between the bracket and the block is inserted a rubber sheet to allow some misalignment and to help isolate any vibration of the linear actuator. The positioner is connected to the guide using the same bracket. The function of the positioner is to move cable blocks from one position to another as described above. Also attached to the bracket is the reading head of the magnetic linear encoder. The linear scale spans the entire length of the adjuster allowing the reading head to provide closed-loop position feedback of the positioner location to the motion controller that instructs the servo motor. The linear guide firmly holds the positioner and reading head in place, only permitting motion along the length of the adjuster. Finally, the cable block unit contains the cable blocks in a frame with 3 slots as described above.

The positioner is shown in figure 6.8. This mechanism contains 2 pneumatic cylinders that thrust the steel bar forward and backward. The steel bar engages with a cable block when it is thrust forward so that the cable block

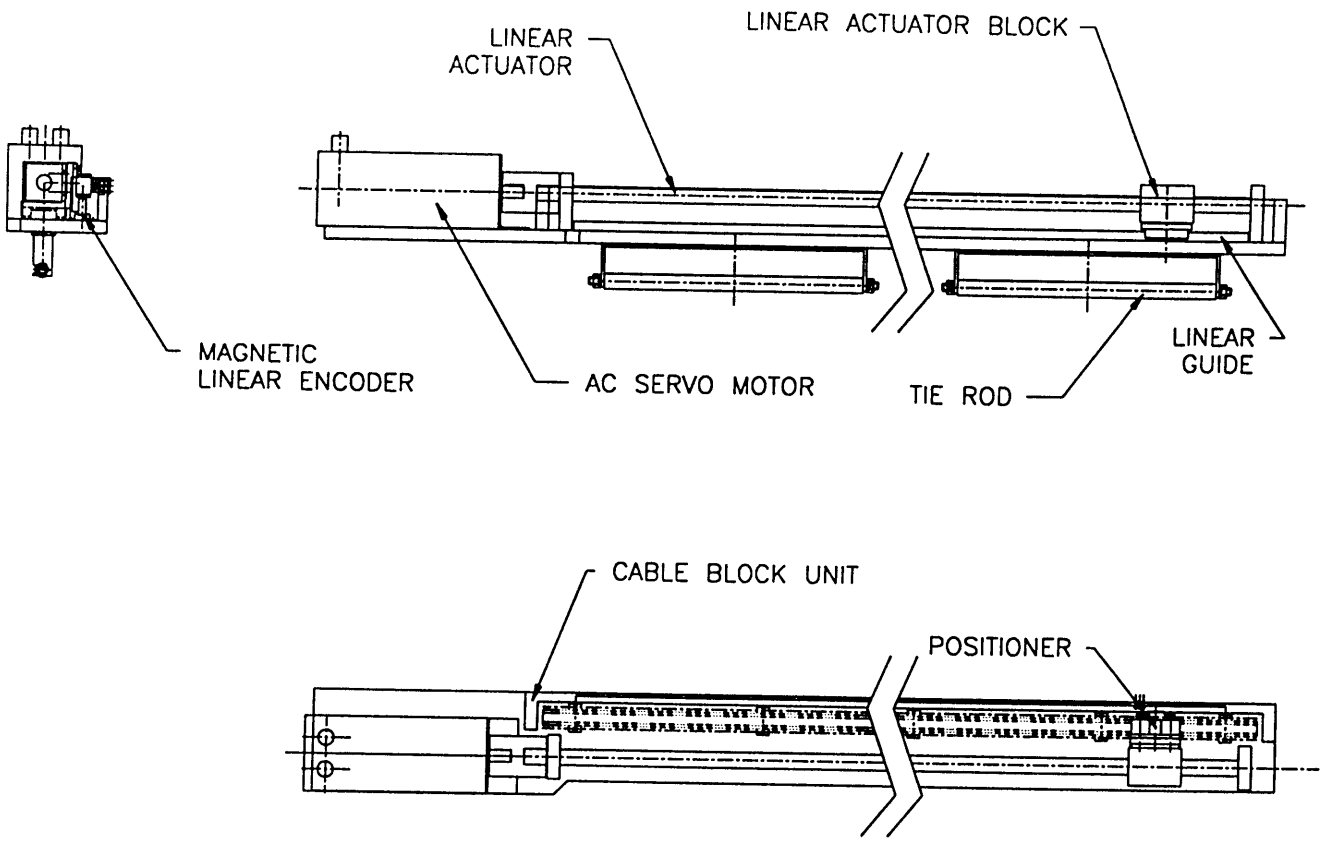

Figure 6.7. Adjuster Assembly.

