An Examination of Transfer Systems in Tire Manufacturing

by

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B.S., Mechanical Engineering (1996)

Massachusetts Institute of Technology

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

This thesis introduces techniques for decreasing the time required to transfer tire products along an assembly line while providing gains in three areas of performances: reliability, noise level, and cost effectiveness. Within the report an original (the Timing Belt Driven) and an existing (the Shock and Propulsion) transfer system design are examined in detail and compared to alternative designs. The methods devised to improve the Shock and Propulsion transfer system resulted in a decrease in transfer time on the Machine Automatic Confection (MAC) line from 3.8 centi-minutes to 3.5 centi-minutes. The transfer time on the Machine Automatic Finishing (MAF) line was decreased from 4.4 centi-minutes to 4.0 centi-minutes. However, experiments conducted on the Shock and Propulsion transfer system showed that the modifications performed in order to decrease transfer time have resulted in an increase in the fracture rate of the transfer system's components. Further analysis of the Shock and Propulsion transfer system revealed that switch to a shock system which is able to provide a more linear deceleration profile would result in about a 33% decrease in the impact forces the system would have to sustain. However, obtaining substantially faster transfer times without sustaining losses in terms of overall operating costs, noise level, and reliability requires switching to a new transfer system design. The Timing Belt Driven transfer system (the "new design") will enable one to achieve a transfer time of 3.0 centi-minutes, on both the MAC and the MAF lines. The Timing Belt Driven transfer system will also increase the reliability of the transfer process while decreasing the noise level and costs associated with transfer.

Thesis Supervisor: Carl Peterson

Title: Professor of Mechanical Engineering

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1. Introduction and Background

The primary motivation behind the research conducted in this report is the desire to decrease cycle time while creating a more stable and reliable process for producing tires on the Machine Automatic Confection (MAC) and Machine Automatic Finishing (MAF) manufacturing systems. More specifically, the research conducted in this study centers on the need to decrease the transfer component of cycle time. Transfer time is defined as the time it takes to move the unfinished tire from one station to the next within the tire assembly line. By reducing transfer time, significant gains in cycle time can be achieved and the number of tires produced a day on the MAC and MAF systems can be dramatically increased.

The tire production process consists of three stages: confection, finishing, and curing. Confection, the initial stage, is conducted on the MAC. Confection consist of laying down the rubber products that form the tire "carcass" which functions as the skeleton of the tire. The MAF then obtains the carcass from a buffer and performs finishing operations that include laying down the steel belts and the tread of the tire. Once the carcass leaves the MAF it becomes a "green tire" and is ready for the last stage of the tire manufacturing process, curing. Curing involves heating the tire so that all the rubber products are solidified into one form.

The scope of this study shall be limited to examining the first two stages of the tire manufacturing process. Therefore, only the MAC and the MAF systems shall be investigated. The MAC and MAF assembly lines both have various posts where different operations are performed on the tire (figure 1.1 contains a drawing of the MAC and MAF assembly lines' layout). The tire is moved from post to post on a carriage which is called a bati.

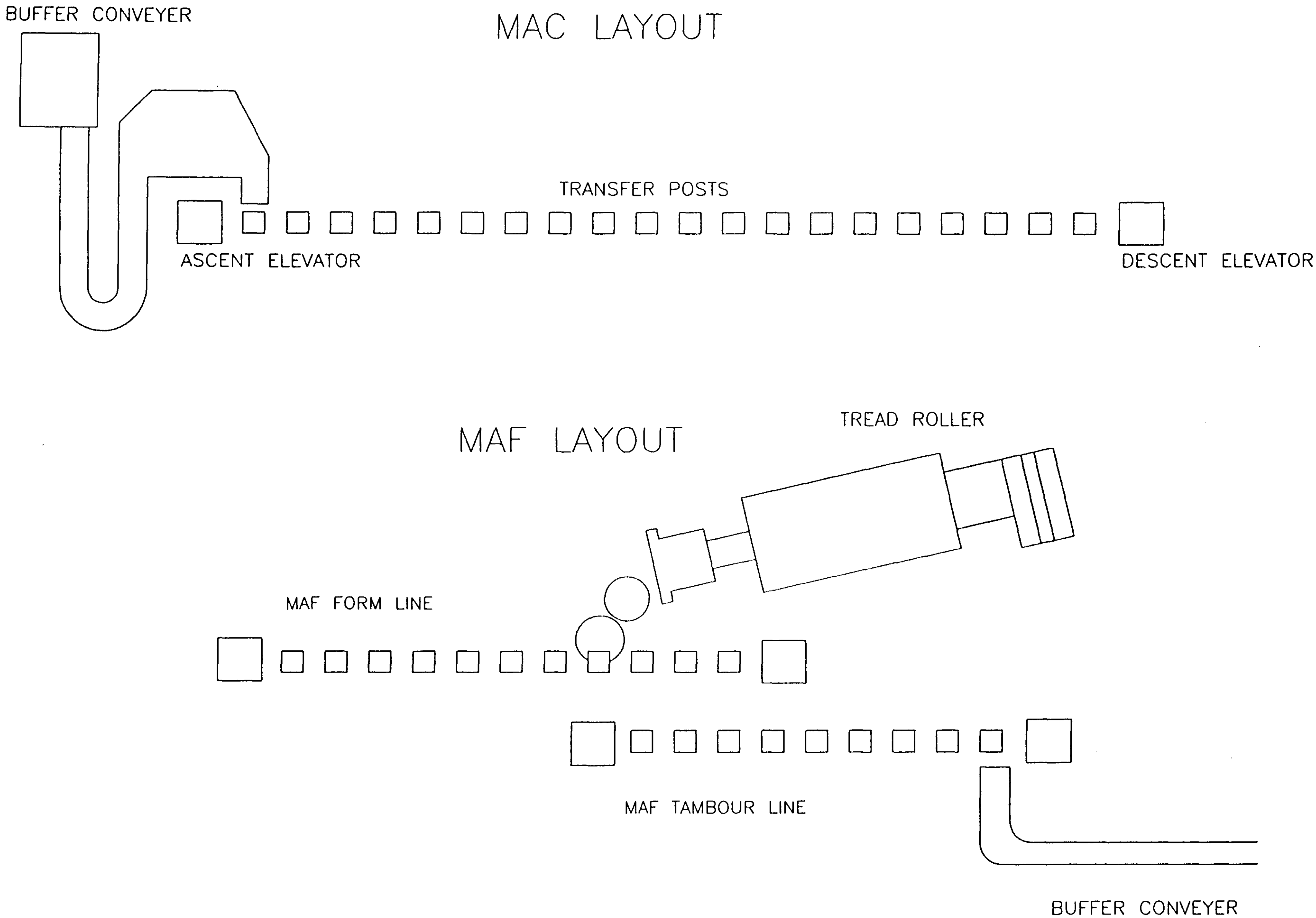


Figure 1.1: Layout of MAC/MAF Manufacturing Lines

The bati contains a drum, know as a tambour, where the rubber products that form the tire are placed (a diagram of the bati and tambour is contained in figure 1.2). At any given time each post contains a bati. After all the posts have finished their operations, the batis are simultaneously fired to the next post using three different types of transfer systems: the Propulsion and Shock transfer system, the MATCH transfer system, and the AC Drive transfer system.

In order to achieve gains in cycle time, stability, and reliability an in depth study of the Shock and Propulsion transfer systems, as well as a brief examination of the MATCH and AC Drive transfer systems, will be conducted in this report. Three new designs ideas will also be explored, with one of these new designs serving as a possible alternative to existing transfer system designs.

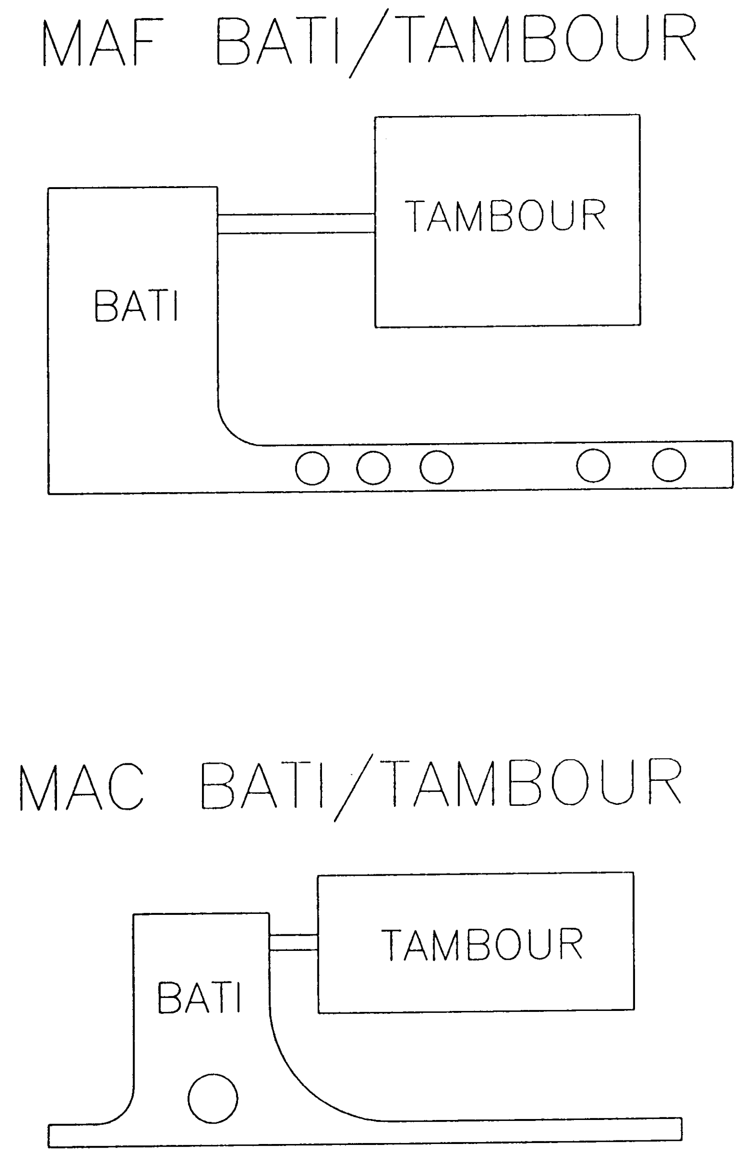


Figure 1.2: Bati and Tambour Schematic

2. Shock and Propulsion Transfer System

Almost all of the MAC and MAF manufacturing lines currently operate using a Shock and Propulsion transfer system. A few manufacturing lines also use MATCH transfer and AC Drive transfer. The MATCH and AC Drive transfer systems are briefly discussed in later sections. The pervasiveness of the Shock and Propulsion transfer system, however, creates the need for greater scrutiny than that which is given to the other transfer systems. Therefore a detailed evaluation of the Shock and Propulsion transfer system shall be performed. The evaluation will provide an explanation of the layout and operation of the system, an assessment of recent design modifications, an analysis of the design modifications' implications, and a general appraisal covering the transfer system's performance.

2.1. Layout and Operation

An examination of the operations involved in performing and monitoring the transfer process shall provide a valuable framework for determining the strengths and the weakness of the Shock and Propulsion transfer system. Before examining the Shock and Propulsion transfer system, though, it is important to note that the sizes and shapes of the transfer components on the MAC and the MAF can vary. However, the MAC and the MAF transfer systems' set-up are almost identical. Keeping this fact in mind, a single schematic will be used to show the layout of the Shock and Propulsion transfer system. With this schematic as guide to reference the various transfer system components we shall examine the way in which transfer time is defined, the layout and procedures involved in performing a transfer, and the techniques used to monitor and maintain the transfer system.

2.1.1. Transfer Time

The transfer time is defined as the time needed to move a bati from one assembly post station to the next. More precisely, the measurement of transfer time begins when an electronic signal is sent to open the valves leading to the propulsion cylinder, and ends when a mechanical switch is trigged by the shock arm. Due to the lack of uniformity in the transfer times of various posts, there is a separate measurement of transfer time along every post. Differences in transfer times are caused primarily by two factors. First, each post on the Shock and Propulsion transfer system contains an independent set of controls which regulate transfer. Second, two posts, even on the same manufacturing line, might contain different types of shock and/or propulsion cylinders. The end result is a transfer system that can vary widely in performance, even within a single manufacturing line.

2.1.2. Transfer Process

The Shock and Propulsion transfer system is composed of a shock assembly and a propulsion assembly located within a transfer block (figure 2.1). The rails on top of the transfer block contain universal rollers which support the weight of the bati. The propulsion assembly is positioned near the back end of the transfer block. It contains a propulsion cylinder used to push the rabbit's foot of the bati. The shock assembly, on the other hand, is located near the front end of the transfer block. Within the shock assembly there is a shock cylinder, a rearm cylinder, and a mechanical switch. These components work in tandem to perform the operations required to stop the bati.

The transfer process in the Shock and Propulsion system is rather straightforward. Before transfer can begin, though, all the posts in the manufacturing line must finish performing their operations and send a signal to the PLC (Programmable Logic Controller) indicating that they are done. At that point, the valves leading to each propulsion cylinder are opened, signaling the start of transfer. Soon after, the air flow into the propulsion cylinder forces the cylinder arm forward. The cylinder arm pushes against the "rabbits foot" which propels the bati to the next post. As the bati moves to the next post it slides freely on the universal rollers until it reaches the shock. Then, the momentum of the bati crushes the shock, forcing oil through the shock cylinder. Once the shock is completely crushed the shock arm triggers a mechanical switch, the pneumatic positioning cylinders center the bati, and the bati comes to rest. When transfer has been completed, the rearm cylinder is

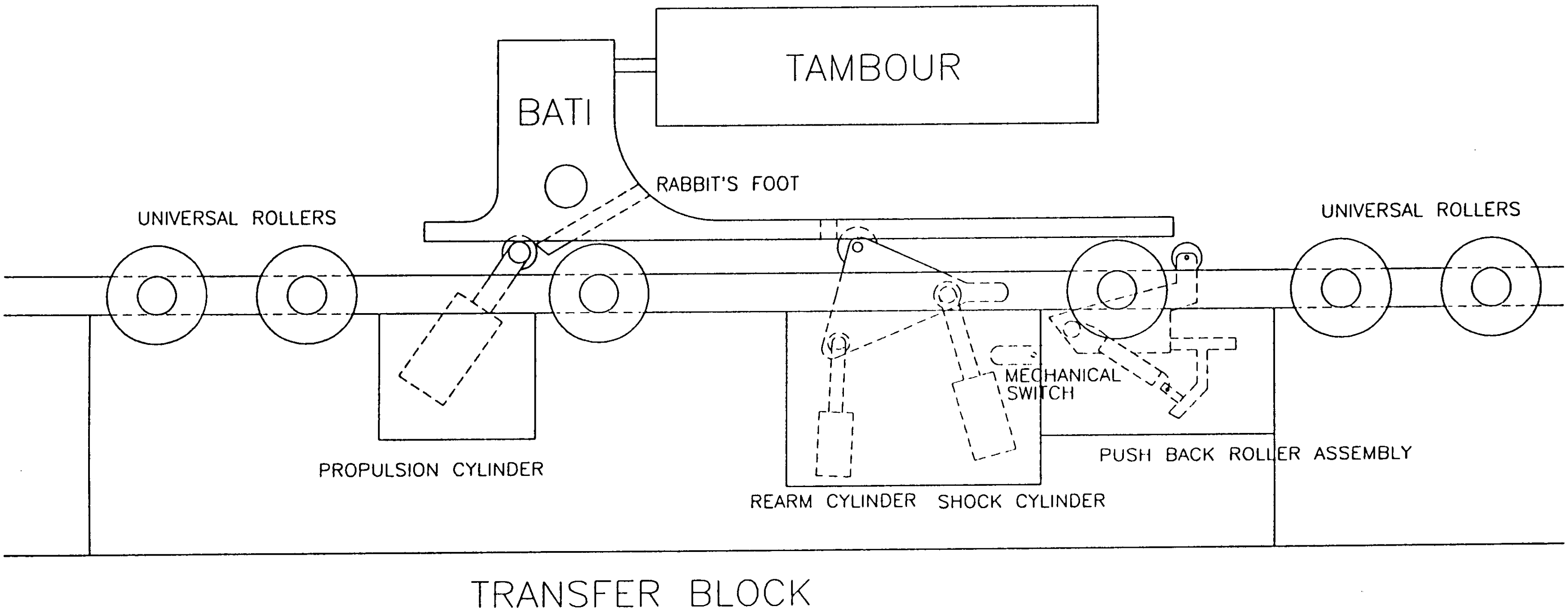


Figure 2.1: Shock and Propulsion Transfer System

activated causing the shock arm to go back to its original position. The shock is then ready to meet the next bati.

2.1.3. Monitoring Techniques

The Shock and Propulsion transfer system is monitored in order to assure reliability. The two techniques used to preserve reliability are periodic machine testing and repair. These techniques decrease the down time created by the transfer system because they work to prevent the root causes of failure before failure can occur.

Periodic repair is very important in assuring that failures which lead to significant levels of down time do not occur. In US1, most of the shock block components are scheduled for preventive repair every 48 months and the propulsion unit components are scheduled for preventive repair every 24 months. Other units within the transfer system are also regularly sent to the repair shop before failure has occurred, whenever trouble shooters find areas of concern during their periodic examination of the transfer system.

Periodic testing is vital to maintaining the operating conditions which are required to prevent part failure. Testing of the Shock and Propulsor unit in US1 is conducted using two testing devices: the portable and the stationary shock testers. Although these devises are relatively new and unique to US1, they have proven to be very useful.

The portable shock tester (figure 2.2) consists of photocells and a timer device that measures the time period it takes an object to travel a fixed distance. Each photocell on the tester sends out a beam of light that is reflected back with the use of reflection tape. When the bati travels past a photocell, it prevents the reflection of the photocell's light.

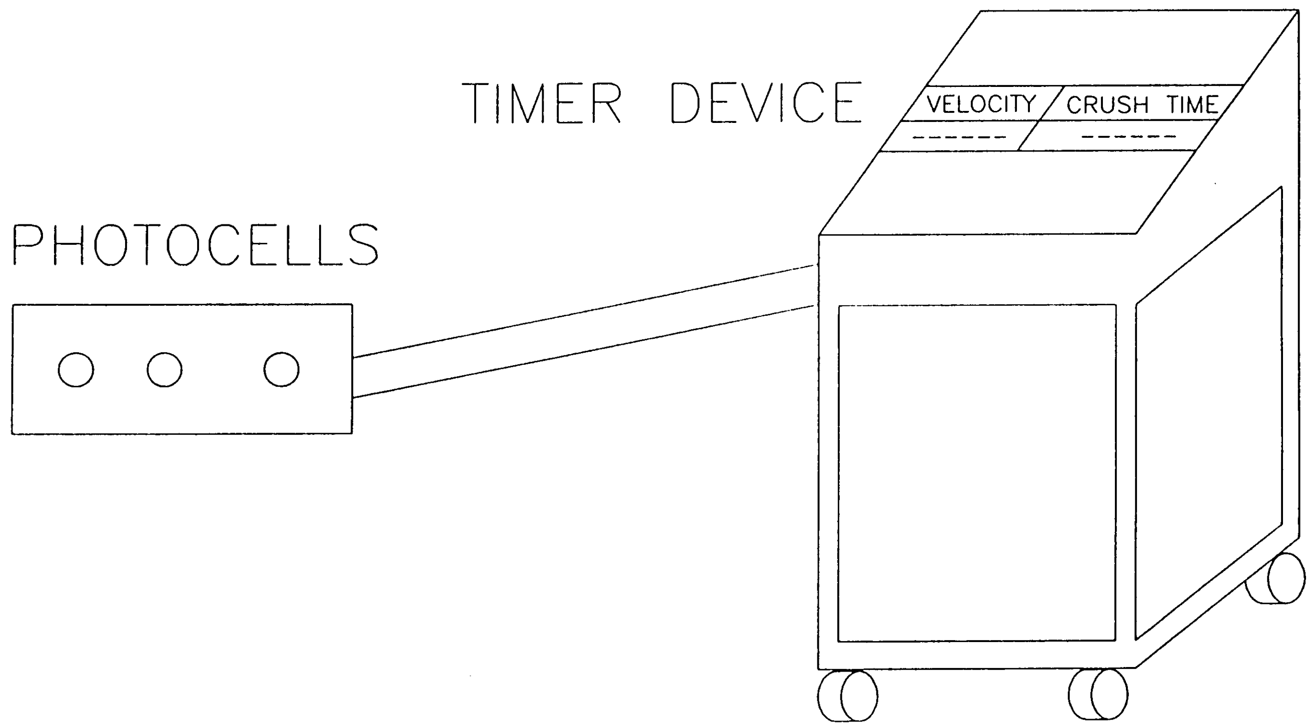


Figure 2.2: Portable Shock Tester

As soon as the light is no longer reflected, the timer records a time reading. The differences between the photocells' time readings are then used to calculate the velocity at which the bati travels and the time it takes to crush the shock. The information gathered by the portable shock tester helps to determine if the shocks and propulsors are functioning properly. High or low readings for the bati velocity indicate that the propulsor is either pushing too hard or too soft on the bati. High or low readings for the shock crush time indicate that the shock may be too stiff or that the shock is bottoming out. Shock testing is scheduled for once every three months. However, the portable shock tester can also regularly be used as a trouble shooting device to determine the source of a problem on the transfer line.

The stationary shock tester (figure 2.3) is an instrument used to adjust the shocks so that they will perform properly once installed on the manufacturing line. The testing of shocks occurs in conjunction with the periodic repair of the shock block. The stationary shock tester works by providing a technique for predicting the way a shock will perform on the manufacturing line. It consists of a pneumatic cylinder, mechanical switches attached to a timing unit, and a control cabinet. The mechanical switches measure the time it takes the stroke on the pneumatic cylinder to crush the shock. This "tester crush time" is displayed on the control cabinet. The shock is then adjusted until the tester crush time (which is proportional to the actual crush time on the manufacturing line) is at a desired level. The use of the stationary shock tester prevents the need for adjusting the shocks on the manufacturing lines and also provides a method for accurately setting the adjustments on the shock block. This helps to decrease the down time associated with shock failure and shock installation.

