UNIVERSITY HONORS PROGRAM

SENIOR PROJECT - APPROVAL

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PROJECT TITLE: University of Tennessee Eastman Project: Acetate Tow Bale Straightener

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: DW Dareing, Faculty Mentor

Date: 5-3-04

Comments (Optional):

EASTMAN

University of Tennessee Eastman Projects

Acetate Tow Bale Straightener

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Executive Summary

At the beginning of fall 2003 Eastman presented a problem, which dealt with product reliability. In packaging bales of acetate tow, specific measurements are automatically recorded in order to regulate bale size and consistency. However, when these measurements were being taken, accurate data was not recorded because the bales were not properly aligned with the measurement equipment. The task presented was to increase the accuracy and reliability of these measurements.

In first addressing the problem, several design concepts were generated that could potentially solve these inaccuracies – distance sensors, large hydraulic rams, and air bearings were considered. Eastman opted for research and development into the air bearing concept. In brief, this concept utilized air bearings to reduce the friction between the bale and the conveyor, allowing for the bale to be easily moved and aligned. This "straightening" of the bale would thus resolve the issue of the misalignment and inaccuracies.

Over the next six months, a prototype was constructed to demonstrate the proof of concept. The prototype incorporates a HOVAIR system in conjunction with a redesign of one conveyor section. Once the HOVAIR is activated, pneumatic cylinders align the bale against a guide rail, which is parallel to the measurement device. The overall result is a quick, automatic, safe, and reliable method for correcting the initial problem. In addition, this solution causes no physical damage to the bale, an important design specification. Hopefully, the ideas presented through this project will provide Eastman with more guidance to implement a practical, economical fix for the bale misalignment.

The design team would like to thank Chris Slaughter, Ken Martin, and Lori Larkins on the Eastman staff for their support, advice, and assistance. The design team would also like to thank Eastman for sponsoring this project and allowing us to gain practical experience on a real engineering problem.

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I. Background

In the fall of 2003, the design team visited Eastman Chemical Co. in Kingsport, TN. The purpose of the visit was to introduce design projects to the class. After the selection of the Bale Straightener project, the team revisited Eastman to collect more information concerning the specific project. The problem initially traced back to product control. In the measurement room the bales are weighed, measured and their density is determined. This data is returned to a Programmable Logic Controller (or PLC) that automatically controls the balers in order to standardize the amount of acetate tow in the bale. The largest factor in this standardization control is the bale "height." The "height" is actually the length of the bale as it passes the measurement room; however when in the baler this is the height of the bale. Unfortunately, the bale height was the dimension which had the most variance from bale to bale. Much of this variance resulted from the measurement device, a light curtain. The bales become skewed on the conveyor system and thus present themselves at an offset angle to the light curtain. This skewed alignment gives false readings for the bale height, which are then fed back into the PLC for adjustment. Manual methods exist for measuring the bale heights, but these methods are cumbersome and time consuming.

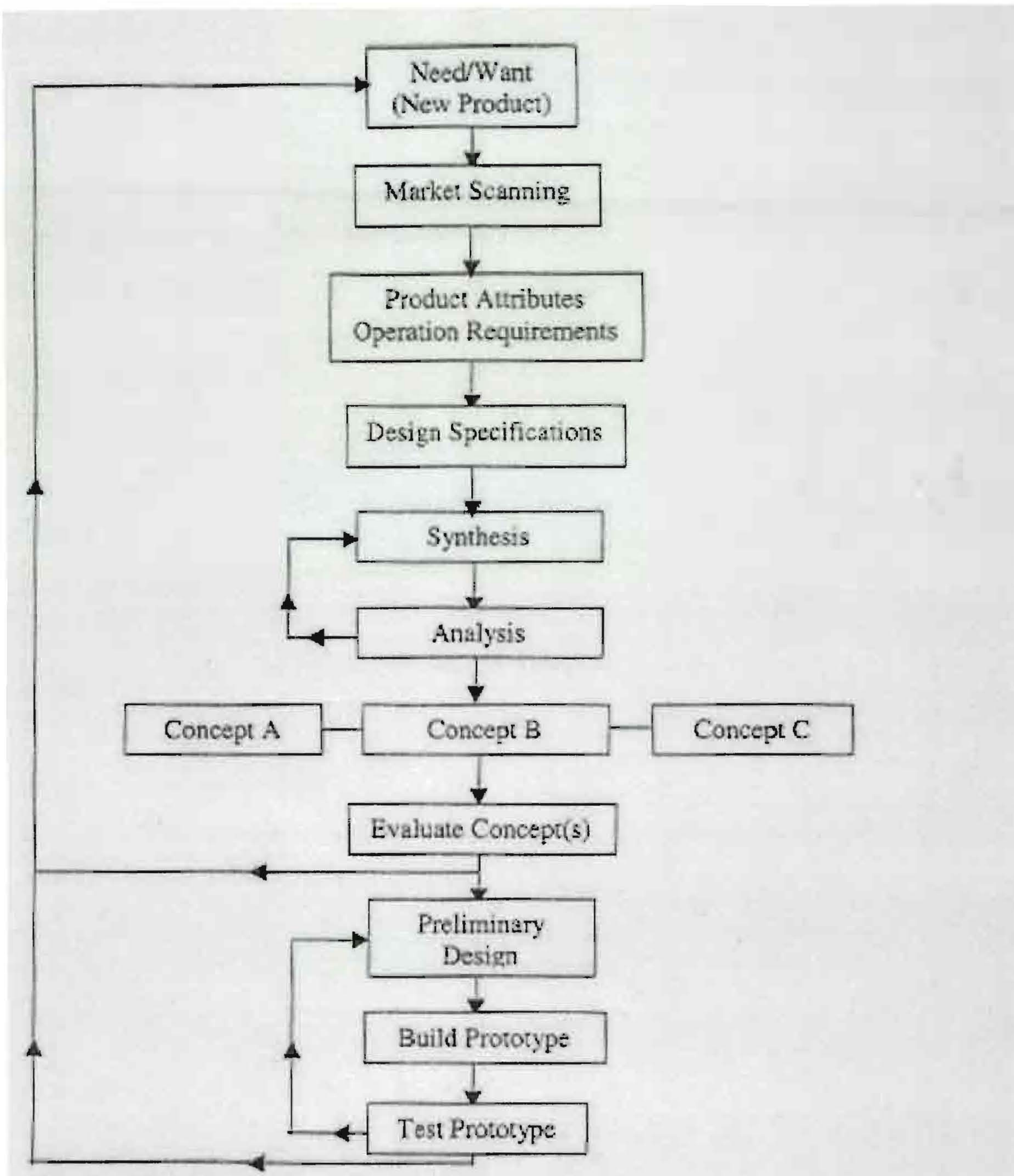
II. Work statement

The goal of this project was to increase the accuracy and reliability of the height measurement. The bales often present themselves nonparallel to a LED light curtain measurement system. For the device to properly measure the height of the bales, they must be parallel to the light curtain. In order to improve the data collecting for the acetate bales, the height measurement must be made more accurate and reliable.