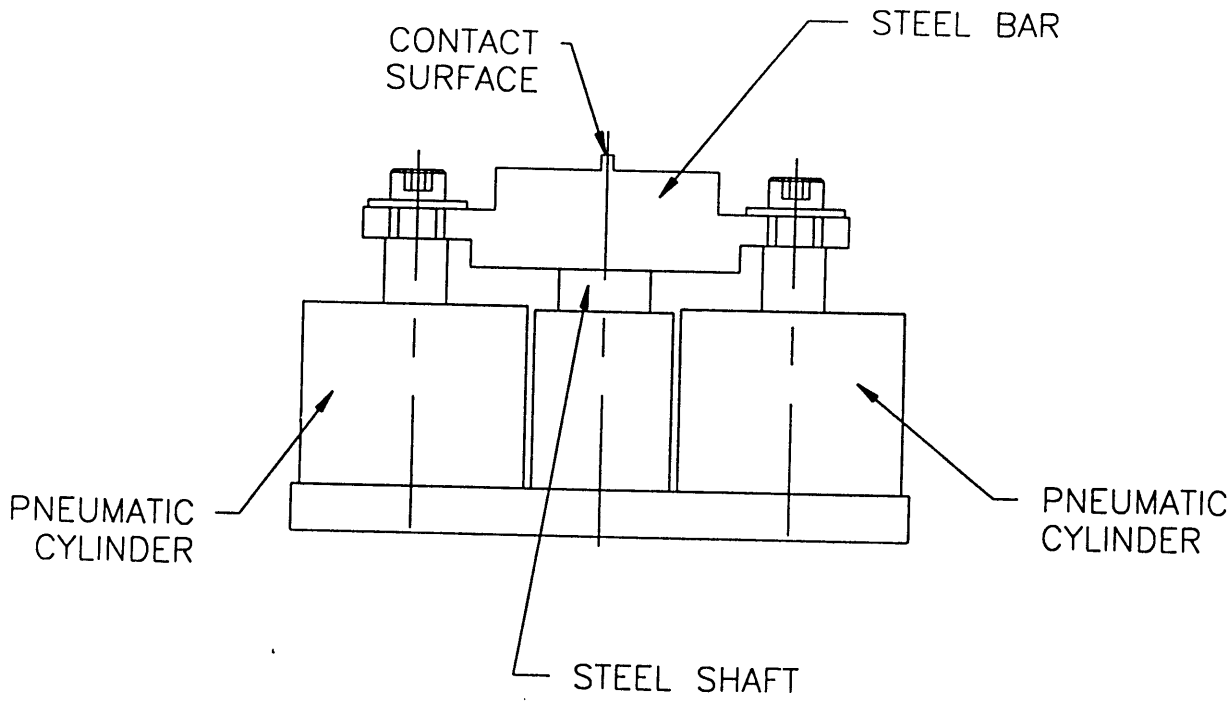

Figure 6.8. Positioner Extended "Forward".

can be repositioned. The contact surface of the steel bar is only 1.6 mm wide. The thin contact surface ensures that only one cable block will be engaged when the steel bar is thrust forward. The steel bar is also attached to a steel shaft that slides in a bronze bushing. The shaft supports the weight of the steel bar and the forces experienced by the bar. The shaft keeps the loads exerted on the piston rods small and does not permit significant deflection of the steel bar. The linear actuator moves the positioner to each cable block; the steel bar of the positioner engages with the cable block. Then, the positioner is moved to the cable block drop-off location, sliding the cable block against the interior wall. At the drop-off location, the positioner pistons disengage the steel bar from the cable block, allowing the cable block to lock in place.

During a pace change, the cable blocks are moved to the pace desired. If a cable is no longer needed, it is moved within the adjuster to the storage locations at the far ends of the assembly. Here, the cables are cut and connected to a tie rod. When these cables are needed in a later changeover, the cable blocks are moved back into the active region. Then, the cables are simply disconnected from the tie rod and combed into the rollers as explained in section 6.3.

6.4.2 Half-Pace Roller Assembly

Figure 6.9 provides the top and side views of the half-pace assembly. This assembly holds the two half-pace rollers in place allowing them to move between their active and change positions. In the change position, the rollers must be free of the cables so that the rollers can be replaced. In addition, the half-pace assembly includes an angle-roller that sets all cables leaving a guide box assembly.

Each roller is placed in a frame that travels between the active and change positions when the crank shown is turned. The crank rotates an acme screw that forces the frame back and forth. Two guide shafts support the load of the frame, the roller, and the cable tension; these guide shafts slide in bronze bushings. The angle-roller spans the entire length of the half-pace