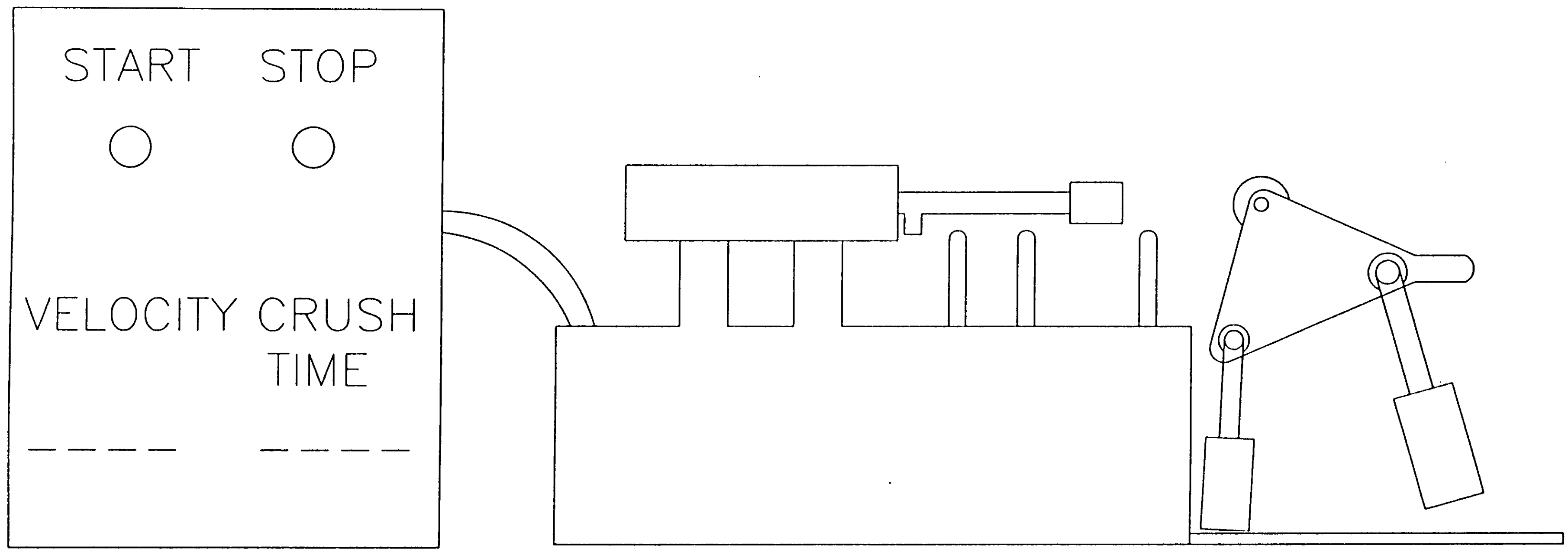


Figure 2.3: Stationary Shock Tester

2.2. Design Modifications

There have been several studies recently completed which have resulted in design modifications to the Shock and Propulsion transfer system. The most notable of these studies were conducted in the manufacturing plants in US1 (plant one in the United States) and C1 (plant one in Canada). The studies resulted in alterations that changed the performance capability of the transfer system.

The studies in C1 lead to several modifications in the propulsion system. The impetus for creating the modifications centered on the desire to increase the force and speed of the cylinder arm that propelled the bati forward. In order to achieve the desired increases in speed and force on the propulsion cylinder arm, new valves with higher flow rates were used to replace the old valves. A separate compressed air header, responsible for providing air pressure to just the propulsion cylinders, was also installed. The separate header prevented the sudden loss of air pressure which air flow demands from other components could previously cause. Furthermore, the study recommended the use of a commercial pneumatic cylinder to replace the old Michelin designed pneumatic propulsion cylinder. Cumulatively all of these modifications resulted in the bati being propelled at a faster and more consistent velocity.

After examining the propulsion system, the C1 study then focused its attention on the shock system. The inside of the shocks were remachined for tighter tolerances and an o-ring seal was added in order to prevent oil leaks that kept reoccurring. The C1 study also examined the merits of switching to a commercially produced shock absorber. However, after modifications to the existing shock absorbers were made, the group conducting the C1 study concluded that switching to a commercially produced shock absorber was unjustifiable because of the large cost involved.

Using the information obtained from the C1 study as a reference source, a separate study was conducted in US1 in order to reduce the US1 MAC and MAF systems' transfer time. As a result of the US1 study, the old Michelin designed pneumatic propulsion cylinders were replaced with commercial pneumatic cylinders. The US1 study also resulted in larger valves and tubes being used in the lines leading to the pneumatic cylinders. However, the specific types of valves and tubes recommended by US1 were different than those recommended by C1. The US1 study even called for the use of commercial pneumatic cylinders that were a different size (stroke length and bore diameter) than the C1 pneumatics. Although the exact methods used to modify the US1 and C1 propulsion systems differ, both sets of modifications effectively increased the pressure, flow rate, and consistency of air flow into the propulsion cylinder. This in turn lead to a faster and more stable operating speed on the bati.

The shock system modifications proposed by the US1 study were dramatically different from those proposed by the C1 study. While the C1 study resulted in only minor modification to the old Michelin designed shock, the US1 study proposed redesigning the shock absorber in a manner that would change the way it functioned. The old Michelin designed shock absorber was built to provide linear deceleration for a known mass with a known impact velocity. However, by adding a single large exit port and an external valve to regulate flow, the new US1 design resulted in a shock that would create nonlinear deceleration. The primary motivation for altering the shock system was the desire to obtain a shock that had an external control to regulate flow.

Neither the C1 nor the US1 study closely examined the implications of the design modifications which were created in order to reduce transfer time. Specially, neither study attempted to build a theoretical or experimental model to predict how the overall system would respond to the proposed modifications. Little was known about how the increase in the bati's velocity would effect the transfer system's reliability. Changes to the existing system were made based primarily on intuition for how the system would respond. In fact, most of the inconsistencies in the recommendations of the US1 and C1 studies are a product of the differences in opinion regarding the intuition for how the transfer system behaves. Therefore an analytic approach is needed to determine the effects of the design modifications on transfer system as a whole.

2.3. Design Analysis

The key factors altered by the design modifications on the Shock and Propulsion transfer system are bati speed and shock performance. As a results of these modifications, the reliability of the transfers system has been called into question. The recent upsurge in the number of fracture cases involving the shock housing and the bati are widely perceived to be linked to changes in the Propulsion and Shock transfer system's design. Therefore the Design Analysis section shall be devoted to providing an analytical evaluation of the effects produced by the transfer system's design modifications.

The effects of the design modification are examined in two stages. Initially a theoretical and experimental examination of the bati's behavior during transfer is performed in order to pinpoint the root causes of bati fracture. Then a secondary experiment is reviewed to determine if the design modifications played a role in increasing the shock housing fracture rate. Through these evaluations a clear correlation is drawn between the design modifications and changes in the reliability of the transfer system.

2.3.1. Bati Fracture Study

The Shock and Propulsion system's batis have been fracturing at an alarming rate. A high bati fracture rate leads to greater levels of down time and higher maintenance/repair costs. Both of these results decrease the overall profitability of the tire manufacturing process. Thus, there is an urgent need to determine the cause of bati failure. Therefore in the following study, we will investigate two possible factors which might have lead to an increase in the bati's fracture rate: a change in the type of shock system used and a change in the speed of transfer.

The first part of the bati fracture study focuses on the theory behind how the type of shock system used and the speed of transfer may result in a change in the bati's fracture rate. After the initial stage, the study centers on investigating an experiment used to verify the theoretical findings. Then, in the last stage of the study, an evaluation of the implications of the theoretical and experimental results is provided.

2.3.1.1. Theoretical Analysis

The bati's speed during transfer plays a key role in determining the peak cyclic impact force that the bati has to sustain. Higher impact forces will lead to an increase in the fracture rate of the bati because the bati is forced to undergo greater levels of stress and strain. Therefore, by determining the relationship between bati velocity and impact force, one can obtain a measure of how the decrease in transfer time on the MAC and MAF systems has effected the bati's fracture rate.

One way of determining how bati velocity and impact force are related is by using the conservation of energy principle. The bati's energy, as a result of its momentum, must be transformed into work performed on the shock in order for the bati to come a complete stop. The following derivation applies this principle to calculate the effects of bati velocity.

Variables:
E = bati's total energy
Q = heat generated within bati during shock impact
W = work performed by bati onto the shock
F = average force during shock impact
x = distance along which bati decelerates (shock stroke length)
V = velocity of bati before shock impact
M= mass of bati and tambour assembly

Units:
G = one gravitation unit of force = 9.8 m/s2
N = Newton
cmn = centi-minutes = 1/100 minutes
s = seconds
m = meters

Conservation of Energy:

$$E = Q + W \tag{2.1}$$

Assumption:

$$Q \approx 0 \tag{2.2}$$

Energy Equations:

$$E = 0.5\ MV^2 \tag{2.3}$$

$$W = Fx \tag{2.4}$$

Substituting equations 2.2, 2.3, and 2.4 into equation 2.1 gives:

$$0.5\ MV^2 \approx Fx$$

$$F \approx (0.5M / x) * V^2 \tag{2.5}$$

Although the relationship between average impact force and bati velocity has now been determined, we still need to clarify how changes in transfer time might effect the fracture rate of a bati. In order to make this clarification, the dependence of transfer time on bati speed must be illuminated. Then, transfer time can be easily related to impact force.

Variables:
T = transfer time (units = seconds unless otherwise stated)
t_a = time required for bati acceleration
t_d = time required for bati deceleration
t_f = time during which bati glides freely from post to post

$n = 2.4$ m = distance between transfer posts
$y = 0.125$ m = stroke length of propulsion cylinder arm
$x = 0.075$ m = stroke length of shock cylinder arm

Transfer Time:

$$T = t_a + t_d + t_f \qquad (2.6)$$

$$T \approx (y / 0.5V) + (x / 0.5V) + [(n - y - x)/V] \qquad (2.7)$$

$$V \approx (n + y + x) / T \qquad (2.8)$$

Substituting equation 2.8 into equation 2.5 reveals the equation relating transfer time to average force during shock impact:

$$F\ (\text{units = Newtons}) \approx (0.5M / x) * [(n + y + x) / T]^2 \qquad (2.9)$$

$$F\ (\text{units = G-s}) \approx \{(0.5M/ x)*[(n + y + x)/T]^2\} \div (9.8M)$$

$$F\ (\text{units = G-s}) \approx (12.8) * [1 / T(\text{units = cmn})]^2$$
(2.10)

Equation 2.10 gives some valuable insight into the bati's average impact force. Using this equation the graph in figure 2.4 was created to pictorially display how average impact force varies with transfer time. However, average impact force is not our only concern. The peak impact force created during shock is likely to play an even greater role in determining bati failure. The shock's peak impact force represents the maximum force that the bati has to sustain during transfer. Average impact force is only equal to peak impact force when the shock system is able to provide perfectly linear deceleration during the entire stroke length of the shock arm. If the deceleration profile is not exactly linear, then the peak impact force value will be larger than average impact force. An actual shock cannot give a perfectly linear deceleration profile, though, it can come close. Different types of shock systems create different types of deceleration profiles. Therefore, even if all other variables

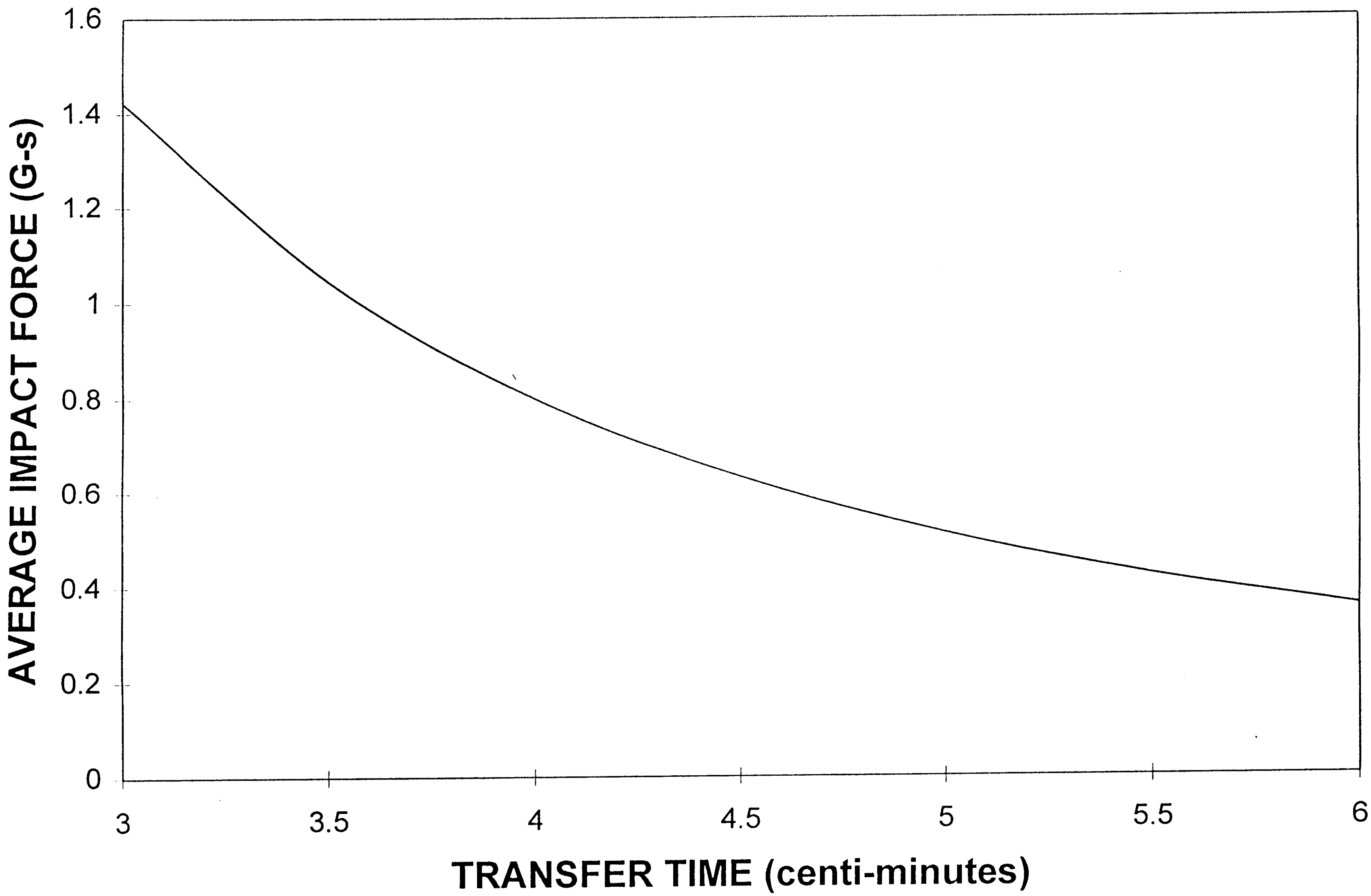


Figure 2.4: Average Impact Force as a Function of Transfer Time

are held constant, changing shock systems can effect the value of peak impact force.

Within the US1 plant there are currently two different types of shock systems being used: the old Michelin designed shock (regular shock) and the new US1 modified shock (modified shock). The regular shock (figure 2.5) contains a system of metering orifices along which the piston arm of the shock passes. During the start of the shock action, the bati is traveling at its largest velocity and the oil in the piston has the greatest amount of orifice surface area to travel through. Then as the velocity of the bati decreases, the piston arm moves along the shock cylinder decreasing the number of metering orifices through which the oil can travel. The method employed by the regular shock system, "varying orifice area proportionally with the decay of impact velocity", has the effect of providing a more constant force distribution during the entire shock process. The modified shock (figure 2.5), however, does not allow orifice area to vary. It contains a single orifice with a constant surface area. When the bati initially impacts the modified shock, there is a high level of resistance because the oil is being forced through the orifice at a rapid rate. Then as the bati's velocity decreases the resistance by the modified shock also decreases, since the rate at which oil must travel through the orifice declines. Because the modified shock system results in changes in the shock's resistance level, it provides a less constant force distribution than the regular shock system.

To better understand the type of force distribution that is created by the regular shock and the modified shock, it may be helpful to utilize some graphs. Ideally the regular shock would cause the bati's velocity to decrease in a linear fashion, by balancing the speed of the bati with the shock orifice area so that pressure in the shock cylinder remains constant. Figure 2.6

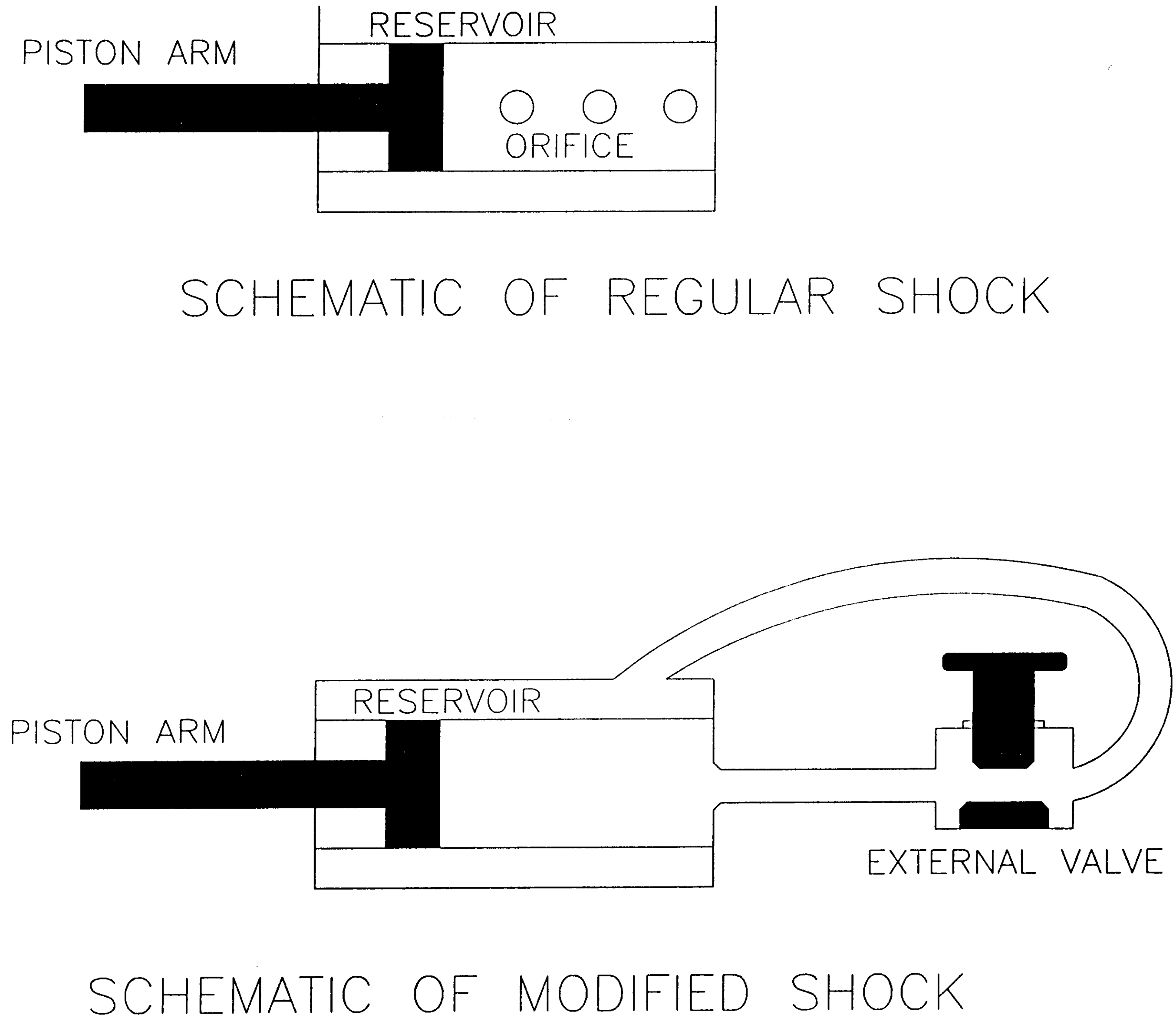


Figure 2.5: Schematic of Shock Designs

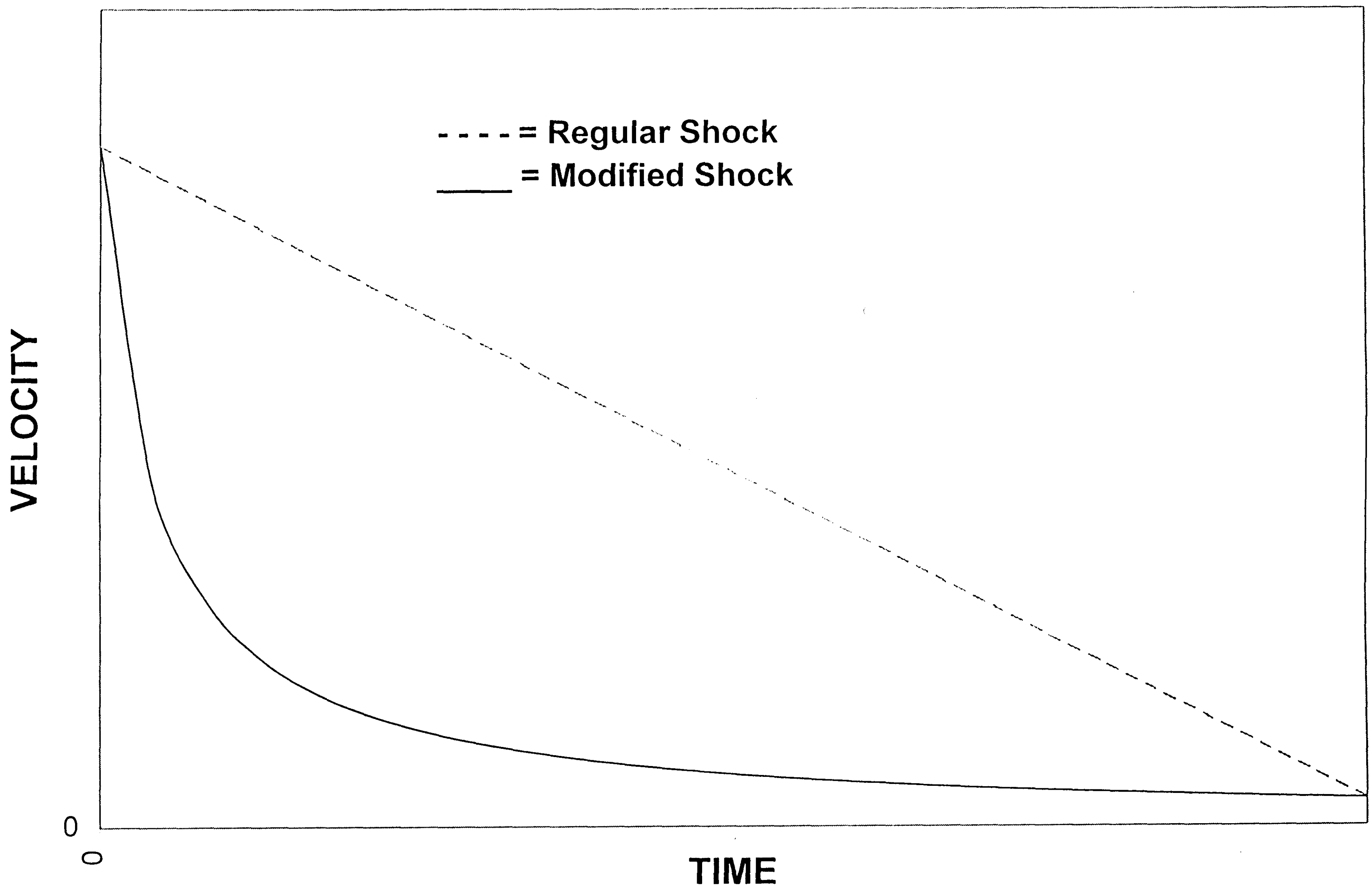


Figure 2.6: Expected Bati Velocity Profile During Impact with Shock

depicts how velocity would theoretical vary according to shock crush time (time it takes to travel the length of the shock arm) for a regular shock. Figure 2.6 also displays the velocity/crush time profile of the modified shock. The modified shock initially causes the bati's velocity to decrease rapidly and then more gradually. The dramatic rate of change in the bati's velocity is caused by the shock's inability to compensate for high and low bati velocities with a constant orifice area.