III. Design Methodology

In beginning the design process, a proven design approach was implemented. The initial steps were to understand the problem and develop a specific objective for the design as discussed previously. After gathering information from the Eastman representatives, a detailed list of specifications was developed which guided and directed concepts, evaluations, and performance. In order to keep the project active, a gant chart was developed, and has been provided in the Appendix. This initial planning was critical in ensuring the timely and successful completion of this project. Once this overall path was defined, the project was largely a matter of following the mapped out steps. In the fall of 2003, various design concepts were explored and evaluated against the design specifications. In a mid-term meeting with Eastman representatives, a preliminary design was selected for further development. By winter break, preliminary drawings had been submitted for the prototype, allowing fabrication and assembly to begin. The spring of 2004 was used to develop and test the prototype, which resulted in completion as originally planned. Throughout the entire process, Eastman engineers provided feedback and recommendations. The following schematic details the utilized design methodology.

Design Method



IV. Design Specifications

Following initial meetings, detailed specifications that defined the limits and needs for this project were developed. These specifications define an engineering base line by which concepts and evaluations are founded.

Product Title

Acetate Bale Straightener

Purpose

The device will correct the bale height measurement.

Need

Device is required to increase reliability and repeatability of the balers. Eastman reports incorrect data is causing loss of revenue because volume of bale is inaccurate. Eastman also desires a more standard bale height which can only be achieved through accurate measurements because the height measurements are in a feedback loop with the PLC's that control the balers.

Relationship to other equipment

This device must interact with the other machinery and be retrofitted into existing conditions.

Cost limitations

$5000 for prototype

Product Flow

Device must fit within existing product flow. The measurement station is located in line with automatic indexing conveyors. Two lines feed the in feed side. One comes from a larger baler and the other from the smaller. They both converge just prior to the weigh conveyor. One staging conveyor buffers the converging point from the weigh conveyor. After weighing is a turntable for labeling. The out feed conveyors lead to a pick up point for lift trucks.

Information flow

Device must also fit within existing information flow. The weight, moisture content, and height are fed from their respective devices to a PLC and read out for confirmation. The operator locks in the values by scanning the bale label. The height is then fed back to the baler PLC to adjust the bales in order to create more standard sizes.

Physical Requirements

Max Bale Weight: 1900 lbs
Bale Dimensions: 49"W x 24-35" T x 35-45" L
Bale Geometry: Bales have crowning or rounded ends
Conveyor usable Width: 58"
Conveyor Length: 75"
Roller Diameter/Spacing(center to center): 3 ½" / 11"
Plant Air: 90 psi
Conveyor Motors: .75 hp
Available power: 460 V
Product Aesthetics: Device cannot mar the packaging cardboard.

Service environment

Device cannot emit flame or spark. Area is potentially flammable.

Life Cycle

Device ought to require minimum maintenance and be installable while machine is running. Parts ought to be readily available. Operation costs are not limited but should be kept reasonable.

Human Factors

Training may be required but operation should be almost completely automatic.

Safety

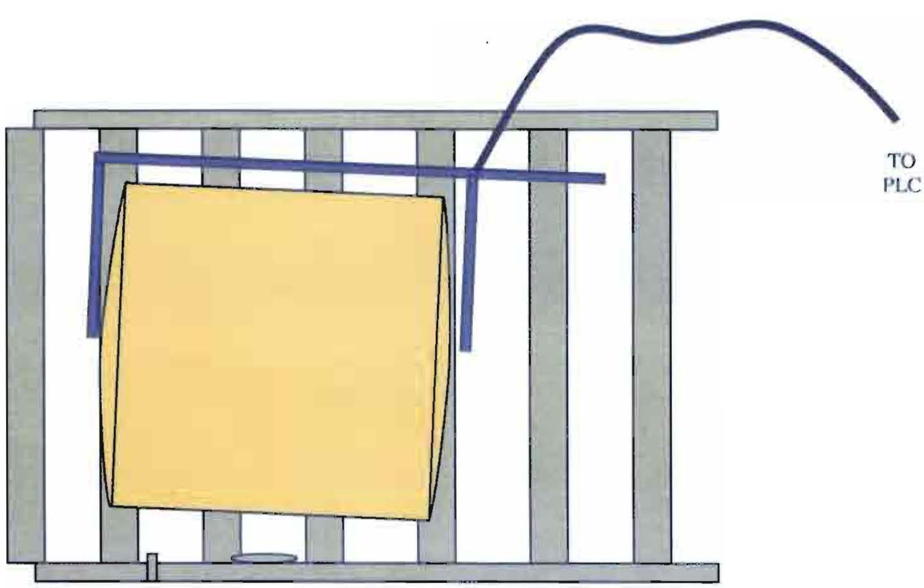
Any moving parts must be guarded to protect pinch points.

V. Design Alternatives

In developing conceptual solutions for the problem, we followed five ideas through to a feasibility evaluation. In the main body, three of these solutions will be presented; the other two are provided in the appendix.

a. Concept 1 – Digital Calipers

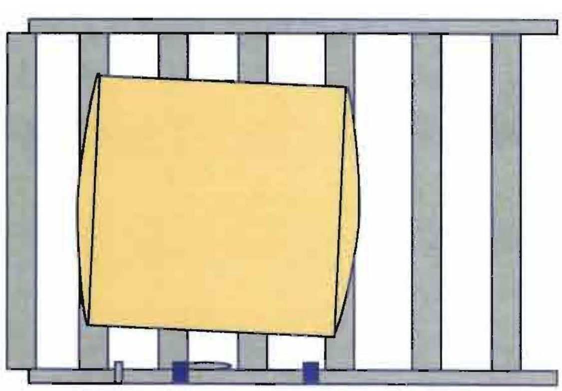
Currently when the height is misread, an operator uses a set of manual calipers to find the correct bale height and manually enters this data in to the user interface, and then the data is fed into the PLC. This concept involves a set of digital calipers that automatically feed back to the PLC, bypassing the manual manipulation of data.