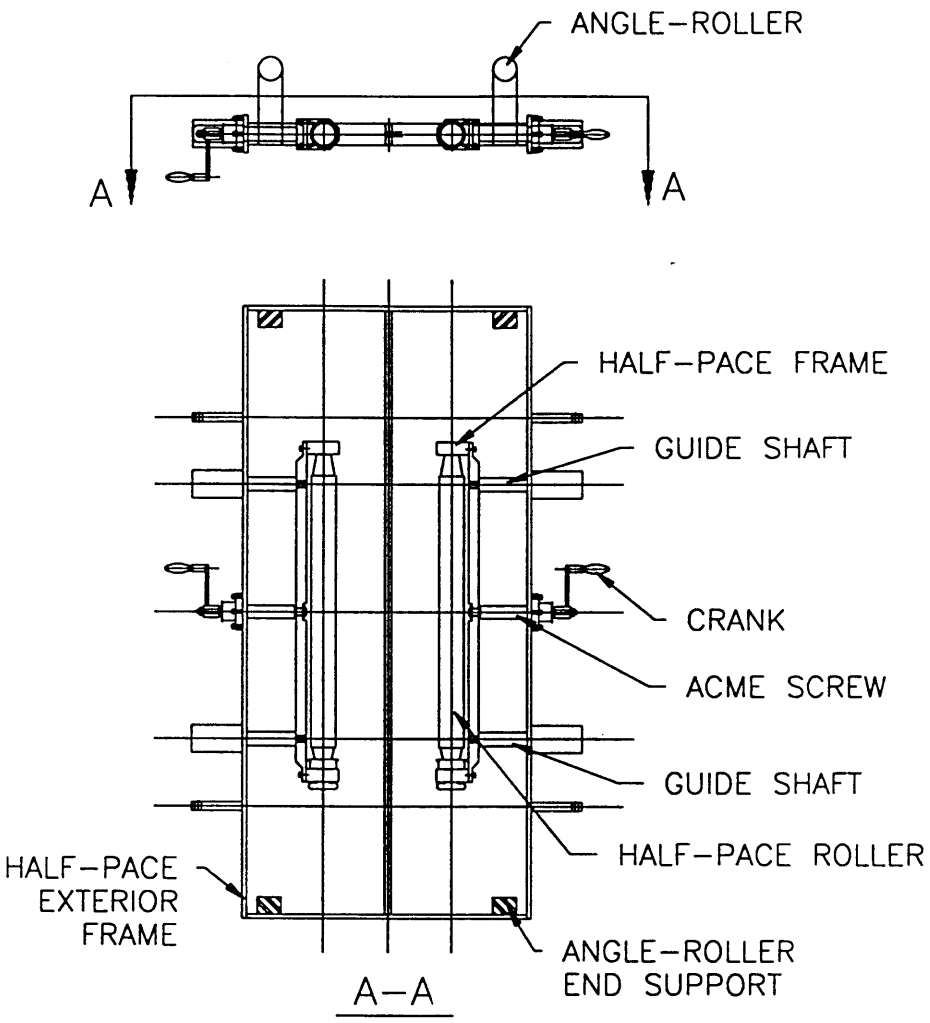

Figure 6.9. Half–Pace Assembly.

assembly; ends of the angle-roller are held in ball-bearings that allow the roller to rotate with the flow of cables. The ball-bearing end supports connect to the half-pace exterior frame as shown in figure 6.9.

Also to this exterior frame is connected the adjuster assembly. As the crank is turned to move a half-pace roller to its change position, the cables enter the adjuster assembly, freeing the half-pace roller of cables.

6.4.3 Full-Pace Roller Assembly

The full-pace roller assembly must satisfy several functional requirements. The assembly supports the full-pace roller at its two ends. Each end must apply a force to the roller when the roller is set onto the rubber tissue and apply a force to lift the roller when the assembly needs to moved to the roller change position. At the change position, operators must be able to quickly release the roller from the ends and to easily insert a new roller. Finally, the ends must support the combined force that the cables exert onto the full-pace roller.

To satisfy the functional requirements, the design given in figure 6.10 is used. Each end support contains a pneumatic cylinder with a 50 mm stroke, that can apply the necessary force to the full-pace roller to press it against the rubber tissue and to lift it for transport to the change position. Also, each end contains two guide shafts that support the load presented by the cables; the steel guide shafts travel in bronze bushings and prevent significant deflection of the cylinder rod.

The cable ends are attached with a steel connector labeled in figure 6.10. The connector ensures that the two ends lift and lower the roller at the same velocity, keeping the roller parallel to the rubber tissue. The pneumatic cylinders are actuated using the pneumatic circuit presented in figure 6.11. Both cylinders are connected to the same control valve so that they are actuated at the same time. In the circuit are placed flow restrictors that can be adjusted to set the rate of air flow; rate of air flow determines the speed at which the roller is raised or lowered.

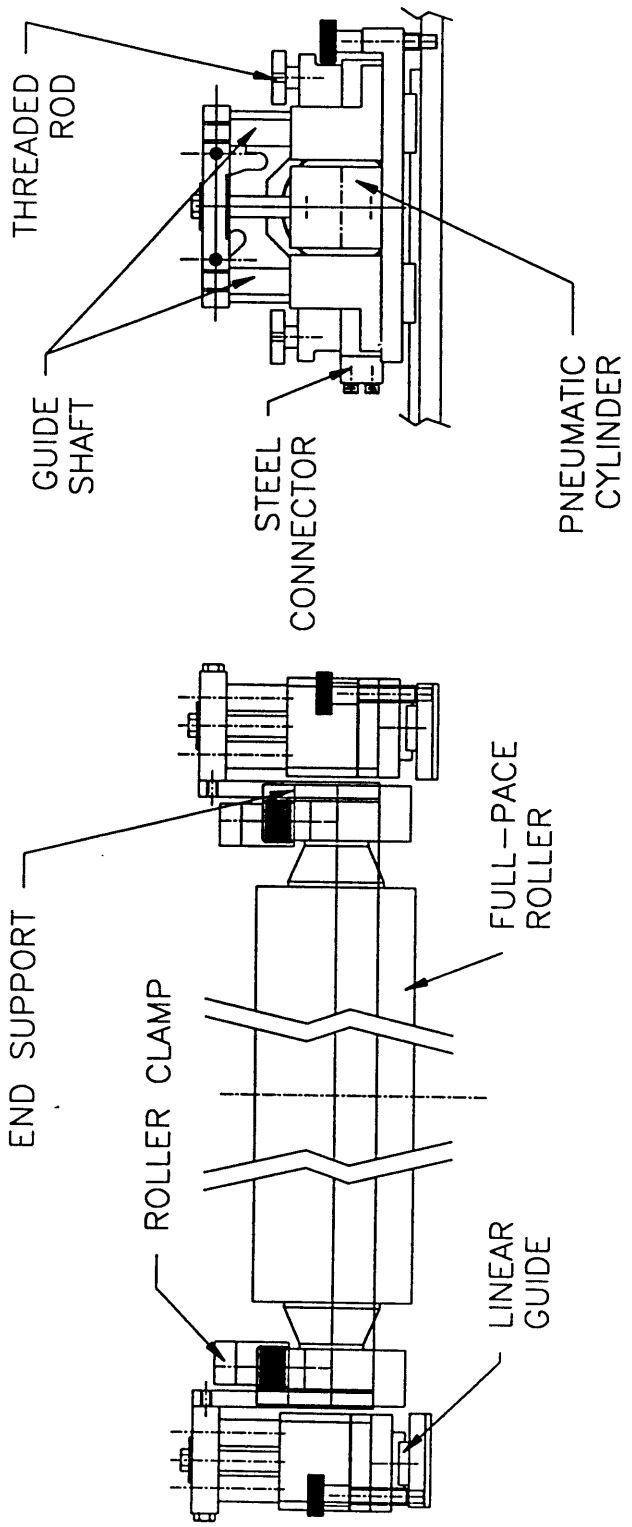

Figure 6.10. Full-Pace Roller Assembly.