From the velocity profile curves in figure 2.6, one can readily obtain a theoretical prediction of how impact force will vary with crush time. Figure 2.7 displays the force distribution each type of shock system can be expected to produce. It was obtained simply by taking the derivative of the curves in figure 2.6. After examining figure 2.7, it becomes obvious that the modified shock can be expected to produce a higher peak impact force than the regular shock, when the two shock system's average impact force is the same (i.e. the shocks must absorb the same energy level).

2.3.1.2. Experimental Analysis

In order to verify the findings from the theoretical models used to predict the behavior of the shock systems, an experiment was performed on the MAF bati. By examining the procedure used to conduct the experiment as well as the results of the experiment, one can obtain a clearer understanding of the forces created by the Shock and Propulsion transfer process. Therefore, the following section shall be devoted to outlining the MAF bati experiment.

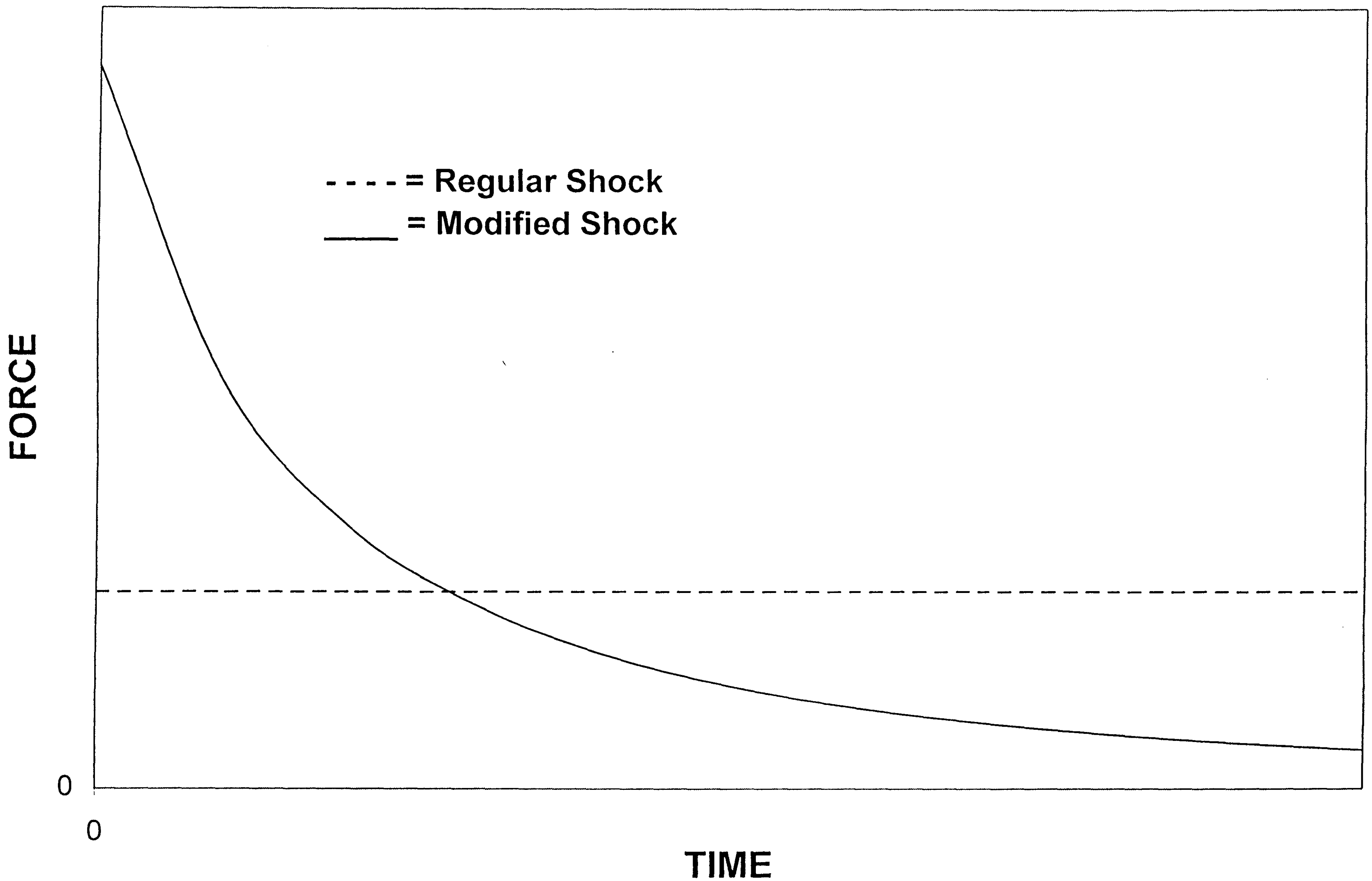


Figure 2.7: Expected Bati Impact Force Profile During Impact with Shock

2.3.2.2.1. **Set-up and Procedure**

The equipment used to conduct the MAF bati experiment included an accelerometer, a "TEAC Data Recorder", and a "Yokogawa Data Analyzer". The data recorder was mounted to the base of the bati as indicated in figure 2.8. The accelerometer was mounted on side of the bati near the portion which provides support for the tambour. A signal conditioner was also used to connect the accelerometer to the recorder. The signal conditioner was responsible for translating the accelerometer's measurements into voltage readings that were proportional to the G forces applied to the bati. After the experiment was concluded the recorder was removed from the bati, and the raw data it contained was manipulated using the data analyzer.

The MAF bati experiment consisted mainly of recording vibrations on the bati during a normal transfer cycle. Initially, the measurement equipment discussed above was placed on the bati, and the bati was inserted into the assembly line. As the bati was transferred from post to post, the accelerometer and recorder assembly measured all the vibration forces that were present. The bati then cycled around the entire MAF line three times. During the same period of time, the average transfer time for each post on the MAF line was recorded using data obtained from Chain Monitoring (a computer software system used to monitor data relating to cycle time). The portable shock tester was also used to record the average shock crush time. At the end of the third cycle, the bati was removed from the manufacturing line and the recorder was taken to a lab area which contained a data analyzer. Using the data analyzer in conjunction with a spreadsheet (Microsoft Excel) the magnitude of the vibration readings recorded during shock crush time was obtained. The vibration data was taken from the recorder's reads using a sample rate of 2 kilohertz. The voltage readings were then converted to G force measurements with the aide of the signal conditioner's

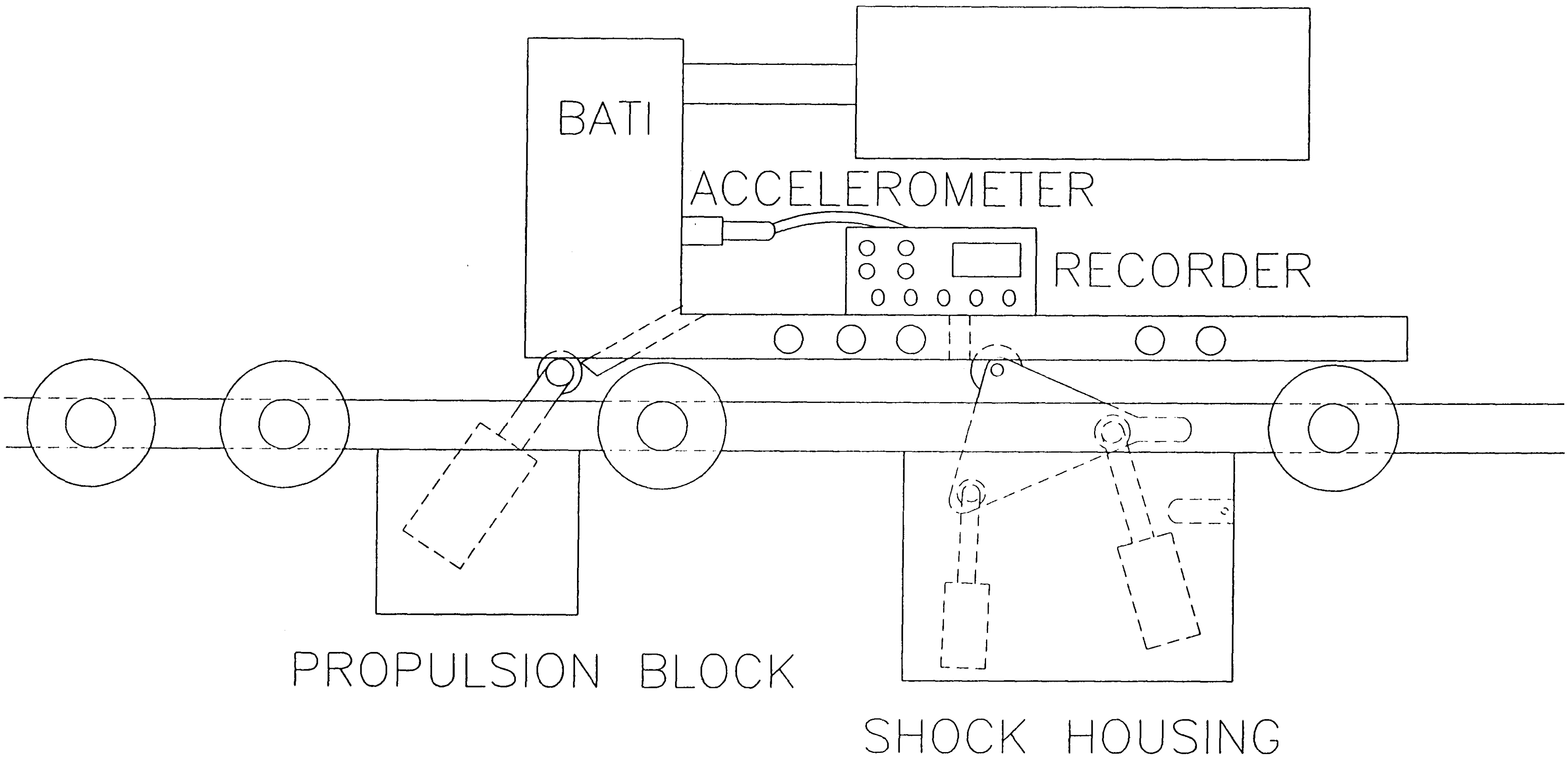


Figure 2.8: Bati Study Experimental Set-up

calibration values. Then, the high frequency vibrations were eliminated so that a shock impact force profile could be obtained.

2.3.1.2.2. Results

One of the major results obtained from the MAF bati experiment was the confirmation of the belief that contact between the bati and the shock creates the largest impact forces present during transfer. However, there were differences in the magnitude of the peak impact forces created by the modified and the regular shock. Using the average crush time, 0.125 seconds, measured in the experiment, a graph of the behavior of the bati during shock impact was obtained. Figure 2.9 displays a typical diagram of the raw data recorded during impact between the shock and the bati. As previously mentioned, the raw data was then converted to a form which revealed the force distribution profile for the modified and the regular shock (figure 2.10). The graphs of the force distribution profiles display that the modified shock creates about a 50% larger peak impact force than the regular shock. The modified shock reaches its peak impact force and then levels back off to a steady state in rapid succession. The regular shock, however, has almost a three stage process in which the impact force gradually rises and then declines. The net result is a more even force distribution profile for the regular shock.

Another important aspect of shock performance which was analyzed was the relationship between average impact force and transfer time. Data collected using posts with slower transfer times revealed that an average impact force of 0.53 G-s was created by a transfer time of 5.0 centi-minutes(cmn) ± 0.2 cmn and that an average impact force of 0.62 G-s was created by a

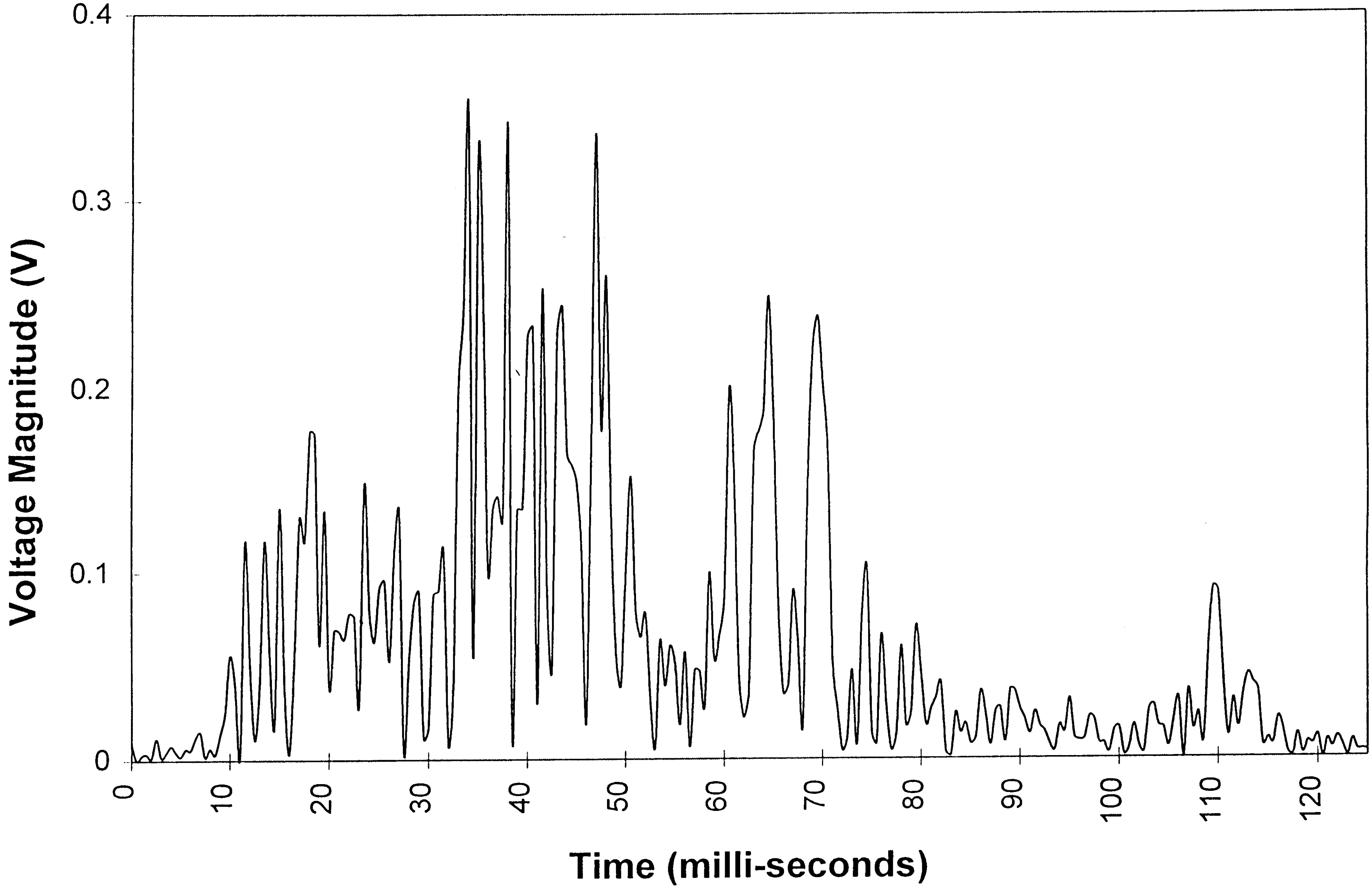


Figure 2.9: Vibration Profile Recorded on Bati During Contact with Regular Shock

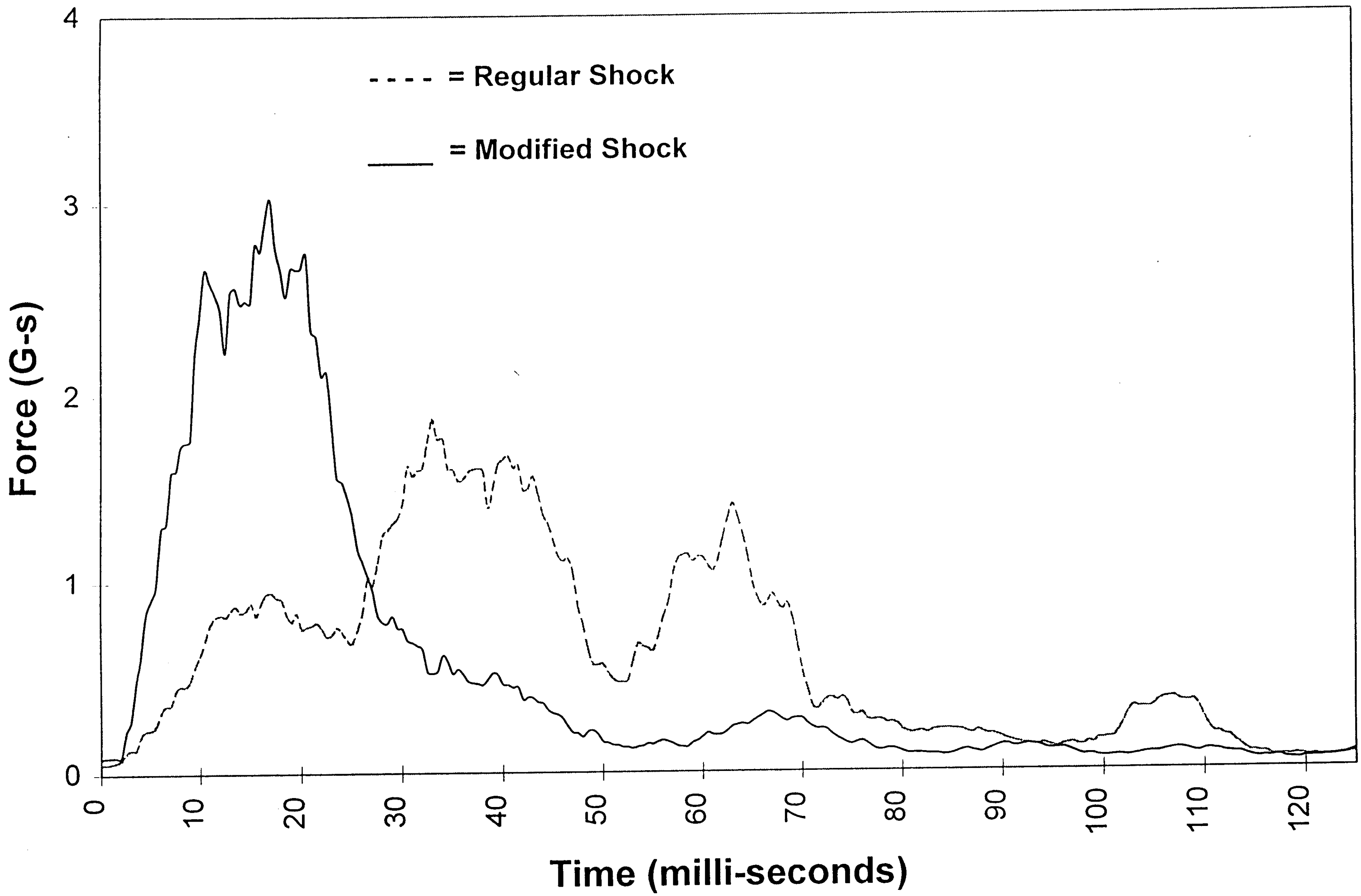


Figure 2.10: Impact Force Profile for Regular and Modified Shock

transfer time of 4.7 cmn ± 0.2 cmn. Detailed information however, could not be gathered for posts with low transfer times, less than about 4.5 cmn. The vibrations created during these fast transfers lead to saturation of the recorded data.