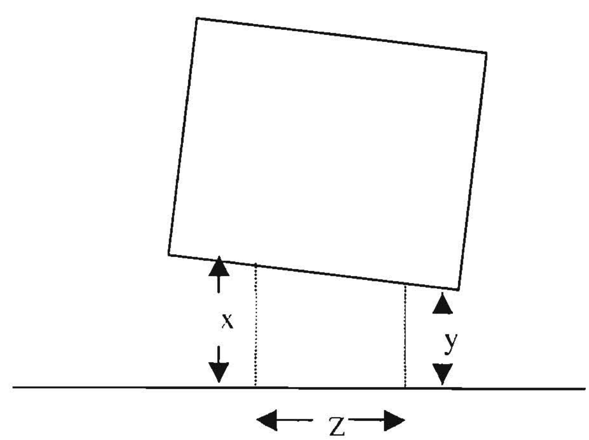


This design offers a simple and safe solution. Although the operator would have another function to perform, he or she would not be interacting with more automated parts. Thus no additional pinch points or potential hazards are evident. Also, no damage to the package would occur. With this solution, however, several limitations are obvious. First is the human factor. The bales are crowned on the sides. In order to get the proper height reading, the calipers must be placed precisely on the outmost point. The possibility exists for an operator to miss this point, resulting in incorrect readings. Because the operator must handle the device to measure every bale, the cycle time per bale could become extensive. Even though the cycle time is not a main design consideration, it could prove to be costly. Another limitation is the direct cost. Calipers that would have an automatic data feed and meet the size requirements would be in the range of $2500 - $3500. Other limitations include sensitivity of the calipers, recalibration, and ergonomics.

b. Concept 2 – Distance Sensors

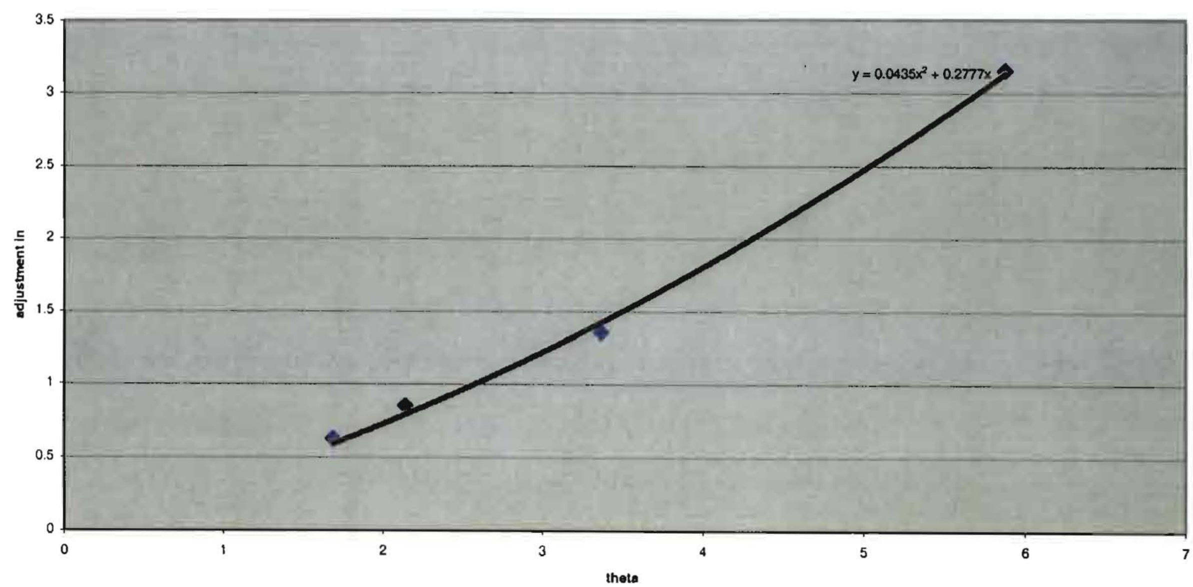
This concept utilizes at least two distance sensors positioned on the conveyor frame. The measurements taken would be used to calculate the angle that the bale is from parallel to the LED measurement syste. The height measurements that are read by the LED and the actual height from the caliper would be recorded for statistical purposes.





By charting the angle offset and amount needed to correct the height of the bale, a trend line forms. This trend line would then be inputted into the PLC so that the PLC could correct for the error in the measurement. A sample of this procedure is below. For this analysis to be more thorough, a larger sampling would be compiled.

X	Y	Z	scale H	theta(degrees)	L(calip)	abs adj
4.5	8	34	41.4	5.877392607	38.25	3.15
5	6	34	42	1.684684318	41.38	0.62
3.3	5.3	34	42.6	3.366460663	41.25	1.35
5.63	6.9	34	42.1	2.139171364	41.25	0.85

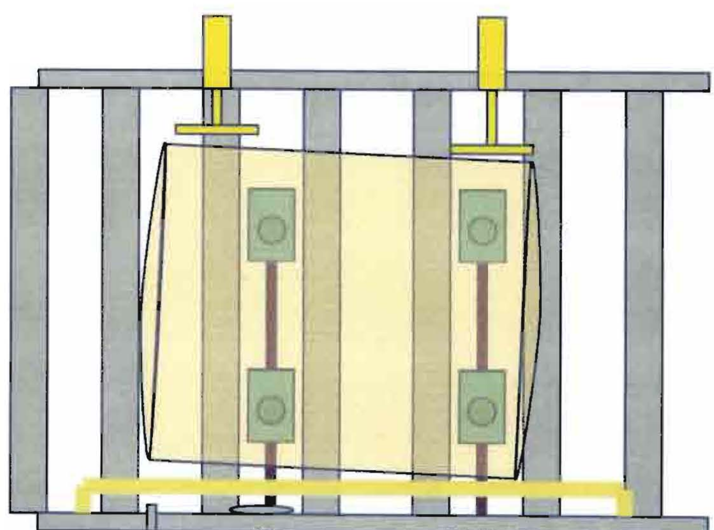


This design solution offers many advantages. It is safe because no moving parts exist; it will fit into the existing set up easily; it would be an automatic correction; and it would not damage the package. The only cost incurred is from purchasing the two sensors and reprogramming the PLC. The only limitations of this design result from the statistical analysis. Outlying data points would not be accounted for, so occasionally too much correction or not enough correction would result. The other limitation is that the adjustment is a best fit, not an exact adjustment for each individual case. Thus, this method may correct a height exactly or may only get within a few tenths of an inch of the actual height. An acceptable correction range would have to be defined to determine if this system would be satisfactory or not.

c. Concept 3 – Air Bearings with a Push/Pull

The air bearings concept reduces the friction force that opposes the straightening motion of the bale. Air bearings are brought into contact with the bale's bottom surface, where the bearings will then create a thin film of air which will significantly reduce the force needed to move the bale. While on the air film, an automated device pushes the bale against a straightening guide rail. This concept will prevent damage to the cardboard while effectively orienting the bale with the light curtain. The low amount of friction reduces the force needed to move the bale, which makes aligning the bale safe for the operator.

One advantage this concept has over the other concepts is that it is considered fully automatic. The air bearings themselves are automatically triggered. The automatic straightening device could consist of a small air or hydraulic ram. This ram could easily be configured to act in synchronization with the air bearings to provide a quick, reliable solution.