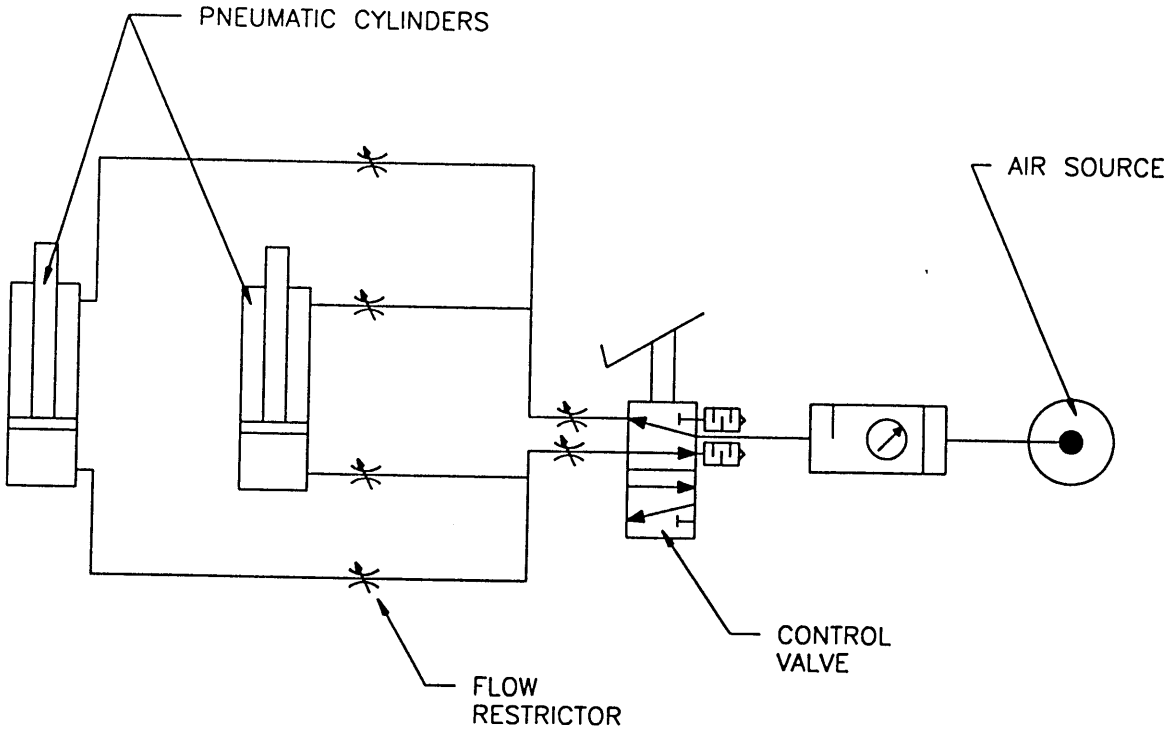

Figure 6.11. Pneumatic Circuit for Full-Pace Roller Assembly.

Each end support travels on a linear guide; the two linear guides are installed in parallel. During a changeover, the full-pace assembly travels on these linear guides to the roller change position underneath the hoist. Here, a clamp at each end holding the roller is removed by unscrewing two threaded rods, freeing the roller for replacement.

6.4.4 Cable-Holding Bar

Before the full-pace roller assembly can be moved to its roller change position, the cables must be held in place. To accomplish this task quickly, operators slide the tool shown in figure 6.12 between the full-pace roller and the cables. Then, the two threaded ends of the tool are clamped into the slots made in the fixed support shown. With the cables held in tension against this tool, the full-pace roller assembly is released and moved to the hoist.

After the roller is replaced, the roller assembly is brought to its initial position against the tool and clamped in place. Then, the tool is released to allow the cables back onto the full-pace roller.

6.4.5 Transfer Clamps

Although not part of a pace change, a transfer influences the design of the pace change area. In a transfer, the full-pace roller assembly, the rubber feeding mechanisms and the finishing assemblies are all moved from one block creel to another. In the process, the half-pace rollers are left behind with the cables.

A transfer, although not performed frequently, requires that a short segment of metallic tissue be left behind. This segment, with the imbedded cables, maintains the position of all cables so that they can be attached back into the rubber feeding mechanisms when this block creel is once again used. Of course, when this segment of metallic tissue is cut near the full-pace roller, the tension in the cables pull the metallic tissue towards the block creel. To firmly hold the tissue in place, a clamp is required.