2.3.1.3. Discussion and Conclusions

The results of the MAF bati experiment confirm the theoretical predictions previously made regarding the behavior of the transfer system. A comparison of figure 2.7 and figure 2.10 reveals the similarities between the expected and the actual behavior of the modified and regular shock systems. For example, the modified shock displays the rapid accent to a peak impact force that was forecasted in figure 2.7. The behavior of the regular shock, also helped to confirm the theoretical findings. As predicted the regular shock, although far from providing a perfectly linear deceleration profile, displays a relatively constant force distribution in comparison to the modified shock system.

Data from the MAF bati experiment showed that equation 2.10 provides an accurate estimate of the average impact force sustained by the bati during shock impact. Equation 2.10 predicts that a transfer time of 4.7 cmn and 5.0 cmn should produce an average impact force of 0.51 G-s and 0.58 G-s, respectively. Although slightly smaller, these values are within a reasonable range of the 0.53 G-s and 0.62 G-s displayed by the shocks for transfer times of 4.7 and 5.0 cmn. There are several possible sources of error which may explain the systematically high average impact forces recorded during the experiment. For example, a small error in the crush time measurement could have prevented the averaging of low G force readings at the end of shock impact. Outside sources of vibration noise, could have also added to the forces measured by the recorder.

The agreement between the experimental and theoretical findings help to display that the increase in the bati fracture rate can in fact be partially attributed to the recent modifications implemented on the MAC and MAF transfer systems. Decreasing the transfer time in conjunction with switching to the modified shock design have resulted in an increase in the impact force experienced between the bati and the shock. Higher impact forces lead to greater levels of stress and strain on the bati, thereby causing an increase in the bati fracture rate.

2.3.2. Shock Housing Fracture Experiment

The purpose of the experiments conducted on the shock housing was to determine the effect of transfer time and the type of shock used during transfer on the load that the shock housing would have to bare. The motivation for this study was created by the large number of shock housings that had been failing on the MAC and MAF manufacturing lines. Various groups in the plant suspected that design modifications to the Shock and Propulsion transfer system were to blame for the increase in the shock housing failure rate. However, they had no real evidence to support their claims. As a result of data collect in the shock housing experiment, though, two important conclusion can now be made regarding the effects of the design modifications: 1) increasing the speed of the transfer system leads to higher levels of forces applied to the shock housing, and 2) the type of shock (US1 modified design or original Michelin design) has a negligible effect on the forces applied to the shock housing in comparison to the speed of the bati.

2.3.2.1. Experimental Set-up and Procedure:

The Shock Housing experiment was set-up as indicated on figure 2.11. An accelerometer with a magnetic back cover was placed on the shock housing. On the MAC assembly line, the accelerometer was placed on the mid rear portion of the shock housing. However, on the MAF, access to the shock housing was more limited. Therefore the accelerometer was placed on the top rear portion of the shock housing. Connected to the accelerometer was a CSI (Computer Systems, Inc.) scope which could analyze and store the accelerometer's input signal. The rest of the transfer system including the shock housing, the bati, and the propulsion assembly were located in their regular position on the transfer

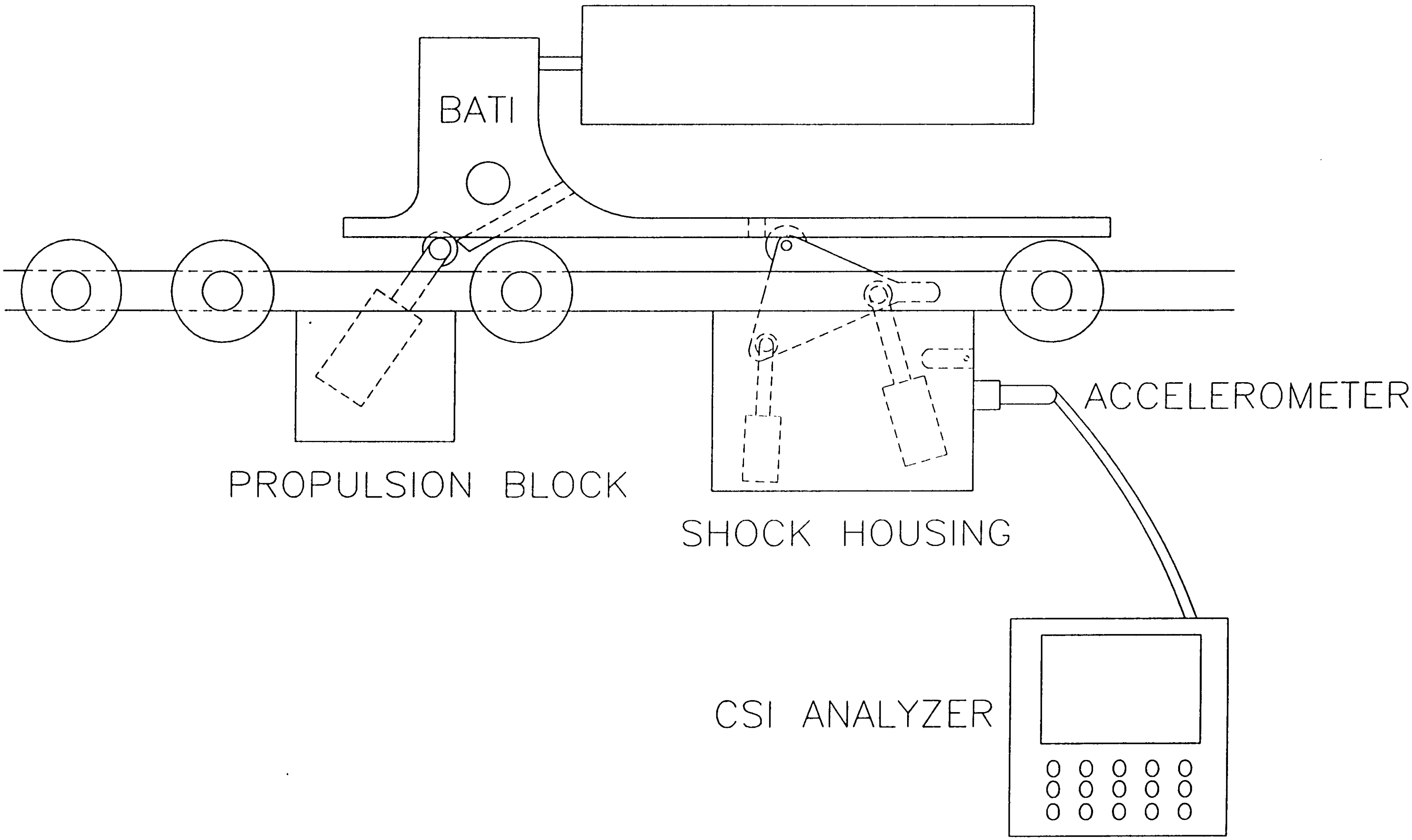


Figure 2.11: Shock Housing Study Experimental Set-up

block. A detailed description regarding the set-up of the transfer components is contained within the previous discussion outlining the layout and operation of the Shock and Propulsion system.

The procedure used to obtain data for this experiment involved two stages. In the first stage, the information in the scope was cleared and the scope was set on trigger mode. Once in trigger mode the scope could recorded data for a set period of time whenever it sensed a signal that was greater than its trigger level. Then, with the scope still in trigger mode, the bati was transferred to the next post. Impact between the shock and the bati at the end of transfer set-off the scope's trigger. The vibration profile of the shock housing could therefore be captured on the scope. The scope was also used to record the peak force during transfer.

The next stage in the experiment centered on recording transfer time. Chain Monitoring measures transfer time on each post during every transfer. Therefore it was used to obtain the transfer time data corresponding to the previously determined peak impact force reading. Each of these two steps was then repeated thirty times on two MAC posts with the same transfer time but with different types of shocks and two MAF posts with the same type of shock but with different transfer times.

2.3.2.2. Results

The shock housing vibration study revealed important patterns in the behavior of the transfer system. The detailed results of the study are summarized in the graphs contained within this section. Before these graphs were created, though, the manufacturer's calibration data had to be used to relate the output voltage recorded to force readings. Then, a comparison of the forces produced by the US1 modified and Michelin designed shocks (a.k.a. modified and regular shocks) was made in figure

2.12. The graph clearly shows, for a given transfer time, the peak forces on the shock housing do not vary greatly with respect to the type of shock used. The mean value of the peak forces created by the modified and regular shock are 5.4 G-s and 5.0 G-s, respectively. The modified shock's mean value has a standard deviation of 0.70 G-s, while the regular shock's mean value has a standard deviation of 0.54 G-s. The mean value of the forces recorded on the shock housing of the regular shock is well within a standard deviation of the modified shock's mean value and visa versa. Therefore, there is not much of a statistical difference between the peak forces imparted by the two shock systems onto the shock housing.

The manufacturer's calibration information was also used to determine the effect of transfer time on the shock housing. A graph of the forces on the shock housing as function of transfer time is depicted in figure 2.13. While the systems in figure 2.13 contained the same type of shocks and were both on the MAF assembly line, they did have different types of propulsion cylinders driving the batis to each post. The system with a transfer time of 4.0 cmn contained the new commercial propulsion cylinder and the system with a transfer time of 4.9 cmn contained the old propulsion cylinder. From figure 2.13 one can infer that the force on the shock housing is dependent on the type of propulsion cylinder used. Although the exact nature of the mathematical relationship between peak forces and transfer time cannot be deduced from the information gathered in this study, the fact that an increase in bati speed (which corresponds to a lower transfer time) will result in a larger force on the shock housing can distinctly be seen. As indicated on the graph, the new and old propulsion systems created a mean peak force value of

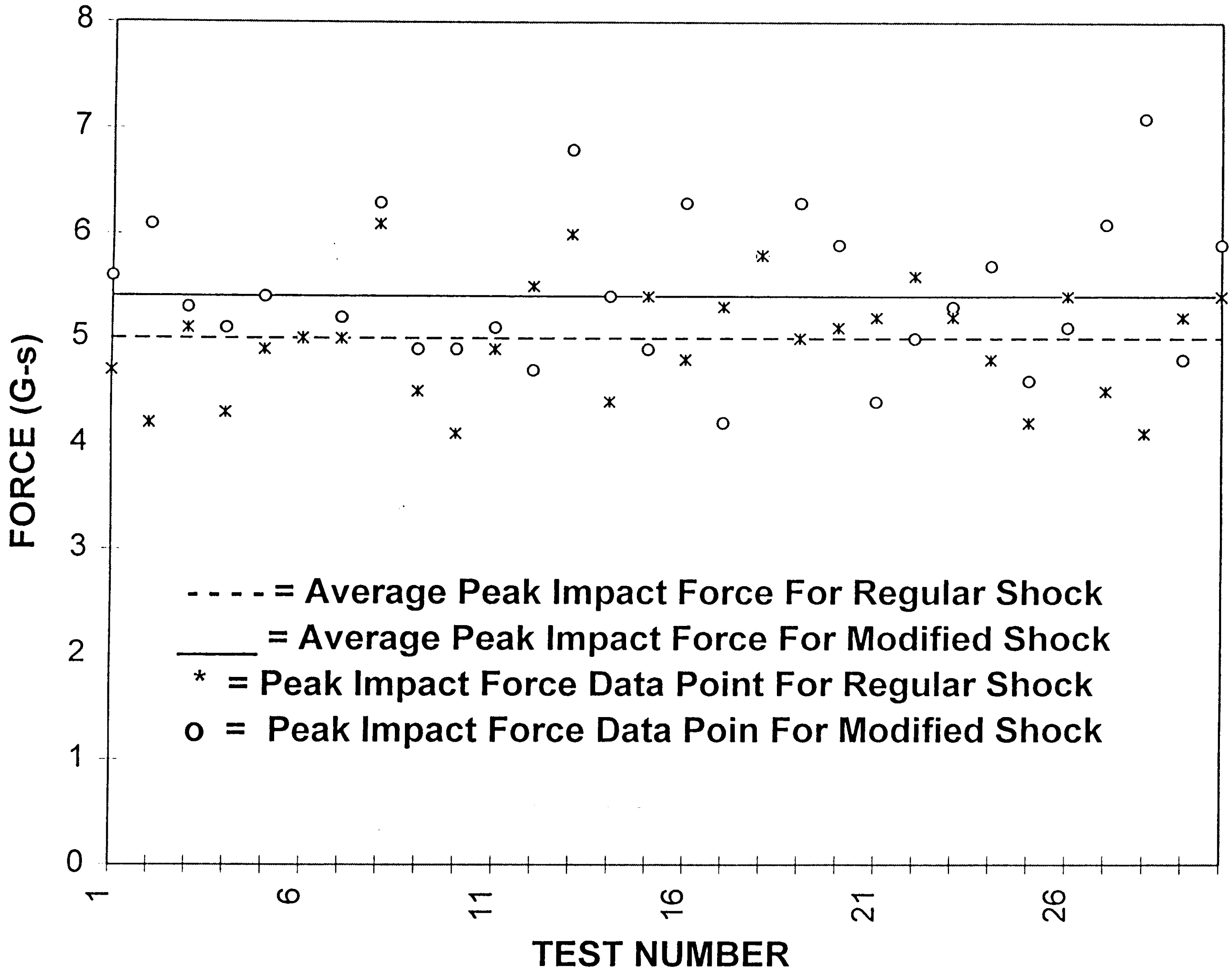


Figure 2.12: Forces Recorded on MAC Shock Housings for MAC Posts with a Transfer Time of 3.5 centi-minutes

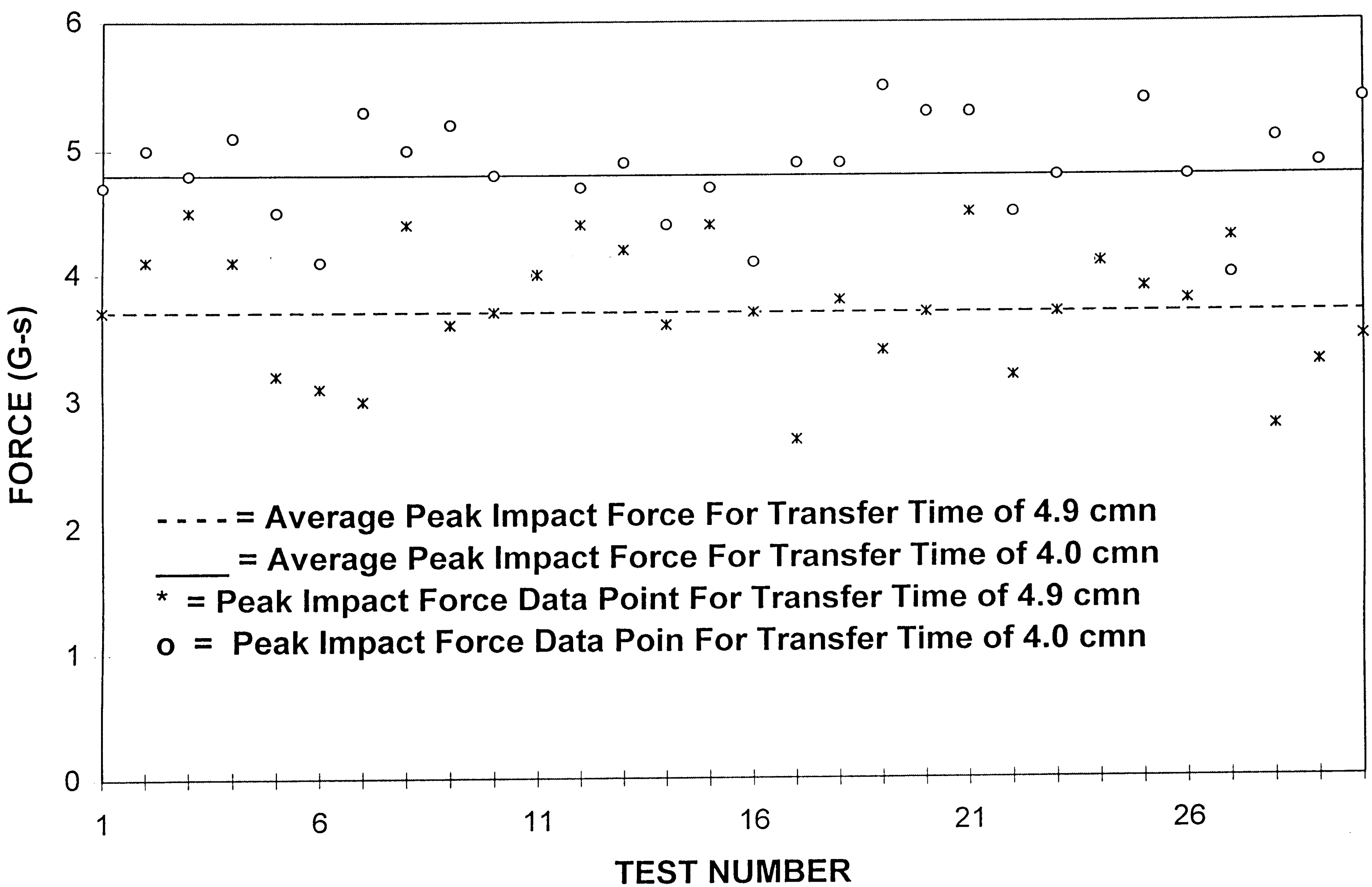


Figure 2.13: Forces Recorded on MAF Shock Housings for MAF Posts with a Regular Shock

4.8 G-s and 3.7 G-s, respectively. The new propulsor's mean value has a standard deviation of 0.43 G-s, while the old propulsor's mean value has a standard deviation of 0.50 G-s. The mean values of each propulsion system is well outside a standard deviation of the other propulsion system's mean value. This leads one to conclude that their is a statistical difference in the peak force values created by the old and new propulsion systems.

2.3.2.3. Measurement Error

Before elaborating on the implications of the findings contained within the report, it must first be noted that the data gathered in this study needs to be evaluated with some care because several sources of experimental error could not be eliminated. In order to understand how the various sources of error effected the data, let us examine in detail how the procedure used to conduct the vibration study could have lead to the contamination of the data.

As previously noted, the process used to conduct the vibration study involved mounting an accelerometer onto the shock housing and then using a portable scope to record vibrations on the shock. It was hoped that these recordings would give an accurate assessment of the forces on the shock housing that resulted when the bati slammed up against the shock. However, due to the shock's ability to absorb a large portion of the bati's kinetic energy before it reached the shock housing, the "noise" created from other sources of vibrations made it difficult to obtain accurate and consistent data. For example the movement of the shock block's rearm cylinder would at times add to the vibration forces created by the bati. Even the motion of the propulsion cylinder would in certain cases create vibration forces which would appear on the shock housing.

Another striking feature of the data collected in this study is that the forces on the MAF's shock housings appear to be less than the forces on the MAC's shock housings. However, the difference in the forces recorded on the MAC and the MAF may be artificial. Vibration readings on the MAC and the MAF, as indicated in the set-up section, were taken on different spots on the shock housing. The attachments (bolt systems) used to connect the shock housing onto the two systems' transfer blocks were also different. These difference could effectively alter the amount of vibration that was recorded, even if the actual forces on the shock housings were the same. Therefore, one cannot accurately make a numeric comparison between the data taken on the MAC and the MAF.

The presents of vibration noise and the non-uniformity in the experimental set-up, inhibit us from reaching quantitative conclusion involving the forces present within the shock housing. However, despite the fact that a healthy dose of caution is required before reaching any conclusions, the data collected in this study does provide some valuable insight into the qualitative behavior of the transfer system.

2.3.2.4. Discussion and Conclusions

After examining the results of this study, some general conclusion can be made about the different types of propulsion and shock systems' effects on the shock housing. The type of propulsion system used can effect the failure rate of the shock housing through determining the speed in which the bati is propelled. Since the new propulsor resulted in a faster bati, it caused larger vibration forces on the shock housing. However the old propulsion cylinder, with a slower bati speed, imparted less force on the shock housing. The greater the forces are on the shock housing, the more likely it is that fracture will occur. Using this information, one can conclude that a faster bati speed will result in a greater probability of fracture within the shock housing.

The data collected in the study also shows that if the speed in which a bati impacts a US1 modified and a Michelin designed shock is the same, then there is not significant difference in the vibration forces present in the shock housing. Similar vibration forces in two systems having the same number of cyclic loads is likely to lead to similar levels of fatigue failure. It can therefore be concluded that the type of shock used plays only a small role in the fracture rate of the shock housing.

2.4. General Appraisal

The overall performance of the Shock and Propulsion transfer system needs to be evaluated in terms of four factors: cost, reliability, transfer time, and noise level. Each of these factors plays a critical role in determining the desirability of using the Shock and Propulsion transfer system on future manufacturing lines.

The cost of the Shock and Propulsion system has been decreasing over time. Initially, Michelin designed and manufactured almost all the components involved in transfer because it did not what to reveal various aspects of its manufacturing process to outside parties. Today however, many of the components, such as the propulsion system, are purchased from commercial venders with mass production capabilities. This has helped to dramatically decrease the cost of building a Shock and Propulsion transfer system. Furthermore, recent gains in the transfer times have helped to decrease the overall cycle time for producing tires. Decreasing cycle time has in turn lead to substantial cost savings, making the Shock and Propulsion system even more cost effective.

The reliability concerns regarding the Shock and Propulsion transfer system center on fracture of the bati and the shock housing. The experiments performed on the transfer system revealed that the fracture rate of these components can be expected to rise with the decrease in transfer time. However, it was also determined that switching back to the old Michelin designed shocks will result in a decrease in the fracture rate without altering transfer time. The reliability of the Shock and Propulsion system can be farther increased by making the periodic testing and repair performed in US1 more universal. For example by implementing the use of US1's portable and stationary shock testers globally, one can effectively guard against improper set-up and assure that excess force is not applied to any component.

The transfer time of the Shock and Propulsion system was improved significantly as a result of the design modifications which were performed. The average transfer time of the MAC in US1 was decreased to 3.5 cmn from 3.8 cmn. The average transfer time on the MAF was decreased from 4.4 cmn to 4.0 cmn. These gains in transfer time have helped to make the Shock and Propulsion transfer system more competitive in comparison to other transfer systems.