The two main limitations of this concept are space and cost. The total amount of equipment dictates a need for significant space. When using air bearings, high tolerances are needed to create a uniform air film. These tolerances reflect a high cost of the equipment needed. Additionally, the fully automated process would cause the price to increase. Estimates put this total cost over $5000.

VI. Evaluation of Concepts

In order to provide a better understanding of how these concepts compare to one another, the concepts are ranked according to a score sheet. Factors that are considered on the score sheet are performance and cost. The performance and cost criteria consist of subcategories that reflect specific goals set forth by the design specifications and Eastman. A concept gets full points or credit for fulfilling the requirement described.

		Distance Sensor and Programming	Digital Calipers that feed to PLC	Push/pull with air bearings
Performance	weight			
Correct for misalignment	20	20	15	20
Cycle time	5	5	1	3
No Damage to Package	15	15	15	15
Fit into existing space/setup	10	10	10	5
Integration into existing system	10	10	8	6
Safety	10	10	10	8
No need for manual bypass	10	10	5	8
Automatic	5	5	0	5
Risk	10	5	8	7
Availability	5	5	2	5
Cost				
Parts cost effectiveness	10	9	7	4
Installation costs effectiveness	10	9	10	4
Maintenance free	15	14	14	10
Subtotal	135	127	105	100
Score		94.07%	77.78%	74.07%

a. Recommendation

After these concepts, as well as those in the appendix, were presented, Eastman opted to pursue the air bearings with a push/pull system. They also expressed interest in the Distance Sensors concept. Our team will design the proof of concept model for the air bearing option but will also do research and make recommendations on distance sensors that would be appropriate for the design presented.

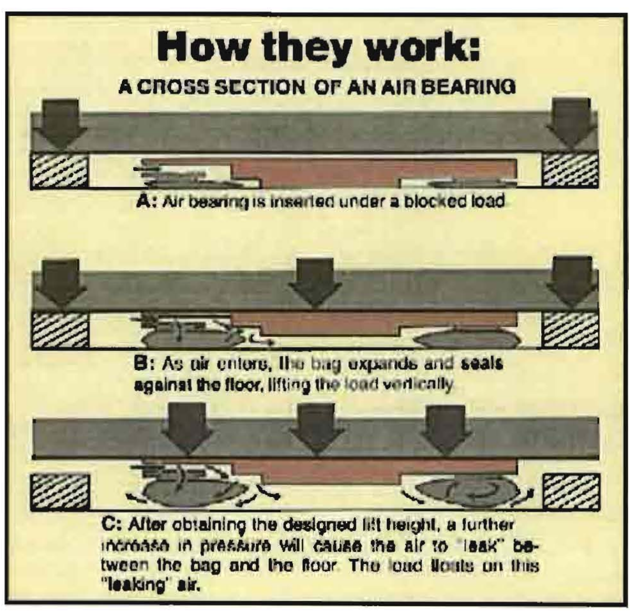
VII. Preliminary Design of Preferred Concept

The air bearing design separates into three distinct design opportunities: air bearing selection and integration, a preloading system, and bale alignment system. Several design options exist for each part of the system. For the air bearings, are they in direct contact with the box or in contact with the floor? Is a preloading system necessary? Do we use pneumatics, hydraulics or a motorized linkage for the bale alignment? These two basic questions provide many challenges and solutions.

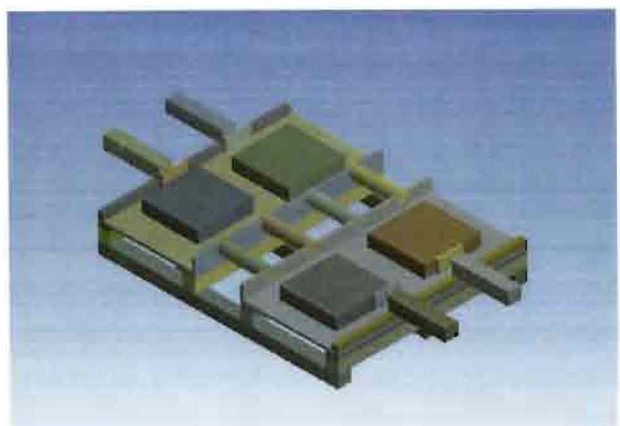
a. Air Bearing Selection and Integration

Our first concepts for the air bearing solution involved using air bearings against the bale. In further development the feasibility of this idea decreased. Further explanation can be found in the appendix.

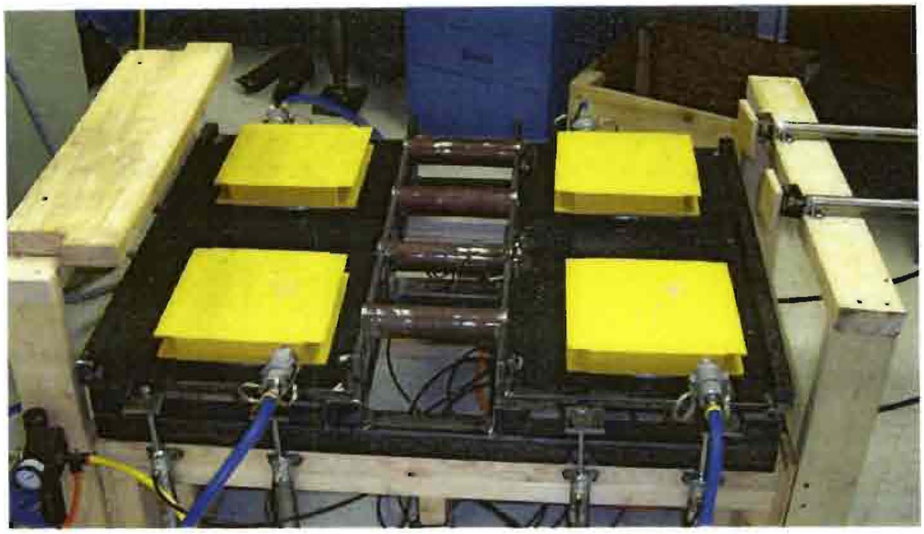
In the process of developing the idea we discovered HOVAIR. HOVAIR's system works like a hovercraft. A rubber bladder inflates and an air film in subsequently created between the rubber and the contact surface. The great feature of this system is that a considerable height difference was created between the deflated and inflated stages. This height difference could hopefully be used in place of the cam mechanism.



However, the HOVAIR configuration would be difficult to fit into the existing conveyor set up. This limitation would lead a conveyor redesign to allow the air bearings to work. The previous solutions had concentrated on adapting a system to the present set up. This new idea is seemingly the only way to allow the air bearings to work properly. Based on the geometry of the HOVAIR system, the prototype frame was designed to allow recesses for the air bearings to operate and for the bale to still be moved.