The clamp design for concept 3 works under same principle as that of the existing clamp on the calender; however, the new design contains fewer

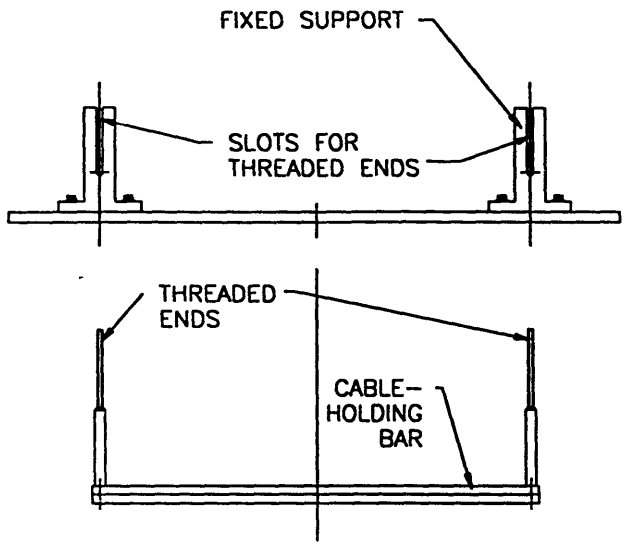

Figure 6.12. Cable–Holding Bar & Fixed Support.

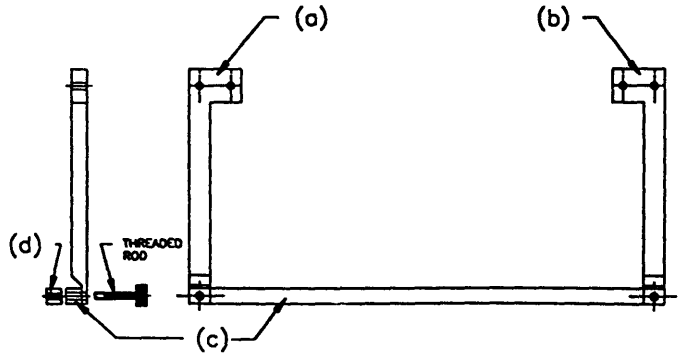

Figure 6.13. An Assembled Transfer Clamp.

parts and can be removed from the pace change area when it is no longer needed. Providing a removable clamp further reduces the congestion of the pace change area.

The proposed clamp design is illustrated in figure 6.13. Parts (a) and (b) in the figure attach to holes in the half-pace frame. Threaded rods are inserted through holes at the other end of these parts and through holes in bar (c). Finally, the threaded rods lock into tapped holes in bar (d). The metallic tissue is brought in between the two bars; the threaded rods are turned until the bars grip the metallic tissue. Bar (d) contains 1 mm grooves cut along its clamping surface. When the rubber is sandwiched between the two bars, the rubber is compressed, forcing rubber into grooves in bar (d); this creates an interference that does not allow the metallic tissue to slide out of the clamp.

6.4.6 Temporary Storage Tray

The temporary storage tray holds two full-pace rollers near the pace change area. Having this tray allows the operators to bring the replacement roller from the storage area using the hoist and to place it on this tray. When the full-pace roller assembly is brought underneath the hoist, the hoist moves the old roller to the second position on the tray and then moves the replacement roller into the full-pace roller assembly.

The temporary storage tray design is provided in figure 6.14. A full-pace roller is placed onto the semicircle grooves at the top plate of the tray. The plate connects to two parallel linear guides so that each roller position on the tray can be moved under the hoist by sliding the plate on the guides. The linear guides provide the hoist with access to the two storage locations.

6.5 Adjuster Control System

6.5.1 Control Layout

For the adjuster to properly move cable blocks to correct locations during a pace change, a control system is needed to stimulate the actuators