The noise levels produced by the Shock and Propulsion transfer system are on average equal to 93 dB. Although attempts to reduce the noise level of the transfer system were not made as part of this study, there have in past been several attempts to reduce the amount of noise produced. Rubber bumpers were added onto the end of the batis and mufflers were added to the exhaust of the propulsion cylinders. However, these attempts to produce a noticeable reduction in noise were not successful. In fact the high sound level of the Shock and Propulsion transfer system is one of the major reasons behind the creation of the MATCH and AC Drive transfer systems.

3. New Transfer Systems

Alternatives to the current standard transfer system containing pneumatic propulsors and hydraulic shocks have been recently developed. In US5 (plant number five in the United States) there are currently two alternative transfer systems operating: the AC Drive transfer system and the MATCH transfer system.

As previously noted, the performance criteria for a transfer system can be divided into four categories: cost, reliability, transfer time, and noise level. The MATCH transfer system performs fairly well in terms of reliability and noise level. However, the cost and transfer time exhibited by the MATCH transfer may not be adequate for future needs. The AC Drive transfer system provides a fast transfer time, low levels of noise, and is cost effective. However, its reliability may be an area for concern.

Overall, the MATCH and the AC Drive transfer systems both have advantages and disadvantages in comparison to the Propulsion and Shock transfer system. In the evaluation that follows, the strengths and the weaknesses of each of the transfer processes shall be examined in a qualitative manner. This examination shall provide a framework on how to take various factors into account when rendering future decision regarding transfer systems.

3.1. MATCH Transfer System

MATCH transfer is composed of three major systems: the cam and roller assembly, the bati and tambour assembly, and the transfer block assembly. Together, these assemblies, provide a simple method for transferring rubber material on the MAC manufacturing line. Initially, during transfer, a single speed drive motor is used to rotate the shaft in the transfer block assembly. The cam is then triggered causing the wheels on the roller to rotate to a maximum of 45 degrees with respect to the transfer block shaft. When the wheels are no longer parallel to the transfer block shaft, the rotary motion of the shaft causes the bati and tambour to move forward (figure 3.1 shows how this process works). After the bati and tambour have almost reached the next post, the cam repositions the wheels on the roller so they are once again parallel to the transfer block shaft. This in turn causes the bati and tambour to stop moving forward. The entire process is then repeated to provide the next transfer.

3.1.1. Cost

A price comparison of the major components within MATCH and within Shock and Propulsion transfer revealed that the initial cost of the two systems is approximately the same. However, before a true cost comparison can be performed, the transfer systems' expected future payoffs must also be factored in. The future payoff of a transfer system can be estimated by evaluating the effect of the system's transfer time on cycle time. Faster transfer times lead to lower cycle times. Lower cycle times, in turn, create cost savings by increasing the production capacity of a line. The average transfer time of the Propulsion and Shock system is moderately faster than MATCH transfer. Therefore it can be concluded that the overall cost of the MATCH transfer

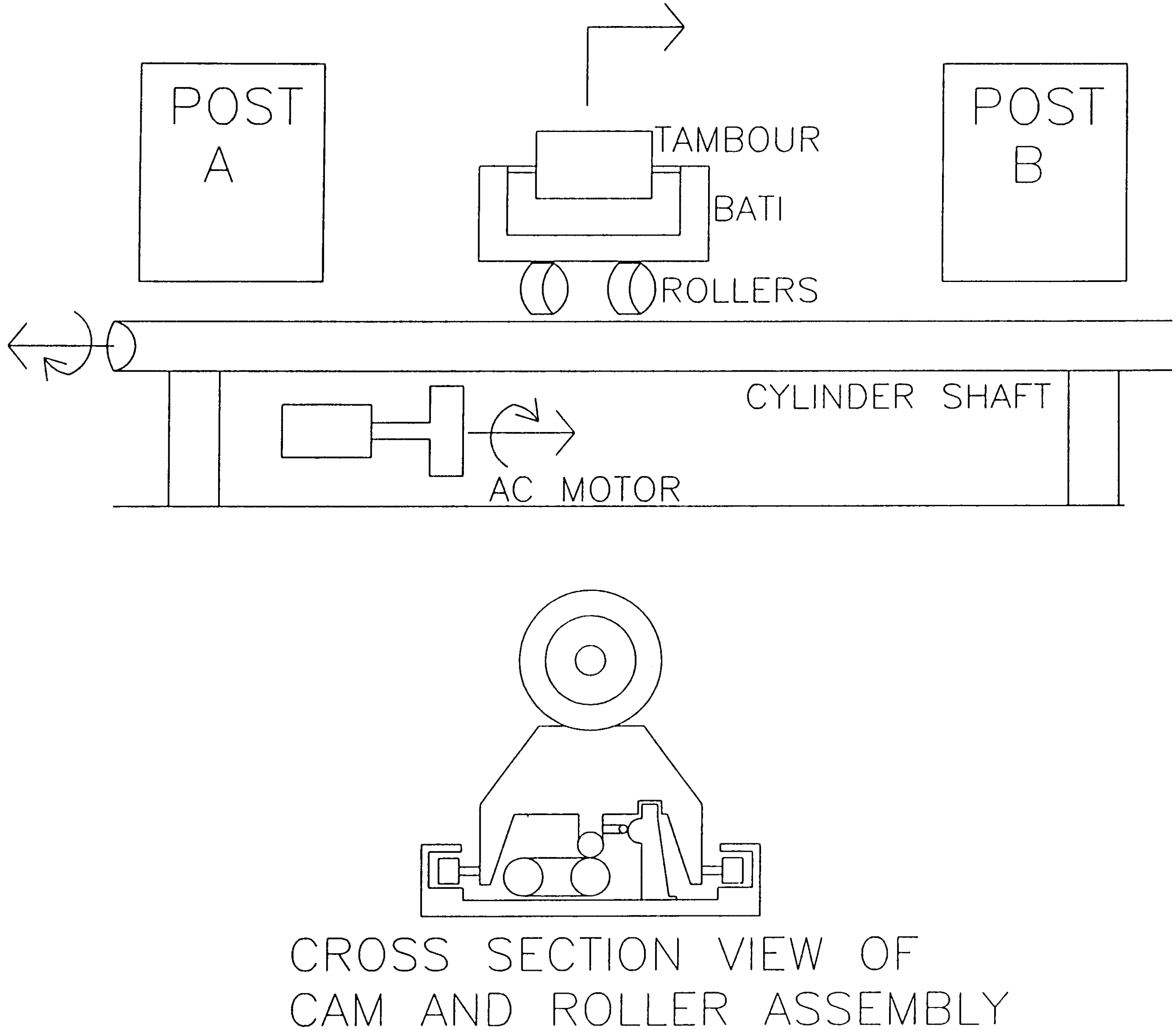


Figure 3.1: MATCH Transfer System

system is slightly greater then the Propulsion and Shock transfer system.

3.1.2. Reliability

The trouble shooters and linemen who work on the MATCH transfer system praise it for its consistency and effectiveness. Compared to the Propulsion and Shock transfer system, the MATCH transfer system has fewer maintenance requirements and less down time. Having made this statement, it is also important to note that MATCH transfer is not without faults in terms of reliability. The primary mode of failure within the MATCH system is fracture of the stop guard. The stop guard is a guard designed as a safety device to assure that the bati and tambour come to a full stop at the end of transfer. If the cam is mis-aligned on the bati, then the bati may still posses some kinetic energy (i.e. it has not fully decelerated) when it comes into contact with the stop guard. This will cause the guard to withstand a high impact force. Eventually, high levels of impact force can cause the guard to fail. Another cause of down time by the system is wear on the rollers attached to the cam. Roller wear can cause slippage and prevent proper travel of the bati.

3.1.3. Transfer Time

The MATCH transfer system in US5 has an average transfer time of about 3.7 cmn (centi-minutes). Keeping in mind that MATCH transfer takes place on the MAC, this is a rather slow transfer time. The Propulsion and Shock transfer system in US1 has an average transfer time of 3.5 cmn on the MAC line. Therefore, on average MATCH transfer will results in a 0.2 cmn higher cycle time. Furthermore due the mechanical nature (use of a cam to position rollers) of the deceleration and acceleration process, it may be difficult to obtain a faster transfer time without a redesign of the system. For example, any attempts to increase the speed of the bati will likely aggravate the problems associated with the bati hitting the stop guard with excess force.

3.1.4. Noise

The MATCH transfer system provides a low noise level transfer. The Shock and Propulsion transfer system, on the other hand, contains large banging sounds created as a result of the sudden impact between the bati and the shock. The Shock and Propulsion system's pneumatic exhausts also create a great deal of noise. The MATCH transfer system however, does not require any sudden physical contact or any pneumatics. Therefore the MATCH transfer system creates on average a 90 dB noise level reading while the Shock and Propulsion transfer system creates 93 dB noise level reading.

3.2. AC Drive Transfer System

The AC Drive transfer system (figure 3.2) is currently being used to provide transfer on the MAF lines in US5. The system consists of a motor powering a group of rollers using timing belts and pulleys. In addition, the AC Drive transfer system also contains a deceleration and stop photocell which provides a signal to the motor to reduce its speed.

The method by which the AC Drive transfer system functions is rather simple. At the start of transfer the AC motor causes the rollers to rotate at a high velocity. This in turn causes the bati to be propelled forward as the rollers push along the skis of the bati. Then, when the bati reaches the deceleration photocell, a message is sent to the motor to decrease its speed. The rollers, in turn, slow down causing the bati to decelerate. Finally, when the bati reaches the stop photocell, the motor is turned off and the rollers along with the bati come to a full stop.

3.2.1. Cost

Although the mechanical layout and function of the AC Drive transfer system appears rather straight forward, the complexity of the variable speed AC motor coupled with the high level of programmable electronic controls that are required creates the foundation for a rather expensive transfer system. The need for a separate AC drive motor for each post also aides in driving up the initial costs. Therefore the cost of installing an AC Drive transfer system is significantly more than the cost of installing a Shock and Propulsion transfer system. However, advances in PLC controls and drive motors may lead to diminished initial costs in the future. Furthermore the savings in transfer time produced by the AC Drive transfer system (as indicated by the "AC Drive

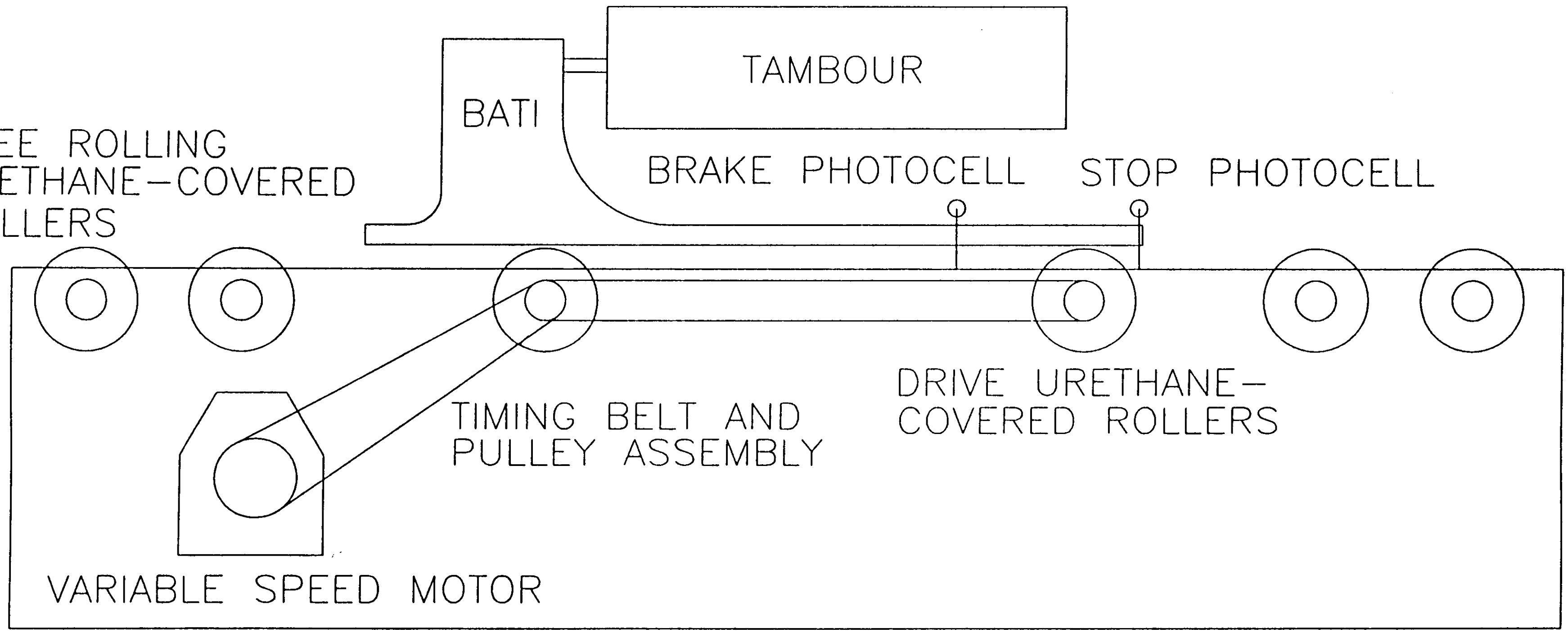


Figure 3.2: AC Drive Transfer System

Transfer System Work Order Report") can be expect to lead to future payoffs which will more than offset its initial cost. Therefore, it can be concluded that the AC Drive transfer system is more cost effective than the Shock and Propulsion transfer system.

3.2.2. Reliability

Reliability is an important concern with an AC Drive transfer system. There have in the past been various types of problems related to overtravel and undertravel by the batis. These erratic transfers were caused by roller contamination, loose idlers on pulleys and tensioners, failure of the AC drive motor, and wear on the bottom of bati skis. Some of these issues have been successfully dealt with. However, a significant amount of preventive maintenance was required to increase the reliability of the system. Even with the additional preventive maintenance, though, reliability is still a major concern. In fact, due to current concerns regarding reliability, there is a mechanical shock system on the TS post and the descent elevator as a safety precaution for overtravel by the bati (overtravel at these posts could lead to high levels of damage). A recent maintenance study also indicated that trouble shooters responsible for repairing equipment on the AC Drive transfer system required high levels of training due to the complex nature of the electronic components found in the transfer system. The study also raised some questions regarding the ability of the AC Drive transfer system to provide transfer for a MAC assembly line. The MAC, which contains a lighter bati and tambour then the MAF, may not provide large enough frictional forces to assure that the bati skis do not slip excessively.

3.2.3. Transfer Time

The AC Drive transfer system provides a fast transfer. The average transfer time of a MAF line in US1 with a Propulsion and Shock transfer system is 4.4 centi-minutes. Current modification to the transfer system are expected to bring transfer time down to 4.0 centi-minutes. The average transfer time of a MAF line in US5 with an AC Drive transfer system is about 3.5 centi-minutes. Therefore even after modifications are made, the AC Drive Transfer System can still be expect to provide a faster transfer than the Shock and Propulsion transfer system. This low transfer time translates to a faster overall cycle time and the production of more tires.

3.2.4. Noise

The smooth deceleration and acceleration process of the AC Drive transfer system allows it to provide a quite transfer. Studies conducted within the "AC Drive Transfer System Work Order Report" revealed that noise levels during transfer have fallen from 93 dB to 88 dB with the elimination of the banging associated with a Shock and Propulsion Transfer System. The low level of sound is an important advantage of the AC Drive transfer system because it allows for compliance with more sever noise ordinances and also helps to decrease the need for ear plugs by workers.

4. Timing Belt Driven Transfer System

In the previous sections we examined the different transfer system designs that are currently in operation. Modest improvements, such as those performed on the shock and propulsion transfer system, can be made for each of the other transfer systems discussed. However, in order to obtain significantly faster transfer times as well as major gains in overall performance a major redesign of the transfer system is required. The basic areas in which a redesigned transfer system would need to excel would remain the same. The change in the objectives of the new transfer system would center on the level of performance that is required. More specifically, the new transfer system would need to be quieter, faster, more accurate, and more cost effective.

Three new ideas for transfer system designs were examined in hopes of finding a system that would provide a better transfer method. In the sections that follow, we shall evaluate in detail the final transfer system design that was selected. This will hopefully provide insight regarding future decisions on methods for upgrading the transfer system.

4.1. Objectives

The motivation for the creation of a new transfer system design centered on the desire to have a transfer system with an average noise level below 90 dB, a transfer time of 3.0 cmn, a simple and accurate method for providing transfer, and an initial cost that is offset by the cost savings it provides. The selected transfer system design, which shall be referred to as the Timing Belt Driven transfer system, meets all of these objectives. In order to understand how the Timing Belt Driven transfer system operates and how it succeeds in meeting the design specifications, a detailed study of the system is needed. This examination shall consist of four parts: a general description of the design, a theoretical and experimental analysis of the system, a cost evaluation, and a discussion outlining the strengths and weaknesses of the design.

4.2. Layout and Operation

The Timing Belt Driven transfer system is composed of a variable speed motor, a timing belt and sprocket assembly, a brake and a stop photocells, and a bati who's base is lined with material from a timing belt. A schematic of the Timing Belt Driven transfer system is contained within Figure 4.1 (more detailed mechanical drawings of the Timing Belt Driven transfer system are located in Appendix A). The variable speed motor is located underneath the rest of the system. Its energy is transmitted to the drive sprockets, via a connection assembly containing sprockets, timing belts, tensioners, and shafts. The drive and rolling sprockets are located just above the top portion of the transfer block. The bati's toothed base, composed of timing belt material, rests on top of the drive and rolling sprockets.

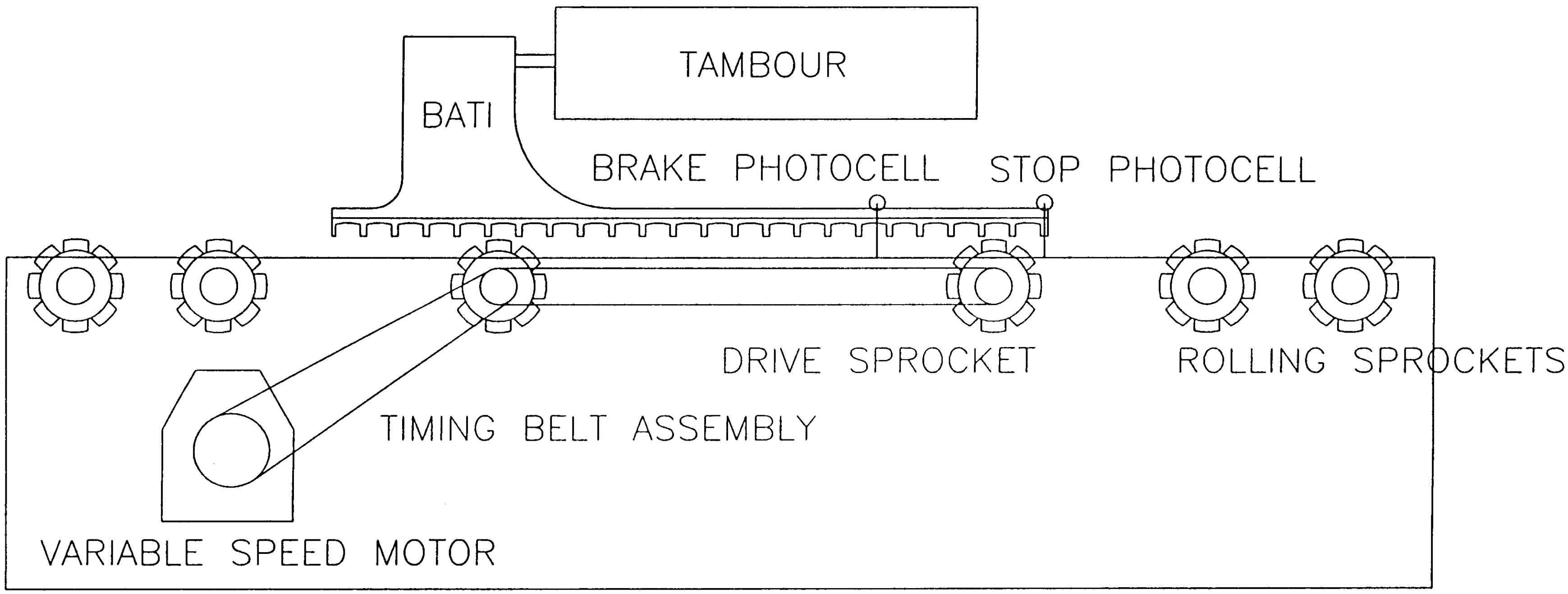


Figure 4.1: Timing Belt Driven Transfer System

How the components in Timing Belt Driven transfer system operate is rather straight forward. At the start of transfer an electrical signal is given to provide power to the motor. The variable speed motor then causes the drive sprockets to rotate by providing a torque, through the connection assembly. The drive sprockets then push the bati forward to the next transfer block as they rotate across the toothed base of the bati. Then, the bati comes into contact with the drive sprockets of the next transfer block. Soon after, the brake photocell is triggered and the brakes on the variable speed motor provide a torque to resist the inertia of the bati. The bati gradually decreases its speed until it comes into contact with the stop photocell. After the bati has come into contact with the stop photocell, a signal is sent to the motor to stop rotating the drive gears and the bati comes to rest.

4.3. Design Analysis

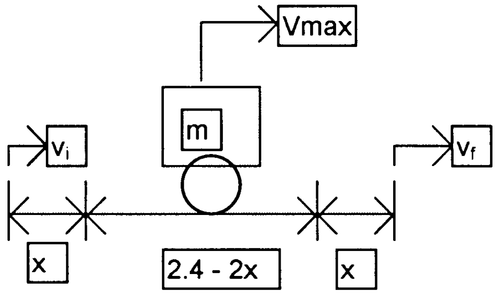
In order to assure that the Timing Belt Driven transfer system would provide a transfer time of 3.0 cmn and a noise level below 90 dB, the proposed final design was carefully analyzed. The power rating of the variable speed motor as well as the dimensions of the various components in the connection assembly were determined using theoretical calculations. The noise level that would be created by the Timing Belt Driven transfer system was determined by using experimental data from the AC Drive transfer system. A thorough evaluation of these techniques will reveal the ability of the Timing Belt Driven transfer system to achieve its design objectives.