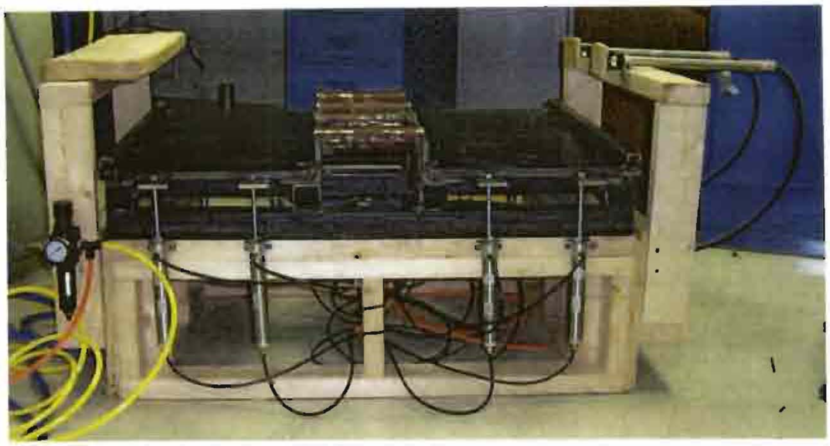
By shortening these rollers we can acquire a great amount of space where the air bearings can be placed without interfering with any measuring equipment. The acquired space would be fitted with two table-like surfaces that would provide clearance for the bearings to move both laterally and vertically. These surfaces would be at a position such that when the HOVAIR system is deflated, the bearings would not be in contact with the bale. When the HOVAIR system is inflated, the bearings will hopefully provide enough lift to clear the shortened roller bed. After the bale has been lifted, an alignment device will push the box until it is oriented parallel with the light curtain. After the bale is correctly aligned, the HOVAIR system will deflate. The alignment device will remain in contact with the bale until the bearings are fully deflated to prevent the bale from becoming askew again. The deflation will be accompanied by a few small springs that will appropriately position the bearings for the next bale.

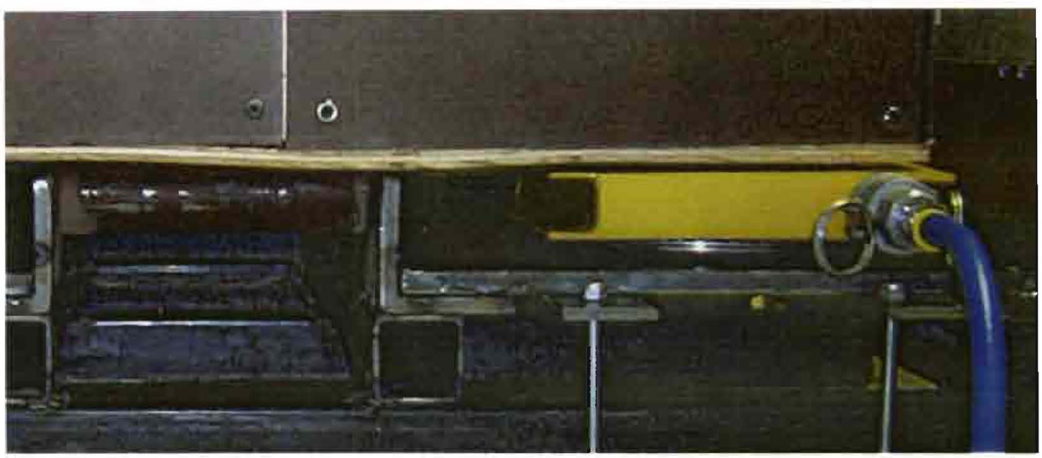


In developing the actual prototype above we found the HOVAIR system had some limitations. Using the air bearings to lift the bale off of the rollers proved to be a problem and a lifting system would need to be incorporated.

b. Preloading System

The air bearings full travel is based on a preloaded cell. In traveling from an unloaded, uninflated state to an inflated state, the actual height change was only .060-.125 inches instead of the expected .300 inches. To use the full .300 inches the air bearings would need to be preloaded before an air film could be created to straighten the bale. Unfortunately this change caused for a change in the design of the platform. The smaller change in height was not going to adequately allow for the bale to "roll" over the conveyor without interfering with the air bearings and still let the air bearings be loaded when inflated. To preload the bearings the recessed steel plates were detached from the frame, and eight two-way pneumatic cylinders were integrated into the system. Four of the cylinders were attached to each of the steel plates used as lift surfaces for the air bearings. These cylinders were placed so that at full stroke, the air bearings would be loaded and raised to a height that would allow the air bearings to lift the bale off of the rollers. Before implementing this solution, it was checked for feasibility and safety using various engineering techniques, and the results are provided in the appendix.



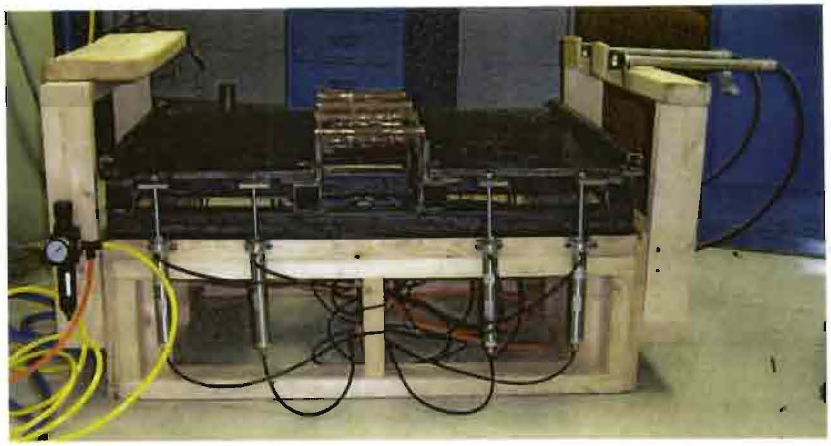


c.

Bale Alignment System

During early stages of the design process, the bale alignment system was conceived as one vague piece of several design concepts, simply described as a pushing or pulling system likely composed of pneumatic or hydraulic rams or a linkage system, with a few minor pressure and area calculations made to test for feasibility. However, once a design concept involving the bale alignment system was chosen, a miniature design cycle was implemented in order to develop the force transmission system. The full discussion of this design cycle is in the appendix.

Initially four pneumatic cylinders, two on each side, were used to square the bale, but an obstacle was encountered. When this set-up was tried the cylinders formed a system in equilibrium that did not move the bale. Several factors contributed to this result: stroke



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Initially four pneumatic cylinders, two on each side, were used to square the bale, but an obstacle was encountered. When this set-up was tried the cylinders formed a system in equilibrium that did not move the bale. Several factors contributed to this result: stroke length, cylinder placement, and air supply. The cylinders being used had an eight inch stroke length but were no more than 4 or 5 inches from the surface of the bale. Therefore when engaged, the cylinders would all reach the bale before reaching full pressure and generate no movement. If the stroke length and placement distance had been equal, this concept should work superior to other options. However, in this prototype case it was more difficult to adjust this than to work around it.