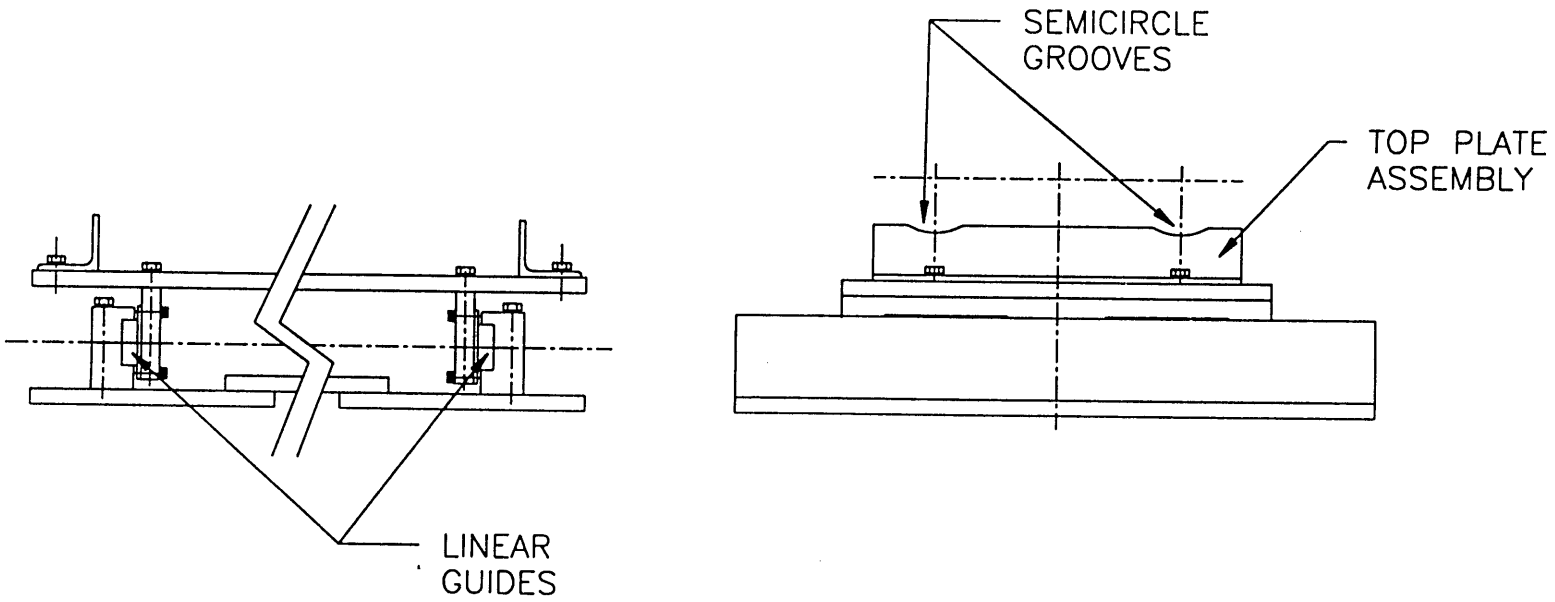

Figure 6.14. Temporary Storage Tray.

correctly. Figure 6.15 shows the schematic of the control circuits for both adjusters in the pace change area. The motion controller accepts initial inputs from the operators, and then utilizes position closed-loop feedback from the magnetic linear encoders to generate the movements that the adjuster's positioner must make.

With signals from the motion controller, the two drives generate velocity profiles for each move and then actuate the motors to move the positioners to each desired location. In addition, the same motion controller actuates the pneumatic cylinders in the circuit. When the positioner reaches each desired location, the motion controller switches the control valves that direct air flow to the pneumatic cylinders.

When the motion controller is initialized for a pace change, operators input information about the pace change, including the new pace and the new number of cables. With these inputs, the motion controller accomplishes a pace change by following certain loops of the program in its memory. The algorithm for this program is provided in appendix B. The algorithm instructs the motion controller on where along the adjuster to find cables and on where to move these cables. Since the positioner spans the entire length of the adjuster, the algorithm also controls the operations of moving cables into storage.

6.5.2 Motor Size

To determine the servo motor size for this application, a model of the system is needed. The linear actuator's manufacturer provides a method to determine the continuous torque needed once the desired velocity is reached. This continuous torque overcomes the frictional forces in the system.

However, to accelerate or decelerate the actuator to 4800 rpm in less than 0.2 seconds, inertial effects must be considered. The motor torque necessary to accelerate or decelerate the system can be determined using the model depicted in figure 6.16 by the bond graph. Table 6.1 provides the meaning of each symbol and units where appropriate. The model leads to the

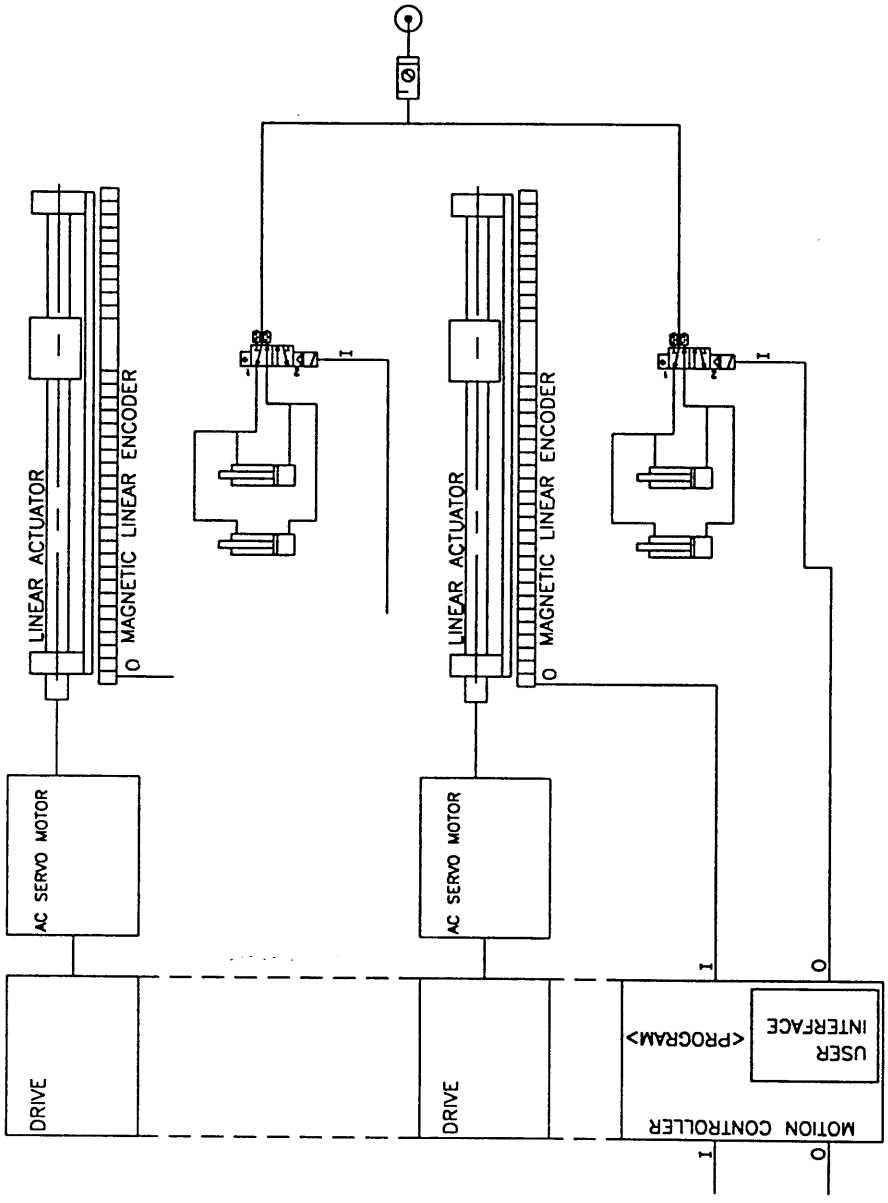

Figure 6.15. Control Circuits for Adjusters.