The various parts which comprise the Timing Belt Driven transfer system were chosen to assure that a transfer time of 3.0 cmn could be safely and reliably achieved at minimum cost. The major part which played a critical role in assuring the performance of the transfer system was the transfer system's motor. Therefore, we shall now focus on the calculations performed to determine the size of the motor.

Motor size calculations were based on two assumption: the bati undergoes linear acceleration and declaration during transfer, and the frictional forces along the transfer block are negligible. The assumptions regarding the acceleration and deceleration behavior of the bati during transfer are reasonable because according to the manufacturer's data involving their constant torque variable speed motor the acceleration and deceleration profile is very close to linear. Furthermore the zero friction assumption is also reasonable, due to the fact that the free rolling nature of the rolling sprockets assures that very little velocity is lost as a result of frictional forces during transfer.

The minimum motor size required (which would represent the least expensive motor) was determined by optimizing the distance over which the bati would need to be accelerating and decelerating in order to achieve the lowest possible power requirement. Optimization of the acceleration/declaration distance involved four steps, during which the equations governing the following relationships were derived: the maximum bati velocity required to produce a 3.0 cmn transfer time as a function of acceleration/deceleration distance, the acceleration/deceleration rate as a function of acceleration/deceleration distance, the power required to provide the necessary torque and angular speed as a function of the acceleration/deceleration distance, and finally the acceleration/deceleration distance that would produce the minimum power requirement. The following summary gives an overview of the process involved in deriving the power minimization equations.

Transfer Model:



Variable Identification
m = mass of bati
r = radius of drive wheel
V_{max} = max velocity of bati
x = acceleration and deceleration distance
F = force
a = acceleration rate = deceleration rate
P = power
τ = torque
ω = angular velocity
α = angular acceleration = angular deceleration
J = Moment of inertia to be driven
x = acceleration distance = deceleration distance
η = mechanical efficiency of system
T = transfer time

Known Variable Values
η = mechanical efficiency of system = 0.8
T = transfer time =3.0 cmn =1.8 sec
r MAC = 0.085 m   r MAF = 0.085 m
m MAC = 320 kg   m MAF = 520 kg

Optimizations Steps for Determining Minimum Power Required

Maximum Velocity
T = acceleration time + free wheel time + deceleration time
$T = [x / (0.5\ V_{max})] + [(2.4 - x) / V_{max}] + [x / (0.5\ V_{max})]$
$T = (2.4 + 2x) / V_{max}$
$T = 1.8\ \text{sec} = (2.4 + 2x) / V_{max}$
$$V_{max} = 1.11\ x + 1.33 \qquad (4.1)$$

Acceleration/Deceleration rate
$a = (dv/dt) = (v_i - v_f) / (t_i - t_f) = V_{max} \div (x / 0.5\ V_{max})$
$$a = V_{max}^2 / 2x \qquad (4.2)$$

Power Required

$P = (\tau / \eta) * \omega$

$P = (mar / \eta) * (V_{max} / r)$ (4.3)

Substituting Equation 4.2 into Equation 4.3 Reveals:

$P = (m/\eta) (V_{max}^3 / 2x)$ (4.4)

Substituting Equation 4.1 into Equation 4.4 Reveals:

$P = (m / 2x\eta) * (1.11 x + 1.33)^3$ (4.5)

Acceleration/Deceleration Distance for Minimum Power Requirement

$dP/dx = (m/\eta) (1.37 x^3 + 2.47 x^2 -1.19) = 0$

$1.37 x^3 + 2.47 x^2 -1.19 = 0$ (4.6)

Solving for the Real Root in Equation 4.6 Reveals:

x = 0.6 meters

The values that are needed to specify a motor are: the maximum torque requirement, the maximum angular velocity requirement, the moment of inertia that needs to be driven, and the power requirement. Having already determined the optimal acceleration/deceleration distance, these values can now be readily calculated. An exact listing of what the calculated values are and how they were obtained, as well as detailed information about the motors which were selected, is contained within Appendix B. However, it is worth noting here that the final motor selected for MAC transfer was a 5.0 hp constant torque variable speed motor with a brake, and the final motor selected for MAF transfer was a 7.5 hp constant torque variable speed motor with a brake.

The dimensions and the specifications of the timing belt assembly were determined by using the manufacturer's guide for sizing timing belts. A detailed listing of the timing belt assembly selection process is contained within Appendix C. Furthermore Appendix D also contains the manufacturer's information on some smaller components that were also used in the design.

4.4. Noise Level Study

The Timing Belt Driven transfer system is very similar to the AC Drive transfer system in terms of the noise level it can be expected to produce. The only difference in the Timing Belt Driven transfer system which could create the potential for a louder transfer is the presence of a larger motor and contact between the drive sprocket and the timing belt material on the bottom of the bati. The MAF assembly line's Timing Belt Driven transfer system requires a 7.5 hp motor as opposed to the 5.0 hp motor required for MAF transfer by the AC Drive transfer system. However, information from the manufacturer indicates that both types of motors create about the same noise level. Therefore, the use of a 7.5 hp motor should not represent any significant increase in noise. The contact between the drive sprocket and the bati is also not a significant source of noise. The timing belt material on the bottom of the bati is plastic and the bati is designed to move at almost the same velocity as the drive rollers during impact. The presence of a plastic contact between two objects traveling at almost the same velocity would cause little if any addition noise. Therefore one can conclude, that by measuring the noise output of the AC Drive transfer system, it is possible to obtain an accurate assessment of the Timing Belt Driven transfer system's expect noise output level.

A noise level study which was performed on the MAF line of an AC Drive transfer system revealed that a average noise level of 88 dB was reached during transfer. Noise level information regarding the MAC line could not be directly obtained due to the lack of an existing AC Drive transfer system on a MAC line. However because the components in a MAC line are smaller and traveling at the same velocity as MAF components, we can easily use the MAF noise levels as an upper limit to what can be expected to be found on the MAC line. Therefore one can conclude that the new Timing Belt Driven transfer will produce a noise level below 88 dB on both the MAC and the MAF. This is a significant improvement over the 93 dB created by the Shock and Propulsion transfer system and it is well below the design objective of 90 dB.

4.5. Cost Analysis

In order to analyze the cost effectiveness of the Timing Belt Driven transfer system, one must compare the annual gross cost saving that is expected with the initial cost of installing the system. In Appendix E the gross cost saving associated with switching to a Timing Belt Driven transfer system from the MATCH transfer system on the MAC and the Shock and Propulsion transfer system on the MAF was determined to be $905,000 per year and $1,280,000 per year, respectively. Switching from either the AC Drive transfer system on the MAF or the Shock and Propulsion transfer system on the MAC resulted in a gross cost saving of $640,000 per year. The initial cost of installing the Timing Belt Driven transfer system on both the MAC and MAF was also estimated as being $630,000 in Appendix E. Using these values as a guide a strong case can be made for the economic benefits of the Timing Belt Driven transfer system.

Within approximately six to twelve months, the initial cost of installing the Timing Belt Driven transfer system can be paid for with the cost savings attained from lower cycle times. After the initial year, the Timing Belt Driven transfer system will net an annual return of investment on each MAC and MAF manufacturing line varying from approximately 100% to 200% depending on the type of transfer system the line originally contained. Although any unproved new design, such as the one for the Timing Belt Driven transfer system contains some risks, the expected large payoff for a successful design serves as a major impetus for developing a prototype of the Timing Belt Driven transfer system.

4.6. Conclusions

After having examined the Timing Belt Driven transfer system in depth, it is now clear that it successfully achieves all of the original design objective. The key feature of the Timing Belt Driven transfer system which enables one to achieve faster and more reliable transfer is the geared contact between the bati and the rollers on the transfer block. Limitations for decreasing transfer time within other transfer systems centered on an inability to provide a method for effectively (quietly and accurately) stopping a bati traveling at high speeds. The Timing Belt Driven transfer system, however, manages to overcome some of these limitations through constant physical contact between the bati and the transfer block components.

The data obtained in the Design Analysis section provides ample evidence that the Timing Belt Driven design can provide a transfer time of 3.0 cmn and a noise level below 90 dB on both the MAC and the MAF systems. The cost analysis performed on the design also shows that this design is economically desirable since it promises a large return on the initial investment. Although the design does contain some previously discussed weakness, such as small differences between the bati and drive rollers velocity during travel and a large initial cost, the overwhelming benefits of the design make the creation of a prototype Timing Belt Driven transfer system highly desirable.

5. Alternative Transfer System Designs

Two other new design ideas were considered before selecting the Timing Belt Driven transfer system. These designs consisted of a transfer system composed of a propulsion/brake/shock assembly, which shall be called the Friction Brake transfer system, and a transfer system using an AC motor connected to a grooved shaft, which shall be called the Grooved Shaft transfer system. Problems associated with each of these designs prevent them from reaching the goals outlined for the new transfer system.

5.1. Friction Brake Transfer System

The Friction Brake transfer system attempts to address some of the cost and reliability problems associated with the other transfer designs. The Friction Brake transfer system does have some important features which help to make it an attractive design. However, it also has certain inherent flaws which create a great deal of apprehension regarding its selection as a new transfer system design. It is the presence of these flaws which served as the impetus for selecting the Timing Belt Driven transfer system over the Friction Brake transfer system. In order to evaluate the merits of the Friction Brake transfer system, one will need to understand how the system functions. Therefore a brief explanation of the operations of the Friction Brake transfer system shall be given, followed by a critique outlining the advantages and disadvantages of the design.

5.1.1. Design Layout and Operation

In the schematic located in figure 5.1 , one can see that the Friction Brake transfer system's set-up is very similar to the Shock and Propulsion transfer system's set-up. Both transfer system's contain a pneumatic propulsor near the front end of the transfer block and a hydraulic shock near the back end of the transfer block. Both transfer system's batis also glide on top of universal rollers as they move from post to post. The Friction Brake transfer system, however, contains a pneumatic cylinder that functions as a brake. The brake is strategically placed between the propulsor and the shock. It is this addition of the "brake cylinder" which causes the Friction Brake transfer system to operate in a different manner than the Shock and Propulsion transfer system.

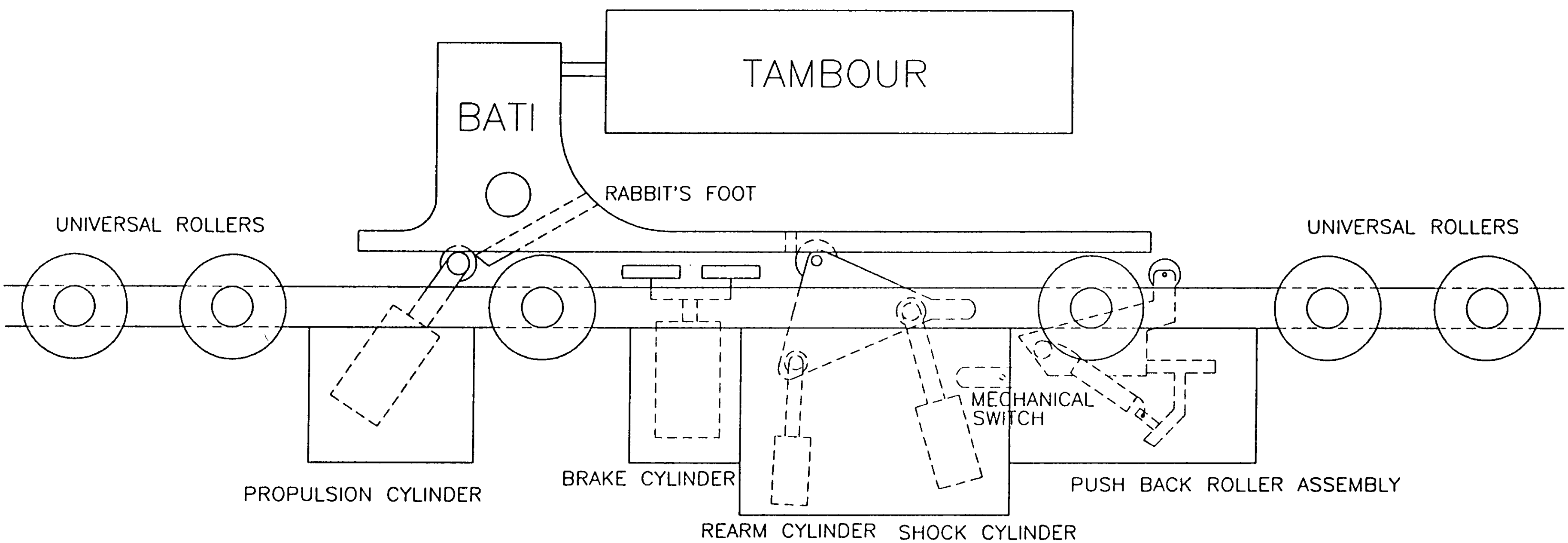


Figure 5.1: Friction Brake Transfer System

The Friction Brake transfer process begins when an electrical signal is sent to open the valve leading to the propulsion cylinder. The rush of air into the propulsion cylinder then causes the propulsion arm to thrust the bati forward. As the bati glides on top of the universal rollers to the next post it triggers the brake photocell. The brake photocell's signal is then used to actuate the brake cylinder. The brake cylinder, which contains a padded arm, pushes up against the bottom of the bati causing it to gradually decelerate. Finally, the hydraulic shock at the end of the post causes the bati to come to a complete stop. Soon after the brake arm goes back to its initial unarmed position.

5.1.2. Design Critique

The Friction Brake is outperformed by the Timing Belt Driven design with regards to all but one of the transfer system design objectives, reliability. Although the Friction Brake design does offer improvement within certain design areas in comparison to current transfer systems, it does not offer the type of major advantages that the Timing Belt Driven design contains. In order to elucidate the precise performance capabilities of the Friction Brake design, this section shall be devoted to examining how the Friction Brake design performs with respect to each of the design objectives: cost, reliability, speed, and noise.

5.1.2.1 Cost

One of the major advantages of the Friction Brake design is that it offers a low initial cost in comparison to the Timing Belt Driven transfer system. The Friction Brake design's low initial cost stems from the lack of a need for complex electronic components. Despite its low initial cost, though, the Friction Brake transfer system is not as cost effective as the Timing Belt

Driven transfer system. The reason for this inefficiency stems from the fact that the Friction Brake transfer system does not create a net reduction in cycle time. Even though its large propulsor is able to move the bati at a faster velocity than the Shock and Propulsion transfer system, the presence of a brake decreases the bati's velocity toward the end of transfer. Therefore, the average transfer time can be expected to be about the same as the Shock and Propulsion systems transfer time. Without a reduction in transfer time, the Friction Brake design cannot offer a source for creating cost savings. This means that the Friction Brake transfer system is not economically justifiable because it produces a positive net cost when it is install in place of transfer systems with faster transfer times.

5.1.2.2. Reliability

The Friction Brake transfer system is a more reliable process than the Timing Belt Driven transfer system as well as all other types of transfer systems examined thus far. The reason for the greater reliability of the Friction Brake transfer system stems from the fact that it contains a sure stop (the shock) and that the bati is traveling at a low velocity (due to the brake) at the end of transfer. Other transfer systems may have a sure stop or a low final velocity, but none of them contains both. Furthermore the simple nature of the transfer process in the Friction Brake design creates the need for less complex components than all other designs, with the exception of the Shock and Propulsion transfer system. Therefore a failure in the Friction Brake design is also likely to lead to a smaller level of downtime, since it will be easier to repair.

5.1.2.3. Transfer Time

As noted within the discussion about cost, the Friction Brake transfer system does not produce a fast transfer time. It can be expected to produce a transfer time of about 3.5 cmn on the MAC and 4.0 cmn on the MAF. Although the transfer time of the Friction Brake system is better than that produced using MATCH transfer, it is considerably worse than the transfer times that the AC Drive and Timing Belt Driven transfer systems would produce. A slower transfer time results in a loss in production capacity, therefore the Friction brake transfer system is undesirable.

5.1.2.4. Noise

The noise level produced by the Friction Brake transfer should be less than that found within the Shock and Propulsion transfer system (93 dB) but more than that found within the AC Drive transfer system (88 dB) or the Timing Belt Driven transfer system. The major source of sound produced by the Shock and Propulsion transfer system can be traced to the impact between the bati and the shock. In Friction Brake transfer, though, the velocity of the bati is dramatically decreased before it comes into contact with the shock. Therefore the Friction Brake transfer produces less noise. However, the Friction Brake transfer system still contains other sources of noise such as the sounds created by the propulsion cylinder. These sounds make the Friction Brake transfer louder than the Timing Belt Driven transfer system which does not contain noise creating from features like propulsion cylinders with rapid air exhaust.

5.2. Grooved Shaft Transfer System

The Grooved Shaft design attempts to provide a quick and economical method of transfer. The system has several advantages over current transfer system designs. However, it does not compare favorably to the Timing Belt Driven transfer system. Before elaborating on the advantage and disadvantages of the Grooved Shaft transfer system, though, let us first examine how the transfer system works.

5.2.1 Design Layout and Operation

The Grooved Shaft transfer system's (a diagram of the system is contained within figure 5.2) main components are an AC motor, a long pipe shaft, and a bati. The AC motor in the design is a single speed motor. The transfer system's pipe shaft contains metal plates which can be triggered to move from the inside diameter of the shaft to the outside diameter by a mechanical switch. The plates on the shaft function as grooves that guide the movement of the bati. The bati used in Grooved Shaft transfer is similar in design to the one found in MATCH transfer. The Grooved Shaft transfer system's bati contains a set of rollers who's angular orientation can be changed by applying pressure to the side of the rollers. In fact, the strategic feature of the Grooved Shaft transfer system involves the use of the metal plates contained on the pipe shaft to adjust the positioning of the bati's rollers.

At the beginning of Grooved Shaft transfer the system's AC motor is activated and the metal plates within the pipe shaft are pushed to the shaft's outside diameter. Then, the energy from the motor causes the shaft to rotate. The rotation of the shaft, in turn, causes the rollers on the bati to rotate. The bati's

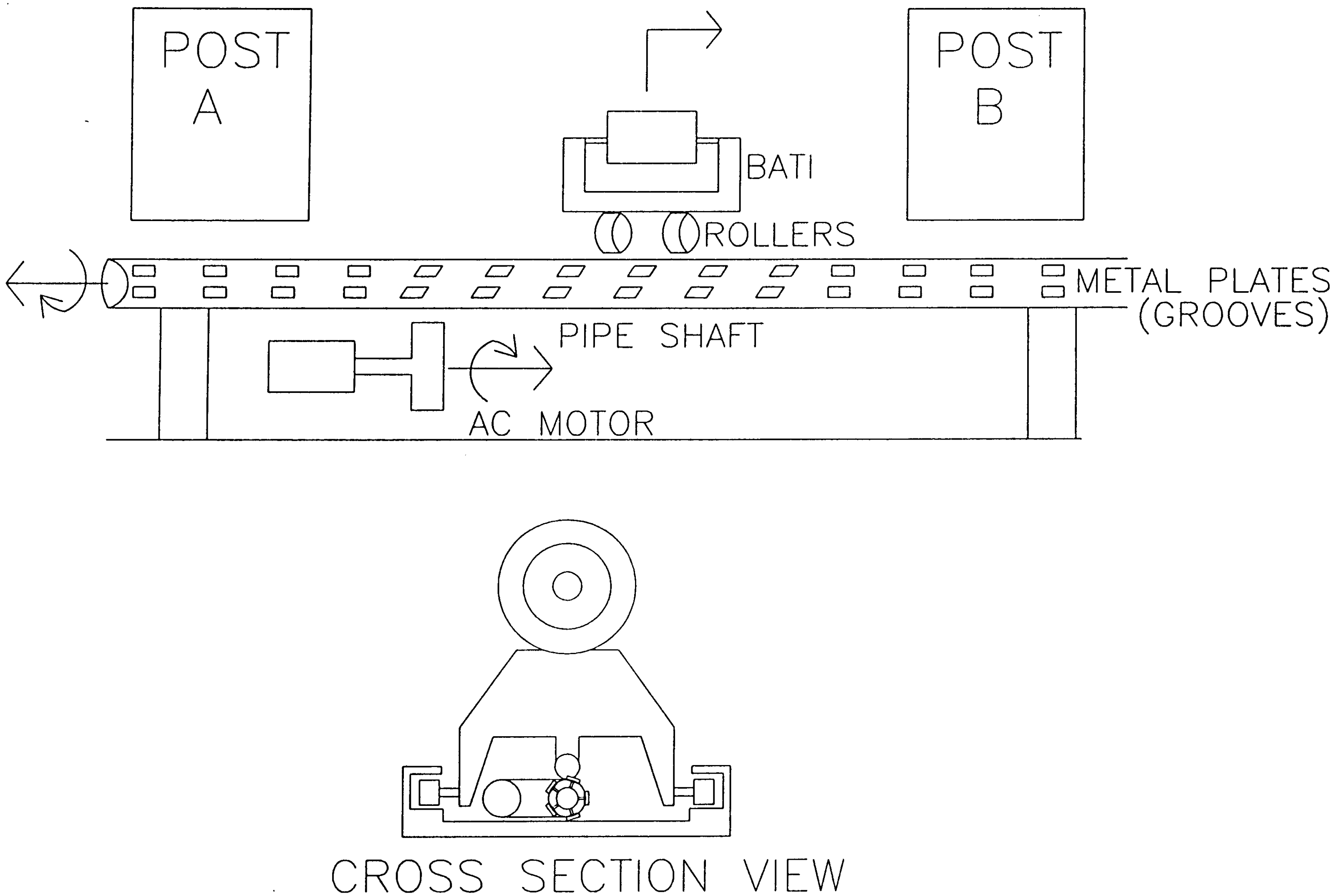


Figure 5.2: Grooved Shaft Transfer System

rollers are initially parallel to the shaft, however as they rotate, the metal plates of the shaft cause the angular orientation of the rollers to adjust. The bati then moves forward as the rollers glide along the shaft's grooves (the metal plates) in a manner similar to a nut being driven into a bolt. Toward the end of transfer the direction of the grooves changes and the bati's rollers are once again moved back toward a parallel orientation with respect to the shaft. The movement of the rollers causes the bati's velocity to rapidly decrease. At this point a trigger on the transfer block sets off the mechanical switch in the shaft and the metal plates move back to the inside diameter of the shaft. The rollers free wheeling parallel to the shaft once the metal plates are pushed back. The bati, therefore, cannot move forward and is forced to come to rest. The AC motor is then de-activated and the transfer process comes to an end.