Thus to straighten the bale, a rail was placed on one side of the bale, which would provide a surface parallel to the light curtain. Two cylinders with spring restricted distribution pads were placed on the side of the bale opposite of the rail. Once the bale is on the air film provided by the air bearings, the two straightening cylinders are engaged to push the bale against the rail. Note that the use of a rail was a previous design consideration.

d. Control System

The next task was to set up a control system that would provide a means for individually controlling the flow to the preloading cylinders from the flow to the air bearings and bale straightening cylinders. A three way pneumatic switch was put in place to control the eight, two way preloading cylinders. This switch determines whether the cylinder receives flow to engage, disengage, or not receive any air. The control for the straightening cylinders is a simple push button switch, that when pressed, sends air into the straightening cylinders. In performing tests, the capacities of the cylinders are adequate to handle the prototype load of ~260 lbs. However, the air supply used for testing was dramatically drained when all systems were engaged. In a manufacturing environment, the air requirements to maintain the system would need to be serious consideration. The air requirements for HOVAIR are in the appendix.

VIII. Suggested Improvements

An improvement that could be made to the prototype, would be a spring return system for the air bearings. The existing prototype requires the bearings to manually be set into place to repeat the straightening process. A spring return system would return the bearings to a preset position after the load was set back onto the rollers and allow for a repeatable process.

Another improvement that would improve the speed of the cycle, would be the use of a PLC to replace the existing control system. The PLC would allow time intervals to be programmed to insure the process would remain reliable.

A final improvement would be to change the set up of the preloading operation. The air bearing plates could be stationary and the conveyor could be on a lift system. Thus to engage the system the conveyor would lower, bringing the bale in contact with the air bearings. This modification would reduce the overall air demand for the system when in operation.

IX. Conclusion

Eight months ago, in August of 2003, Eastman introduced a design problem that at first glance did not seem to be overly complicated or involved – the task of correcting for misalignment of bales. However, when given all the specifications for this project, creativeness proved to be the best solution whether it was applied to conventional or novel ideas. Over the past 8 months, we have developed a mechanical solution to solve this particular problem which incorporates air bearings to create a low friction environment for physically moving the bale. The prototype demonstrates the proof of concept hoped for but is by no means a complete or optimized solution. Hopefully, the ideas presented through this project will provide Eastman with more guidance to finally implement a practical, economical fix for the bale misalignment.

Appendix

a. Other Concepts

Concept IV – Air Bearings with Guide Rails

The guide rail with air bearings concept reduces the friction force that opposes the straightening motion of the bale. Air bearings are brought into contact with the bale's bottom surface, where the bearings will then create a thin film of air which will significantly reduce the force needed to move the bale. While on the air film, the operator will push the bale against a straightening guide rail. This concept will prevent damage to the cardboard while effectively orienting the bale with the light curtain. The low amount of friction also makes aligning the bale very safe for the operator. When using air bearing high tolerances are needed to create a uniform air film. These tolerances reflect a high cost of the equipment needed which will total over $5000. The concept which features air bearings with the guide rail is considered semi-automatic. The air bearings themselves are automatically triggered but the act of straightening the bale is purely manual. To improve this concept an automatic straightening device could be implemented. A small air or hydraulic ram would replace the manual force applied by the operator. This ram could easily be configured to act in synchronization with the air bearings to provide a quick and safe solution. The small coefficient of friction would still be intact from the air bearings. The cost of fully automating the process would increase as would the space needed for the operation.

Concept V - Push/Pull

One solution method improves the height measurement by physically adjusting the orientation of the bales. Once the bales enter the measurement area, hydraulics or air rams orient the bales so that they are perpendicular to the LED light curtain, thus increasing the accuracy of the height measurement. The main advantages of this concept are the simplicity of the concept and the reliability and availability of the technology. Hydraulics and air rams are widely used and readily available, and there is no doubt that this concept would adequately and repeatedly straighten the bales as desired.
Thus this concept itself is low risk.

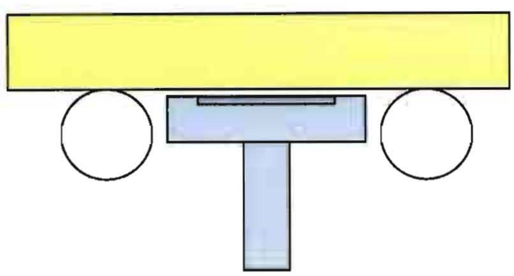
However, its implementation has many drawbacks. Due to the fact that the bales weigh up to 1900lbs, and considering friction between the bales and the rollers on which they sit, a large amount of force is needed to straighten the bales with the push/pull method. This large amount of required force poses several problems. This force creates a safety risk for the personnel working near the apparatus, and causes significant damage to the cardboard packaging of the bales, an unacceptable result. These drawbacks alone, not considering the generation of the relatively high pressure needed to create the required force, make the simple push/pull method undesirable.

b. Recommendation for Distance Sensor

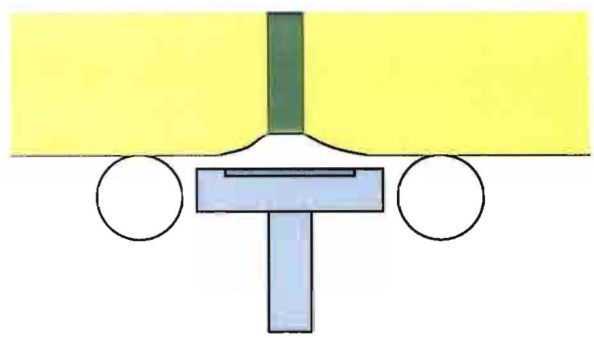
After researching, one sensor that meets the requirements for operation as described in this concept is the SICK OD proximity distance sensor. It has a measurement range of 26-400 mm or approximately 1-15 inches. The accuracy of the sensor is 1-1500 micrometers (μm).

Another distance sensor that appears to meet the specifications is Senix Ultrasonic Sensor. Its cost is in the $500-900 range. This sensors range and resolution are less precise as compared to the SICK. However, with any sensor reliability, accuracy, precision, and durability are often trade offs with cost. More detailed study would be needed to determine the best sensor if this design is to be prototyped.

c. Air Bearing Selection Discussion

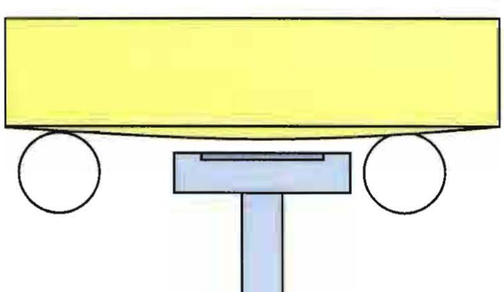


(A)



(B)

Initially our design was to have the air bearings form an air film between themselves and the bale (A). However, in the evaluation of this idea several problems were posed. What is the resulting performance when the air bearing interfaces with a strap (B)? How does this design account for curvature (C)? Can the air bearings be placed close enough so as not to cam them into place? Because these dilemmas appear to have no easy solution, we moved to a modified version of the design.