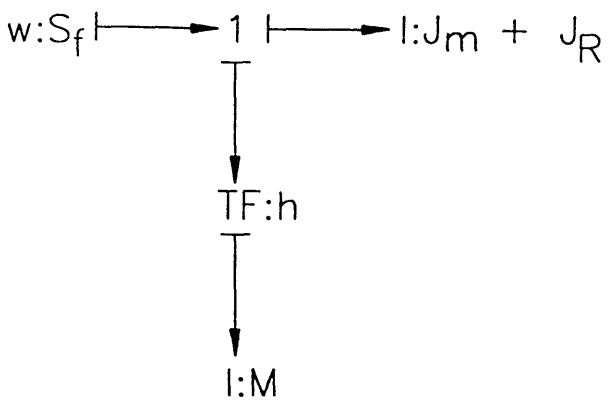

Figure 6.16. Bond Graph Model of Adjuster.

Table 6.1.	Bond Graph Symbols.	
Symbol	Meaning	Units
w:S_f	Represents the Motor as a flow source (sets rotational velocity)	
1	A common flow junction. All flows in the system are set by the motor.	
I:J_m + J_R	Represents Inertia of Rotating Elements. J_m=shaft inertia J_R=rotor inertia	kgm^2
TF:h	A transformer representing rotational-to-linear conversion h = "pitch" of shaft	m
I:M	Inertial element. M = Mass moved by linear actuator.	kg

following equation:

$$T = (J_m + J_R + h^2 M)\frac{dw}{dt}$$

where T represents the motor torque and w represents the rotational velocity of the motor. This equation provides the peak motor torque necessary to generate the acceleration (dw/dt) desired.

7.1 Conclusions

Although both concepts 2 and 3 promise a much reduced pace change time from the existing procedure, a prototype is necessary to test the concepts and to make final modifications to the design. To determine which concept to pursue with a prototype, positive and negative qualities that determine the probability of success of each concept are considered.

Concept 3 proves to have several advantages over concept 2 that make concept 3 the best option to pursue with a prototype. The main advantage of concept 3 over concept 2 is speed. In concept 2, 8 movements are necessary to move each cable; the movements include: (1) move positioner to pickup location, (2)actuate pneumatic cylinders forward, (3) close grippers, (4) retract pneumatic cylinders, (5) move positioner to drop-off location, (6) actuate cylinders forward, (7) open grippers, and (8) retract pneumatic cylinders. In contrast, the adjuster in concept 3 employs only 4 movements to move each cable; the movements include: (1) move positioner to starting cable block location, (2) actuate cylinders forward, (3) move positioner to new cable block location, and (4) retract cylinders. As a result of fewer movements, the total time necessary to accomplish a pace change in concept 3 is 8 to 12 minutes, whereas concept 2 requires 15 to 20 minutes.

Two other important advantages make concept 3 the best choice. Concept 3 provides a less congested pace change area than does concept 2; this is clear when comparing figure 6.1 with figure 5.1. Figure 6.1 shows a pace change area that has greater accessibility to operators. For this area, accessibility is directly related to operator safety as discussed in chapter 1. A main drawback of concept 2 is its use of photoelectric sensors to locate roller centers. Although these sensors will locate the centers if setup properly, their precision and accuracy over time is questionable. Concept 3 avoids the use of photoelectric sensors by moving cable blocks that are always at known

locations. For these reasons, concept 3 should be prototyped.

7.2. Recommendations for Future Work

To verify concept 3 with a prototype, the following procedure is recommended. Although several assemblies have been described for this concept in chapter 6, only one adjuster assembly and its control components should be constructed. Once the adjuster is assembled, the cable blocks should be placed in their initial positions manually. Then, the motion controller should be initialized to move the cable blocks to a certain pace. The motion controller should be setup to accomplish one step in its program at a time. Careful observations need to be made of how well the positioner moves each cable block, of how well the cable blocks lock into their new locations, and of how easily the blocks slide in their slots. Once the adjuster is tested and if necessary, modified, other assemblies of the pace change area can be constructed so that the entire system can be tested on how well it accomplishes a pace change.

Appendix A.
Present Pace Change Procedure

In this section is given the step-by-step procedure for a pace change in the existing design. This procedure is created from the calender 800 operator's manual.