5.2.2. Design Critique

The advantages of the Grooved Shaft transfer system stem from its ability to provide a fast transfer time at a low initial cost. However, it cannot match the Timing Belt Driven transfer system in terms of cost effectiveness. The major reason for this is that the Grooved Shaft transfer system, while quick, is not as fast as the Timing Belt Driven transfer system. The Grooved Shaft transfer also produces more noise and is less reliable than the Timing Belt Driven transfer system. The rest of this section shall provide the details explaining why the Grooved Shaft transfer system is outperformed by the Timing Belt Driven transfer system in terms of cost, reliability, speed, and, noise.

5.2.2.1. Cost

The Grooved Shaft transfer system has a lower initial cost than the Timing Belt Driven transfer system. The lower initial cost of Grooved Shaft transfer is in part due to the fact that it only requires a single speed motor instead of the variable speed motor need to provide Timing Belt Driven transfer. Furthermore, the Grooved Shaft transfer system does not require the type of sophisticated speed regulating electronic controls associated with Timing Belt Driven transfer. The Grooved Shaft transfer system's cost effectiveness, however, does not compare as favorably. Limitations on the Grooved Shaft transfer system's speed, prevent it from being able to provide the level of cost saving created by the Timing Belt Driven transfer system. Since the Timing Belt Driven transfer system's cost savings more then compensate for it's larger initial cost, it is the more cost effective system.

5.2.2.2. Reliability

The reliability of the Grooved Shaft transfer system is a primary area of concern with the design. There are two major reliability issues which could pose problems: failure of the mechanical switch to trigger the metal plates in the pipe-like shaft and the presents of bati momentum at the end of transfer. The mechanical switch will be firing and re-firing constantly to move the metal plates from the inside to the outside of the shock. Therefore the likelihood of fatigue failure is significant. If failure does occur, the bati may continue moving along the grooves onto the next post. Continued bati movement after the end of transfer has the potential to cause a great deal of damage.

Roller slippage at the end of transfer is also a major reliability concern. The moment in which the metal plates (i.e. the grooves) along the shaft retract has to coincide with the parallel orientation of the rollers. However the deceleration behavior of the bati cannot be precisely predicted. A miscalculation or even regular wear on the bati's rollers could cause the bati to contain some momentum at the end of transfer. This momentum will in turn force the bati to slip past its stopping point. Although the Timing Belt Driven transfer system has its own reliability concerns (as previously discussed), they are not as compelling as those present in the Grooved Shaft transfer system. In fact with the exception of the AC Drive transfer system (which also has a high risk of slippage), the Grooved Shaft transfer system demands greater precision than the other designs considered to operate effectively.

5.2.2.3. Transfer Time

The speed of the Grooved Shaft transfer system is limited by the loads that the grooves can withstand and by the need to reduce the risk of slippage at the end of transfer. These factors prevent the Grooved Shaft transfer system from providing transfer below 3.7 cmn. MATCH transfer, which in some respects is similar in design to Grooved Shaft transfer, has a 4.0 cmn transfer time. The difference in the two systems capabilities stems from the fact that the rollers are guided in Grooved Shaft transfer. With guided rollers the bati can be accelerated and decelerated more efficiently, thereby allowing faster transfer times. As noted earlier, though, the Timing Belt Driven transfer system has a 3.0 cmn transfer time which is much faster than the 3.5 cmn transfer time of the Grooved Shaft transfer system. Therefore, the Timing Belt Driven transfer is the better design for achieving faster speeds.

5.2.2.4. Noise Level

The Grooved Shaft transfer system can be expect to produce about the same amount of noise level as MATCH transfer, 90 dB. This is slightly larger then the noise created by the Timing Belt Driven transfer system. The reason for the Grooved Shaft transfer system's greater noise level stems from it's need for physical contact between the roller and the grooves to provide acceleration and deceleration as well as the presents of a mechanical switch to spring metal plates in and out of a shaft. Therefore, we can conclude that noise level is an advantage of Timing Belt Driven transfer over Grooved Shaft transfer.

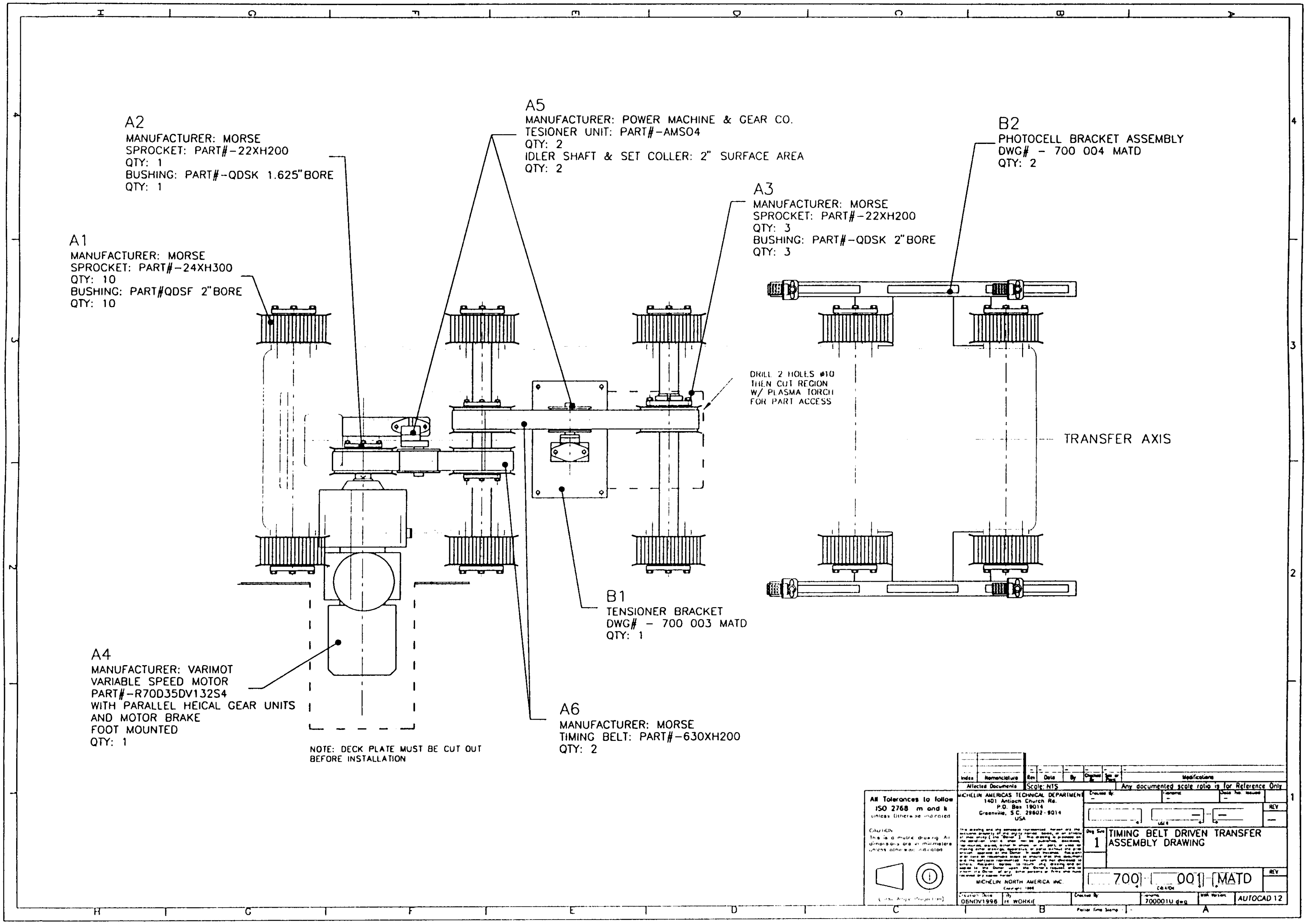
6. Final Remarks

Within the context of this report six different types of transfers systems have been examined: Shock and Propulsion, AC Drive, MATCH, Timing Belt Driven, Friction Brake, and Grooved Shaft transfer system. Now it is time to step back and evaluate the role that these transfer systems should play in meeting the future needs of Michelin. Each of these transfer systems has its own set of advantages and disadvantages, however, some of the systems do not possess a great deal of potential. More specifically, the Friction Brake and Grooved Shaft transfer systems do not merit more rigorous examination beyond this point. The other transfer systems can and should play a role in either the short or long term future of the MAC and MAF manufacturing lines.

In the short term, the Shock and Propulsion, AC Drive, and MATCH transfer systems can each be used. The beneficial modifications performed in US1 and the information regarding reliability concerns covered in this study can be incorporated to help improve the Shock and Propulsion transfer systems throughout most of the plants containing MAC and MAF lines. Opportunities for providing continued improvements on the AC Drive and MATCH transfer systems can be studied as well. Also in the short term, a prototype of the Timing Belt Driven transfer system can be built. As previously discussed, the Timing Belt Driven transfer system has several advantages that are likely to lead to improvements in every aspect of transfer system performance.

Assuming that a prototype of the Timing Belt Driven transfer system is built, the long term benefits of the various transfer system can be readily compared. If the Timing Belt Driven transfer system is able to meet its design objectives, it could serve as the transfer system of choice for new MAC and MAF lines that are built. Then, the design may also be used to replace the transfer systems of current manufacturing lines which are performing poorly. However, if problems appear in the Timing Belt Driven transfer system that were not originally anticipated, then a re-evaluation of each of the transfer systems will need to be performed. After this re-evaluation the transfer system which shows the greatest potential should be used in all future MAC and MAF lines.

Appendix A: Mechanical Drawings
(MAF Timing Belt Driven Transfer System)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QTY: 2
A2
MANUFACTURER: MORSE
SPROCKET: PART#-22XH200
QTY: 1
BUSHING: PART#-QDSK 1.625" BORE
QTY: 1
B2
PHOTOCELL BRACKET ASSEMBLY
DWG# - 700 004 MATD
QTY: 2
A3
MANUFACTURER: MORSE
SPROCKET: PART#-22XH200
QTY: 3
BUSHING: PART#-QDSK 2" BORE
QTY: 3
A1
MANUFACTURER: MORSE
SPROCKET: PART#-24XH300
QTY: 10
BUSHING: PART#QDSF 2" BORE
QTY: 10
DRILL 2 HOLES #10
THEN CUT REGION
W/ PLASMA TORCH
FOR PART ACCESS
TRANSFER AXIS
B1
TENSIONER BRACKET
DWG# - 700 003 MATD
QTY: 1
A4
MANUFACTURER: VARIMOT
VARIABLE SPEED MOTOR
PART#-R70D35DV132S4
WITH PARALLEL HEICAL GEAR UNITS
AND MOTOR BRAKE
FOOT MOUNTED
QTY: 1
A6
MANUFACTURER: MORSE
TIMING BELT: PART#-630XH200
QTY: 2
NOTE: DECK PLATE MUST BE CUT OUT
BEFORE INSTALLATION
All Tolerances to follow
ISO 2768 m and k
unless Otherwise indicated
CAUTION
This is a metric drawing. All
dimensions are in millimeters
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USA
MICHELIN NORTH AMERICA INC.
Dwg Size
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TIMING BELT DRIVEN TRANSFER
ASSEMBLY DRAWING
700 001 MATD
REV
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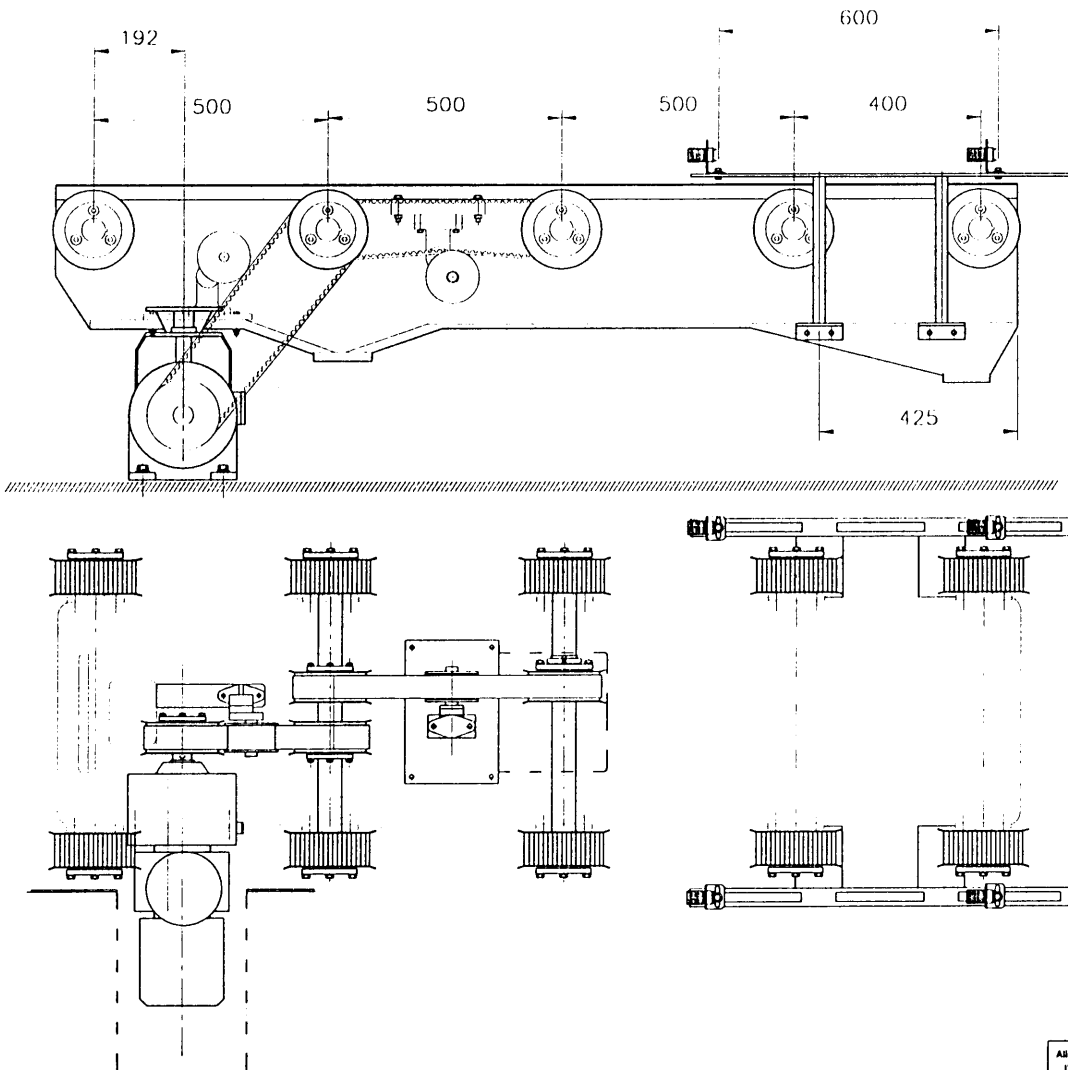
06NOV1996
H WORKIE
Checked By
700001U.dwg
AUTOCAD 12
Plotter Time Stamp



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Date No. Issued: -

REV —

Dwg Size: 1

TIMING BELT DRIVEN TRANSFER
LAYOUT DRAWING

700 - 002 - MATD

Creation Date: 06NOV1996
By: H. WORKIE
Checked By:
Filename: 700002U.dwg
AUTOCAD 12

PART#: B1

QTY REQUIRED: 1

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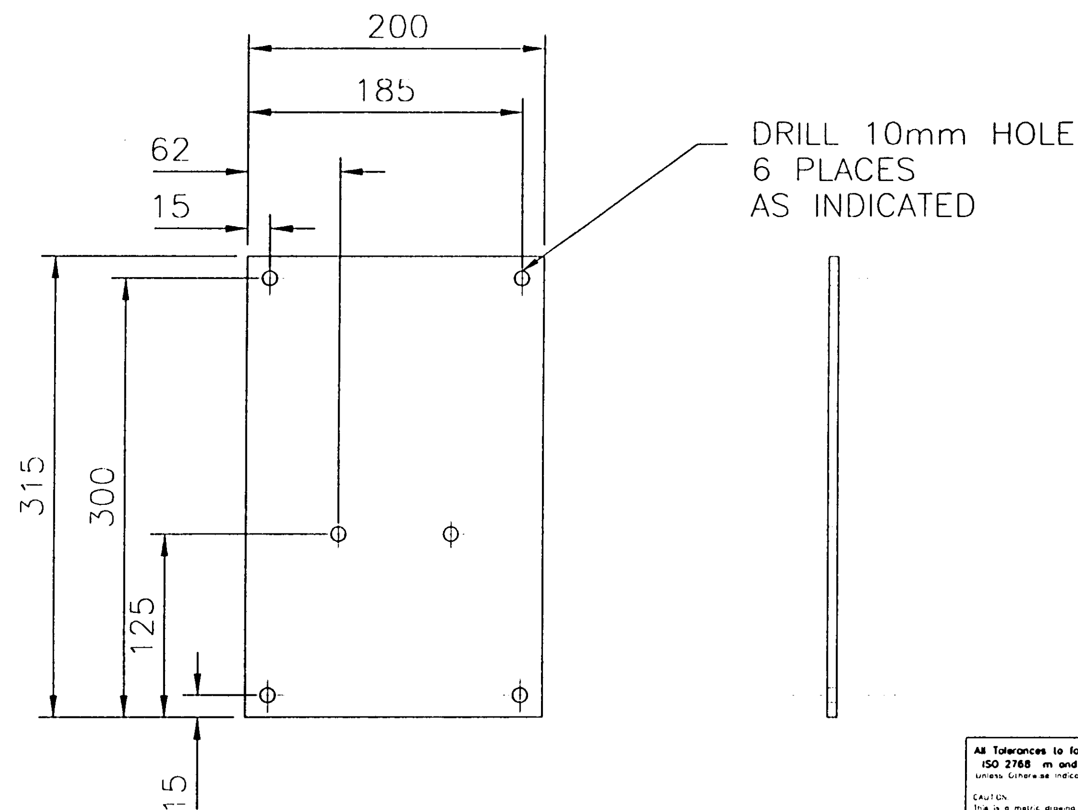

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TENSIONER BRACKET
DETAIL DRAWING

700 - 003 - MATD

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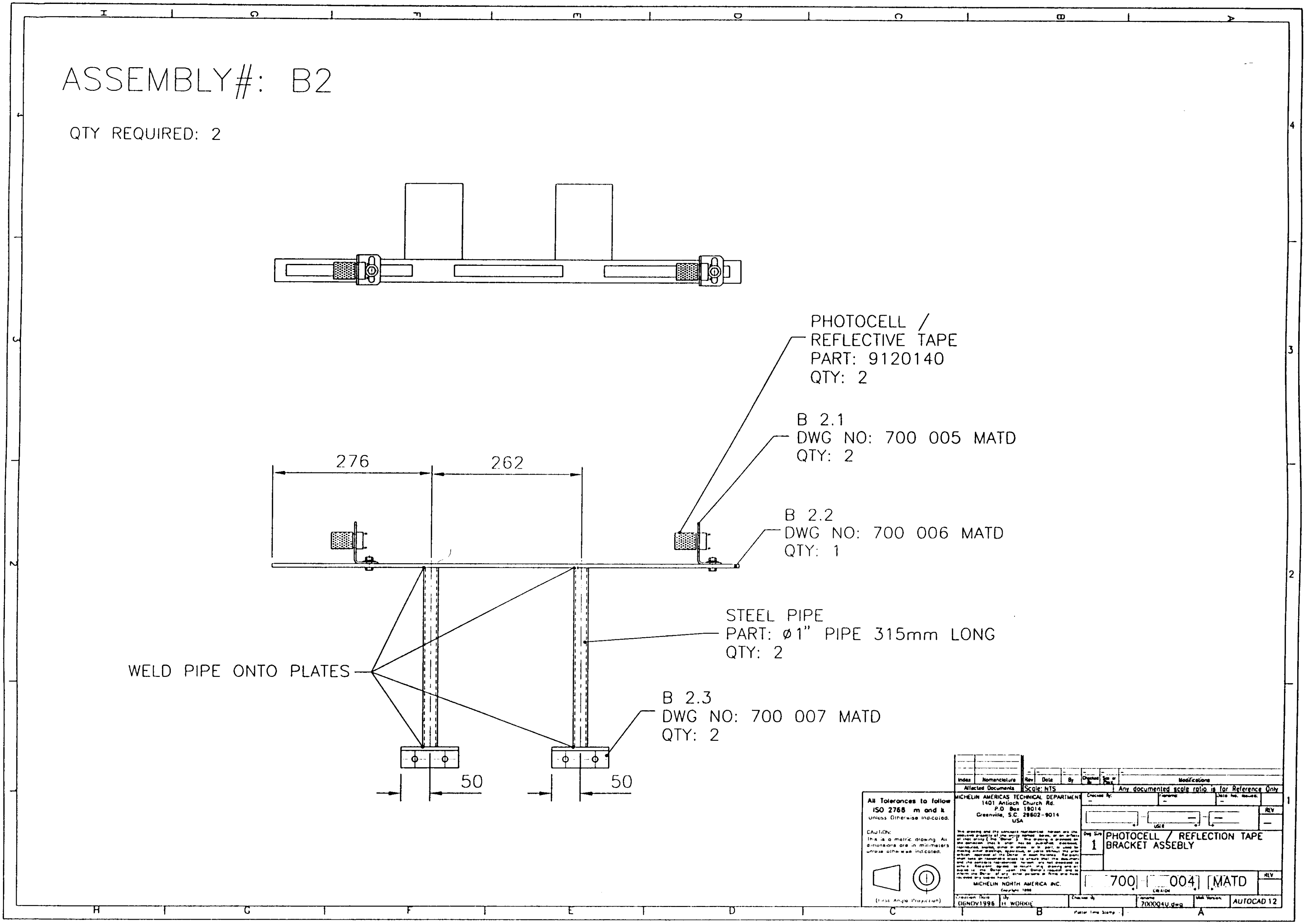
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WELD PIPE ONTO PLATES
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BRACKET ASSEBLY
700 004 MATD
Creation Date
06NOV1996
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AUTOCAD 12