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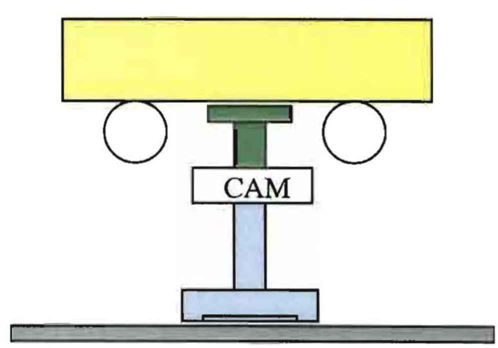
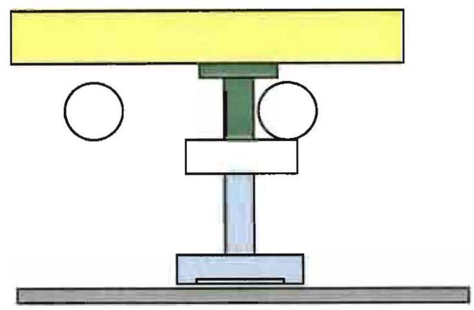


(D)

Our second concept was to use the air bearing against the floor and have a cam mechanism that would come in contact with the bale (D). The bearings would then float on the floor and the cam would retract when the bale was in position. This concept seemed to have more potential than the first. However, it had is limitations as well. How big does the contact pad have to be not to mar the bale? How far will the pads move when the box is squared? What cam mechanism should be used? Rough calculations showed that the center of the contact pad would move nearly 2 ¾" for a max design correction of 10 degrees. In the prototype design this size would restrict the contact pad to a few inches in diameter. What would happen if the cam mechanism gets the pad above the roller plane(E)? This solution would allow for a larger contact pad, but when the bale was to be lowered it would pinch the pad between the bale and the rollers.



(E)

d. Bale Alignment Design Process

First the objective was defined: to physically manipulate the bales such that they are aligned with the LED measuring device. Considering the objective of the system, available budget, space limitations, and other factors, several basic concepts were devised, including a pneumatic system, a cam-follower system, and a linkage type system. The pneumatic system consisted of two or four air-driven cylinders which would apply force to the bale, pushing the bale either against one another or into a stationary guide rail, and thus straightening it. The cam-follower system concept consisted of a precisely machined eccentric or varying radius cylinder, which when rotated about a shaft, would drive a spring loaded ram, extending and retracting the ram to apply force to the bales. Third, a linkage system, consisting of typical mechanical components such as rotors, rockers, etc. would be driven by a small motor, causing a regular and repeated pushing motion which would transfer force to the bales. Once each concept was defined, more detailed factors were considered for each concept, feasibility calculations were made, and each concept was evaluated concerning various aspects of performance, cost, and safety.

Upon evaluation, it was determined that all three force transmission system concepts had the capability to be designed to correct the misalignment of the acetate tow bales. The benefits of the linkage system concept were simplicity of principle, cost effectiveness, extremely repeatable, easy automation, and relatively low cost. However, given the space limitations at the Eastman facility, the concept of a linkage system did not develop into a practical solution. In terms of space limitation and practicality, the cam-follower system scored well in the concept evaluation. The cam-follower design also provided a high degree of repeatability, automation, and safety. However, the high precision required in the machining and design of the cam, and the need for recalibration, translated into less availability of equipment and higher costs.

The final concept, the pneumatic ram system, scored well during concept evaluation for providing cost effectiveness, ease of integration and fit into existing setup, availability of equipment, automation, safety, and low maintenance required. Due the nature of the air cylinder concept, wherein an air driven cylinder extends and retracts within a housing to a certain length, the motion and thus available force is highly repeatable and adjustable with the pneumatic ram system. Also, since air cylinders are relatively small, and air would already be required to power the air bearing system also being used in the design project, the pneumatic system would be easily integrated with the existing setup. Since air cylinders are readily available, in virtually all sizes, from many manufacturers and distributors, and the system would most likely not require any specialty equipment, the air cylinder concept would be a very cost effective solution. When coupled with an air bearing system, the required pressure for straightening the bale would be less than 50 pounds per square inch, and thus the air bearing system would not pose any significant danger to any employees working near it. Maintenance concerns would be minimal with the pneumatic system since many purchased air cylinders are pre-lubricated, sealed, and have other features which help insure relatively long life with minimal maintenance required.

Due to the obvious advantages of the air cylinders, as detailed above and shown below in the chart, the initial decision was to devise a system with two air cylinders positioned on each side of the bale, thus pushing from both sides. This was preferred since it would decrease the total distance traveled by the bale, whereas pushing from only one side had the potential for requiring more travel to straighten against a guide rail or similar structure. However, in order for this design to work, we determined that the air rams would need place and calibrated such that when they were all extended to full stroke, they would align the bale. For the purposes of this design project, however, it was not possible to do so.