1. Locate new full-pace roller in roller storage racks and use hoist to bring to calender.
2. Remove full-pace roller.
3. Get new half-pace rollers.
4. Get new intermediate rollers from roller racks.
5. Insert new full-pace roller.
6. Tighten full-pace roller into turret.
7. Return old full-pace roller to storage.
8. Remove old intermediate rollers.
9. Raise, rotate, and lower full-pace roller turret.
10. Unscrew half-pace roller endcaps.
11. Exchange half-pace rollers.
12. Tighten half-pace roller endcaps.
13. Return half-pace rollers to racks. Carry combs to calender.
14. Rotate half-pace rollers and work on placing cables in grooves. add or delete cables as necessary.
15. Comb cables from rear half-pace roller into full-pace roller.
16. Jog rear cables into pace.
17. Comb cables from front half-pace roller into full-pace roller.
18. Jog front cables into pace.
19. Return old intermediate rollers to storage racks.
20. Insert new intermediate rollers.
21. Return combs to storage racks.
22. Calender patch through boles.
23. Adjust rubber-feeding mechanisms and finishing assemblies for new product.
24. Start Calender

Appendix B.
Algorithm for a Pace change

Inputs from Operator:

Pa = starting pace
Pb = ending pace
Na = starting # of cables
Nb = ending # of cables
T = total # of cable blocks in adjuster
d = distance of 1st storage location from center

Variable definitions:

n, k, q	counters
y	location of positioner
A = (T-Na)/2	# of cables in each storage
D = d - 2.2A	Distance of 1st available storage location from center

Program: -- note: various loops account for 8 possible scenarios.

```
if Pa >= Pb,

    {if Na > Nb,

        {n = Na/2 - 0.5
         q = Nb/2 - 0.5
         k = 0
        while n > q,
                {y = (n)(Pa)
                 positioner forward
                 y = D - 2.2k
                positioner backward
                n = n - 1
                k = k + 1       }
        n = Na/2 - 0.5
        k = 0
        while n > q,
                {y = -(n)(Pa)
                 positioner forward
                 y = -(D - 2.2k)
```

```
                positioner backward
                n = n - 1
                k = k + 1       }

        if Pa = Pb, exit loop

        n = 0.5
        while n <= q,
                {y = (n)(Pa)
                 positioner forward
                 y = (n)(Pb)
                 positioner backward
                 n = n + 1      }
        n = 0.5
        while n <= q,
                {y = -(n)(Pa)
                 positioner forward
                 y = -(n)(Pb)
                 positioner backward
                 n = n + 1      }       }

if Na < Nb,
        {n = 0.5
         q = Na/2 - 0.5

        if Pa "does not equal" Pb,

                {while n <= q,
                        {y = (n)(Pa)
                         positioner forward
                         y = (n)(Pb)
                         positioner backward
                         n = n + 1 }
                n = 0.5
                while n <= q,
                        {y = -(n)(Pa)
                         positioner forward
                         y = -(n)(Pb)
                         positioner backward
                         n = n + 1 }    }

        n = Na/2 + 0.5
        k = 0
        q = Nb/2 - 0.5

        while n <= q,
```

```
                    {y = D - 2.2k
                     positioner forward
                     y = (n)(Pb)
                     positioner backward
                     n = n - 1
                     k = k + 1      }

              n = Na/2 + 0.5
              k = 0
              while n <= q,
                    {y = -(D - 2.2k)
                     positioner forward
                     y = -(n)(Pb)
                     positioner backward
                     n = n - 1
                     k = k + 1      }       }

        if Na = Nb,
              {n = 0.5
               q = Nb/2 - 0.5
              while n <= q,
                    {y = (n)(Pa)
                     positioner forward
                     y = (n)(Pb)
                     positioner backward
                     n = n + 1      }

              n = 0.5
              while n <= q,
                    {y = -(n)(Pa)
                     positioner forward
                     y = -(n)(Pb)
                     positioner backward
                     n = n + 1      }       }       }


if Pa < Pb,

        {if Na > Nb,

              {n = Na/2 - 0.5
               q = Nb/2 - 0.5
               k = 0

              while n > q,
                    {y = (n)(Pa)
```

```
            positioner forward
            y = D - 2.2k
            positioner backward
            k = k + 1
            n = n - 1       }

      n = Na/2 - 0.5
      k = 0
      while n > q,
            {y = -(n)(Pa)
            positioner forward
            y = -(D - 2.2k)
            positioner backward
            k = k + 1
            n = n - 1       }

      n = Nb/2 - 0.5

      while n >= 0.5,
            {y = (n)(Pa)
            positioner forward
            y = (n)(Pb)
            positioner backward
            n = n -1        }

      n = Nb/2 - 0.5

      while n >= 0.5,
            {y = -(n)(Pa)
            positioner forward
            y = -(n)(Pb)
            positioner backward
            n = n - 1       }       }

if Na < Nb,

      {n = Na/2 - 0.5
      while n >= 0.5,
            {y = (n)(Pa)
            positioner forward
            y = (n)(Pb)
            positioner backward
            n = n - 1       }

      n = Na/2 - 0.5
      while n >= 0.5,
```

```
                {y = -(n)(Pa)
                 positioner forward
                 y = -(n)(Pb)
                 positioner backward
                 n = n - 1      }

        n = Na/2 + 0.5
        k = 0
        while n <= q,
                {y = D - 2.2k
                 positioner forward
                 y = (n)(Pb)
                 positioner backward
                 n = n + 1     }

        n = Na/2 + 0.5
        k = 0
        while n <= q,
                {y = -(D - 2.2k)
                 positioner forward
                 y = -(n)(Pb)
                 positioner backward
                 n = n + 1     }       }

if Na = Nb,
        {n = Nb/2 - 0.5
         while n >= 0.5,
                {y = (n)(Pa)
                 positioner forward
                 y = (n)(Pb)
                 positioner backward
                 n = n - 1      }
        n = Nb/2 - 0.5
        while n >= 0.5,
                {y = -(n)(Pa)
                 positioner forward
                 y = -(n)(Pb)
                 positioner backward
                 n = n - 1      }       }       }
```

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