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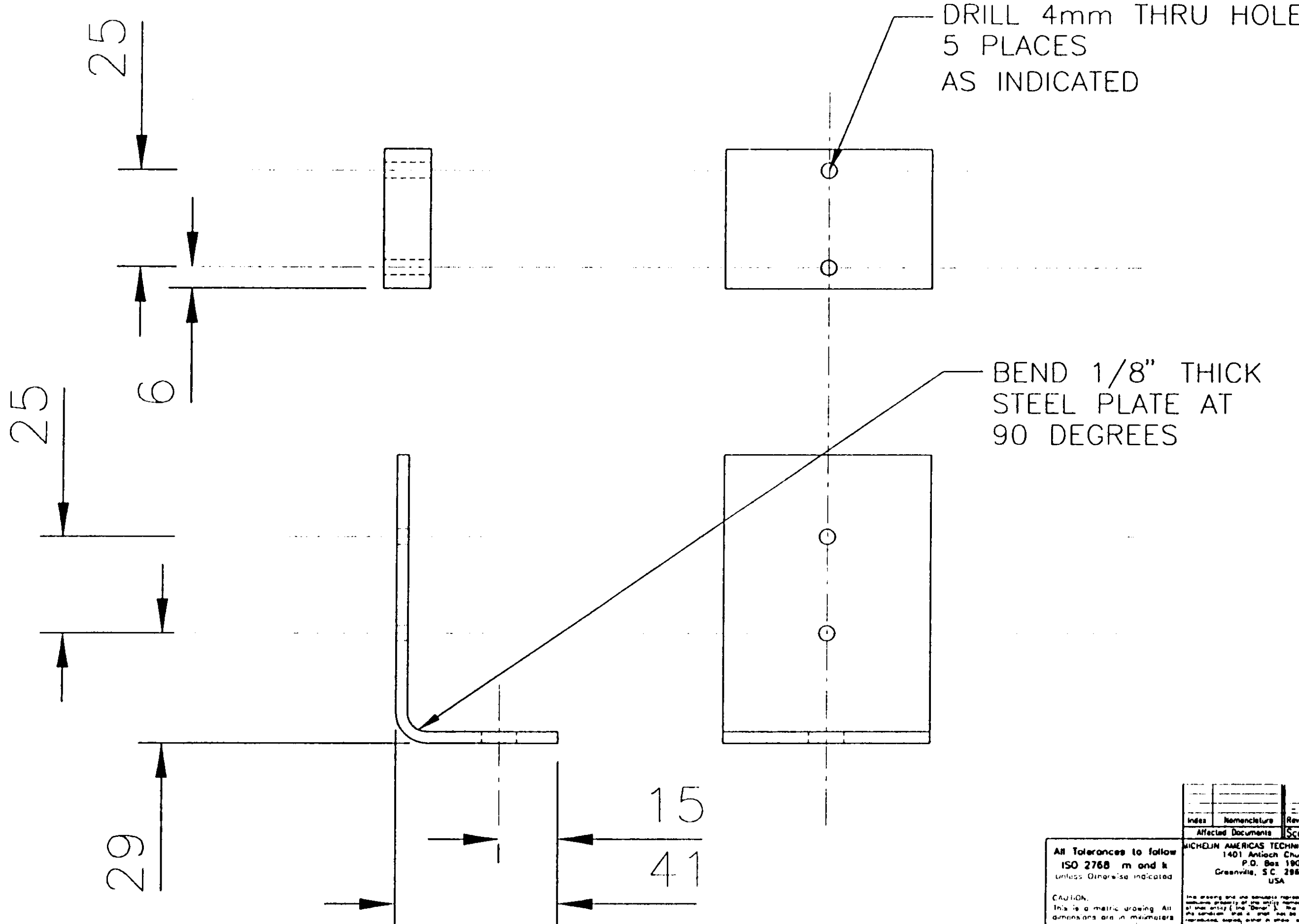

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PHOTOCELL / REFLECTION TAPE HOLDER DETAIL DRAWING

700 - 005 - MATD

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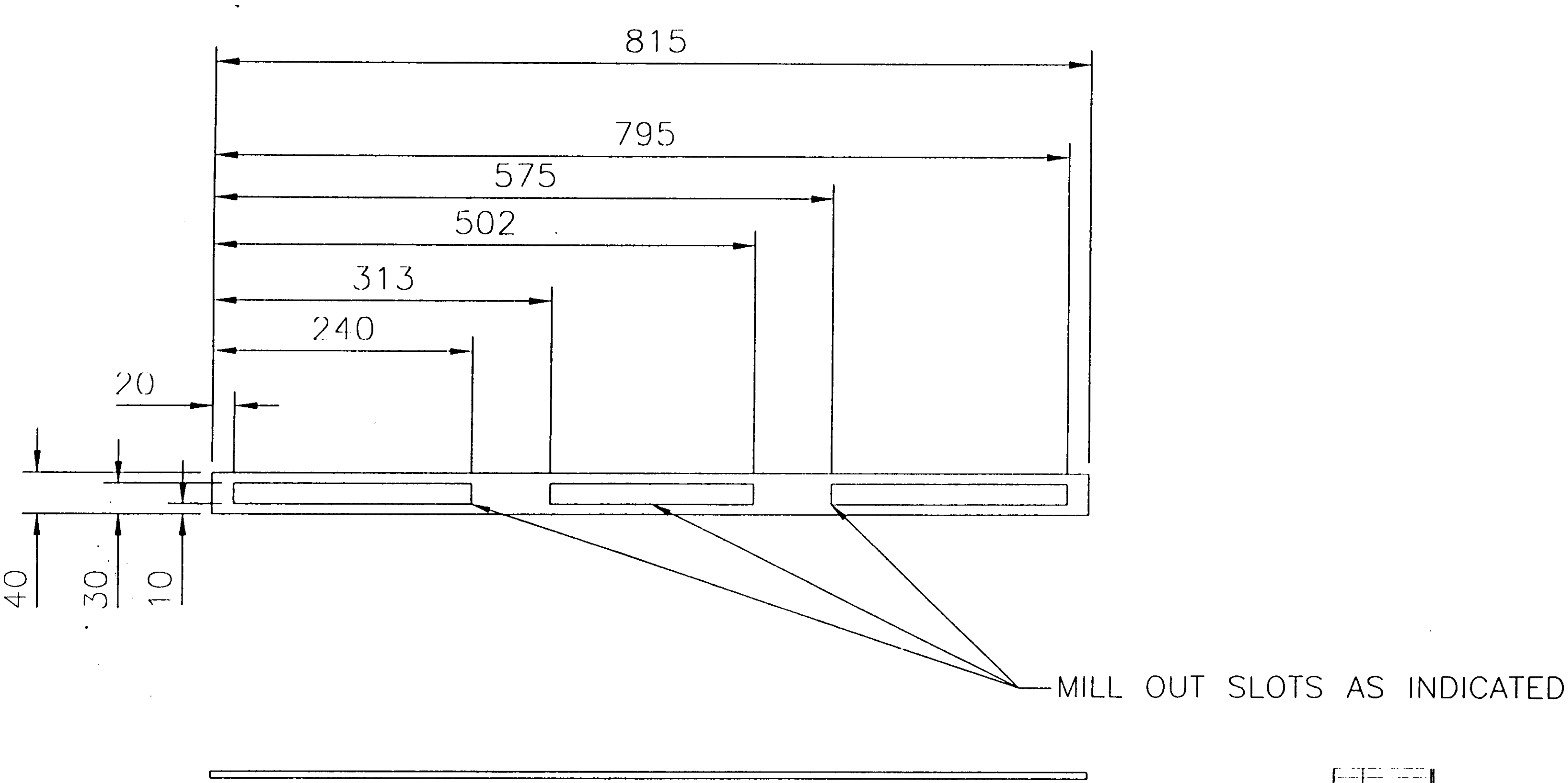

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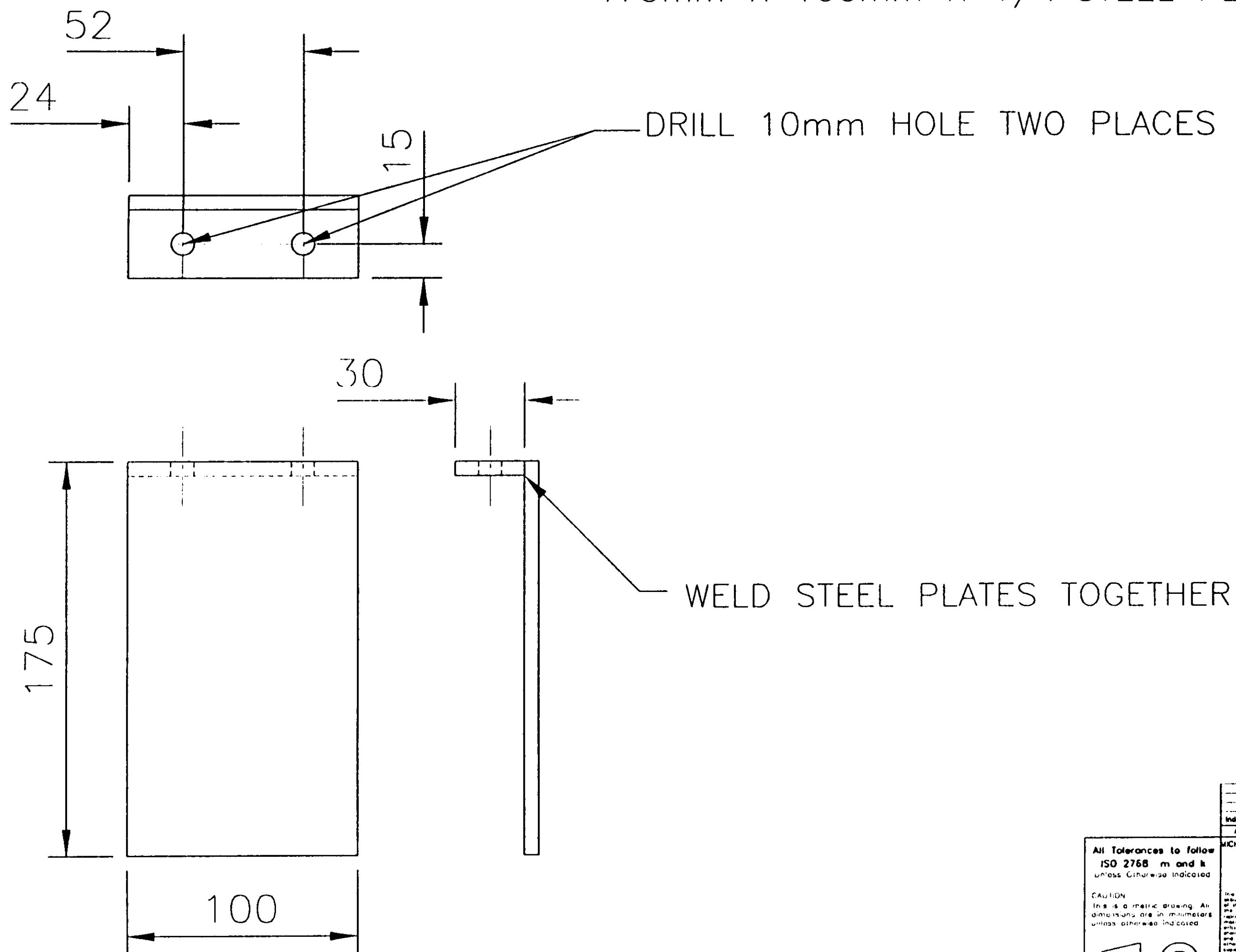
100mm X 30mm X 1/4" STEEL PLATE
175mm X 100mm X 1/4" STEEL PLATE



All Tolerances to follow ISO 2768 m and k unless Otherwise Indicated

CAUTION
This is a metric drawing. All dimensions are in millimeters unless otherwise indicated

(First Angle Projection)

Index	Nomenclature	Rev	Date	By	Checked By	Modifications
Affected Documents		Scale: NTS				Any documented scale ratio is for Reference Only

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Dwg Size: 1

PHOTOCELL / REFECTION TAPE BRACKET STAND DETAIL DRAWING

700 - 007 - MATD

Creation Date	By	Checked By	Filename		
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Appendix B: Motor Selection

The motor selection process for the Timing Belt Driven transfer system centered on using the SEW EURODRIVE catalog along with the calculated input requirements on the drive rollers to make an appropriate motor choice. The selection process consisted of two stages. In the first stage, the motor specification values (moment or inertia to be driven, torque, angular velocity, and power) were determined. Then, the selection procedure in the SEW EURODRIVE catalog was used to find a suitable motor which could be purchased. The following calculations shall outline the steps involved in each of these stages.

Stage 1: Motor Specification Values
Known Variables:
x = acceleration and deceleration distance = 0.6 meters
Vmax = max velocity of bati = 2.0 m/s
a = acceleration rate = deceleration rate = 3.33 m/s^2

Calculated Variables:
Moment of inertia to be driven
J = bati inertia + connection assembly inertia ≅ bati inertia
$J = mv^2 / \omega^2$
J MAC = 2.32 $kg\text{-}m^2$ = 55.1 $lb\text{-}ft^2$
J MAF = 3.77 $kg\text{-}m^2$ = 90.5 $lb\text{-}ft^2$

Torque Requirement
$\tau = mar = J\alpha\omega$
τ MAC = 90.7 m-N = 803 lb-in
τ MAF = 147 m-N = 1300 lb-in

Angular Velocity Requirement
ω = Vmax / r
ω MAC = 23.5 rad/s = 225 rpm
ω MAF = 23.5 rad/s = 225 rpm

Power Requirement
$P = \tau\omega / \eta$
P MAC = 2660 Watts = 3.58 hp
P MAF = 4320 Watts = 5.79 hp

Stage 2: Use of SEW EURODRIVE Catalog to Purchase Motor

Selected MAC transfer system motor:
Manufacturer: SEW EURODRIVE - VARIMOT with Parallel Gears
Part #: R70 D34 DT100L4 -R
Input/Output Power: 4.0 / 5.0 hp
Desired Additional Feature: Motor Brake w/ torque ≥ 803 lb-in
Duty Cycle = 24 hour operation
Mounting Position: Foot Mounted
Output Torque = 1010 lb-in
Output Shaft Speed = 52 - 253 rpm

Selected MAF transfer system motor:
Manufacturer: SEW EURODRIVE - VARIMOT with Parallel Gears
Part #: R70 D35 DV132S4 -R
Input/Output Power: 7.5 / 6.2 hp
Desired Additional Feature: Motor Brake w/ torque ≥ 1300 lb-in
Duty Cycle = 24 hour operation
Mounting Position: Foot Mounted
Output Torque =1510 lb-in
Output Shaft Speed = 53 -259 rpm

Appendix C: Timing Belt and Sprocket Assembly Selection

Selection of the Timing Belt and Sprocket assembly was performed by following the steps outlined by the MORSE Catalog. These steps involved relating the behavior of the motor shaft to the desired behavior of the drive sprocket. Proper part selection had to be carefully made in order to assure that the timing belt would be able to support the required motor torque and the required sprocket size. The calculations below display the steps used to obtain the correct timing belt and sprocket assembly for the Timing Belt Driven transfer system.

MORSE Catalog selection steps for Timing Belt and Sprocket:

MAC transfer system
1) Horsepower to be transmitted = 4.1 hp
2) Service Factor = 2.5
3) Design Horsepower = 4.1 * 2.5 = 10.25 hp
4) Center Distance = 21 inches, Driver RPM = 225, and Driven RPM = 225
5) Required Ratio Driver/Driven ratio = 1:1
6) Pitch Selection: 7/8″
7) Minimum No. of Teeth = 22XH
8) Teeth Selection:
   Motor Drive: Belt = 630XH, Sprocket = 22XH
   Bati Drive: Belt = 1120XH, Sprocket = 24XH
9) Motor Belt Width = 2″ Bati Belt Width = 3″

MAF transfer system
1) Horsepower to be transmitted = 6.0 hp
2) Service Factor = 2.5
3) Design Horsepower = 6.0 * 2.5 = 15 hp
4) Center Distance = 21 inches, Driver RPM = 225, and Driven RPM = 225
5) Required Ratio Driver/Driven ratio = 1:1
6) Pitch Selection: 7/8″
7) Minimum No. of Teeth = 22XH
8) Teeth Selection:
   Motor Drive: Belt = 630XH, Sprocket = 22XH
   Bati Drive: Belt = 1120XH, Sprocket = 24XH
9) Motor Belt Width = 2″ Bati Belt Width = 3″

Selected Parts from MORSE Catalog

MAC/MAF Motor Timing Belt Part Numbers:
Belt - 630 XH 200   Sprocket - 22 XH 200 with QD-SK-2” bushing
MAC/MAF Bati Timing Belt Part Numbers:
Belt - 1120 XH 300   Sprocket - 24 XH 300 with QD-SF-2” bushing

Appendix D: Tensioner and Tensioner Bearing Selection

Using the Brewer Machine & Gear Co. and the Thomas Ball Bearing catalogs, the tensioners and tensioner bearings needed for Timing Belt Driven transfer were selected. The first step of the selection process involved calculating the loads that would be placed on the bearings. Then, the critical dimensions for mating parts were specified. After these part requirements were determined, the final part was select.

Brewer Machine & Gear Co. Tensioner Selection
Selected Tensioner Part No. - " AM-SO-4 "

Requirements and Actual Performance:
Required and actual angle of rotation adjustment = 360 degrees
Required bearing surface area > 3.0 inches
Actual bearing surface area = 4.125

Thomson Ball Bearings Selection
Selected Bearing Part No. - " Super 16 "

Requirements and Actual Performance:
Required and actual inside diameter = 1.0 inches
Required bearing width > 2.0 inches
Actual bearing width = 2.25 inches
Required bearing load rating > 300 lbs
Actual bearing load rating = 780 lbs

Appendix E: Analysis of Return on Investment

The gross cost savings and initial costs associated with switching to a Timing Belt Driven transfer system were originally calculated in order to determine the cost effectiveness of the design. The following appendix shall provide a detailed account of how each of these two values, gross cost savings and initial cost, were derived.

Gross Cost Savings

The level of gross cost savings achieved is proportional to the reduction in transfer time. For example a 1.0 cmn reduction in transfer time results in a greater cost savings than a 0.5 cmn reduction in transfer time. Therefore, the cost savings obtained from a "X" cmn reduction in transfer time shall be calculated and then used to determine the cost savings values associated with switching from all existing systems to the Timing Belt Driven transfer system. Below is a listing of the reduction in cycle time that can be achieved by using the Timing Belt Driven transfer system.

MAC systems
Reduction in cycle time created by switch to Timing Belt Driven transfer from:
MATCH transfer = 0.7 cmn
Shock and Propulsion transfer = 0.5 cmn

MAF systems
Reduction in cycle time created by switch to Timing Belt Driven transfer from:
AC Drive transfer = 0.5 cmn
Shock and Propulsion transfer = 1.0 cmn

The cost savings obtained by the Timing Belt Driven transfer system was calculated using a three step procedure. First the number of minutes that a MAC or MAF production line is operational during the course of a year was determined. Then, the number of production minutes that is saved each year as a result of a "X" cmn reduction in transfer time was calculated. As a last step, the cost savings was determined using information regarding the cost of production and the number of production minutes that are saved.

Variables:
PPT = possible production time (min/year)
APT = actual production time (min/year)
N = number of APT minutes saved each year
S = gross cost savings
t = normal cycle time in centi-minutes
X = reduction in cycle time in centi-minutes
c = cost of a minute of actual production time
η = manufacturing efficiency
Given Values:
t = 18 cmn
c = 60 $/min
η = 0.75

1) Actual Production Time
PPT = (# of min / year) - (# of min shutdown / year)
PPT = (525600) - (28800) = 496,800 min/year
APT = PPT * η = 372,600

2) Minutes of Production Time Saved
N = [t / (t -X)]*APT - APT = [X / (t - X)] *APT
N = [X / (18 - X)] * 372,600

3) Gross Cost Savings
S = N * c
S = 22,356,000 * [X/ (18 - X)]

MAC systems
Gross Cost Savings created by switch to Timing Belt Driven transfer from:
MATCH transfer = $905,000 per year
Shock and Propulsion transfer = $640,000 per year

MAF systems
Gross Cost Savings created by switch to Timing Belt Driven transfer from:
AC Drive transfer = $640,000 per year
Shock and Propulsion transfer = $1,280,000 per year
Total Initial Cost

An estimate of the initial cost of switching to a Timing Belt Driven transfer system must factor in the type of labor and material that will be required. A large amount of skilled labor will be needed to install the electrical circuitry, as well as mechanical instruments, within the Timing Belt Driven design. Furthermore, there is also a need for high tech parts such as the electrical controls, motors, and timing belt assemblies. Through taking the factors associated with material and labor costs into account, in conjunction with the information obtained from vendors and from the AC Drive transfer system work order, a cost estimate was created. The cost estimate revealed that the expected initial cost of the Timing Belt Driven transfer system is $630,000.

Variables:
C = total initial cost for MAC and MAF systems
L = total labor costs
M = total material costs
h = # of labor hours required per post
p = # of posts (excluding ascent and descent elevator) + return line
l = cost of labor ($ / hour)
m = cost of mechanical parts per post
e = cost of electrical parts per post

Given values
p = p MAC = p MAF = 21
h = 350 hr/post
l = 40 $/hr
m = 3500 $/post
e = 12500 $/post

Initial Costs:
L = h * l * p = $294,000
M = (m + e) * p = $336,000
C = L + M = $630,000