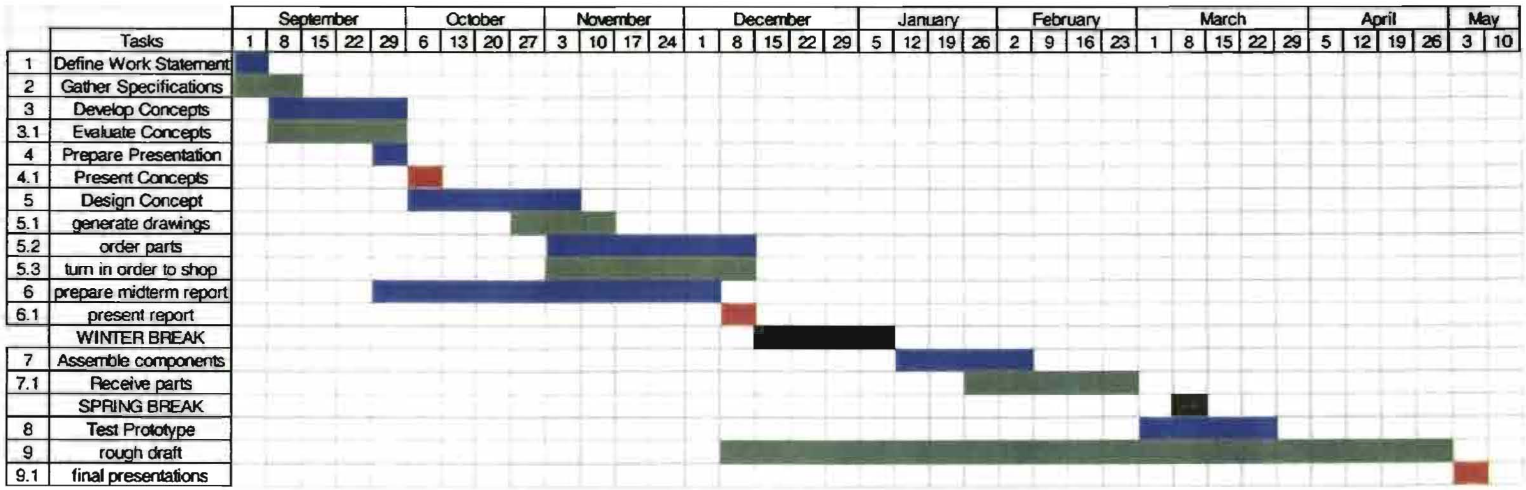
Concept Evaluation for Alignment System

		Air Ram	Cam System	Linkage System
Performance	weight			
Correct for misalignment	20	20	20	20
No Damage to Package	15	15	15	15
Fit into existing space/setup	10	9	9	5
Integration into existing system	10	10	7	5
Safety	10	10	10	9
No need for manual bypass	10	10	10	8
Automatic	5	5	5	5
Low Risk	10	9	9	7
Availability	5	5	3	2
Cost				
Parts cost effectiveness	10	9	5	8
Installation costs effectiveness	10	7	5	6
Maintenance free	15	12	8	10
Subtotal	130	121	106	100
Score		93.1%	81.5%	76.9%

e. HOVAIR Data Sheet

MODULE	BEARING	CAPACITY	DIMENSIONS - INCHES				FLOW - SCFM		LAND	WEIGHT - POUNDS	
Number	Number	Pounds	Width	Length	H1 Air Off	H2 Air On	½ Load	Full Load	Sq. In	Mod	Brg
SA9	9NSG	600	9.0	9.0	2.0	2.3	2	3	3.1	9	1
SA9-HD	9NSG-HD	1200	9.0	9.0	2.0	2.3	3	6	3.1	9	1
SA12	12NSG	1000	12.6	12.6	2.0	2.4	2	4	7.1	10	2
SA12-HD	12NSG-HD	2000	12.6	12.6	2.0	2.3	4	8	7.1	10	2
SA16	16NSG	2000	16.8	16.8	2.0	2.5	3	5	19.6	15	3
SA16-HD	16NSG-HD	4000	16.8	16.8	2.0	2.4	5	10	19.6	15	3
SA18	18NSG	2500	18.8	18.8	2.0	2.7	3	6	19.6	16	4
SA18-HD	18NSG-HD	5000	18.8	18.8	2.0	2.5	6	12	19.6	16	4
SA22	22NDGE	4000	24.8	24.0	2.0	2.8	4	8	38.5	26	6
SA22-HD	22NDGE-HD	8000	24.8	24.0	2.0	2.7	8	16	38.5	26	6
SA28	28NDGE	6000	30.3	30.0	2.3	3.3	5	9	45.6	44	9
SA28-HD	28NDGE-HD	12000	30.3	30.0	2.3	2.9	9	18	45.6	44	9
SA34	34NDGE	10000	36.0	36.0	2.3	3.5	6	12	55.0	62	11
SA34-HD	34NDGE-HD	20000	36.0	36.0	2.3	3.2	12	24	55.0	62	11
SA40	40NDGE	14000	42.0	42.0	2.3	3.7	8	15	64.0	79	15
SA40-HD	40NDGE-HD	28000	42.0	42.0	2.3	3.3	15	30	64.0	79	15
SA44	44NDGE	18000	46.0	46.0	2.3	3.8	9	17	69.0	103	18
SA44-HD	44NDGE-HD	36000	46.0	46.0	2.3	3.3	17	34	69.0	103	18
SA4870	4468NDGE	30000	48.0	70.0	2.3	3.8	12	23	172.0	174	26
SA4870-HD	4468NDGE-HD	60000	48.0	70.0	2.3	3.3	23	46	172.0	174	26

f. Gant Chart



September
October
November
December
January
February
March
April
May
Tasks
1 8 15 22 29 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 16 23 1 8 15 22 29 5 12 19 26 3 10
1 Define Work Statement
2 Gather Specifications
3 Develop Concepts
3.1 Evaluate Concepts
4 Prepare Presentation
4.1 Present Concepts
5 Design Concept
5.1 generate drawings
5.2 order parts
5.3 turn in order to shop
6 prepare midterm report
6.1 present report
WINTER BREAK
7 Assemble components
7.1 Receive parts
SPRING BREAK
8 Test Prototype
9 rough draft
9.1 final presentations

g. Air Bearing Preload System Design Checks

Initial Stress Check:

$\sigma = \frac{Mc}{I}$, where

$$M = (65lb)*(4") = 260 \ lb-in$$

$$c = 0.25 \ \ in$$

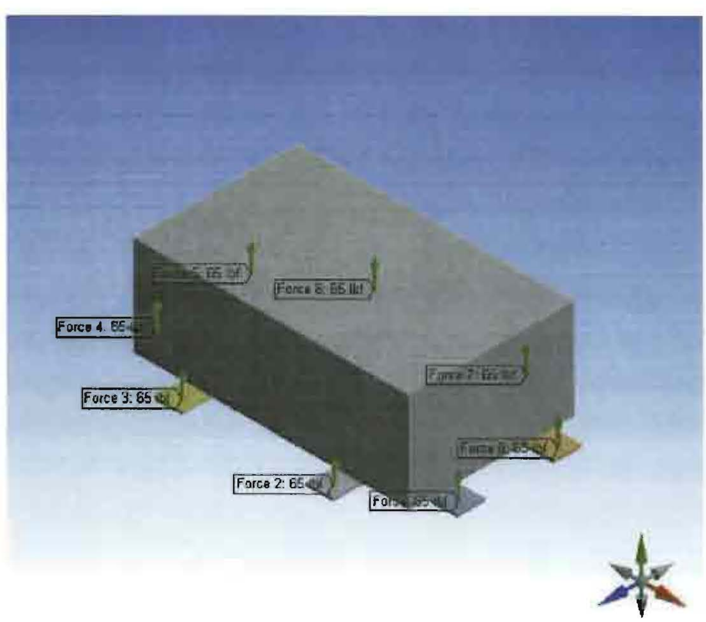
$$I = \frac{bh^3}{12} = \frac{(2)*(0.25)^3}{12} = 0.002604 \ \ in^4$$

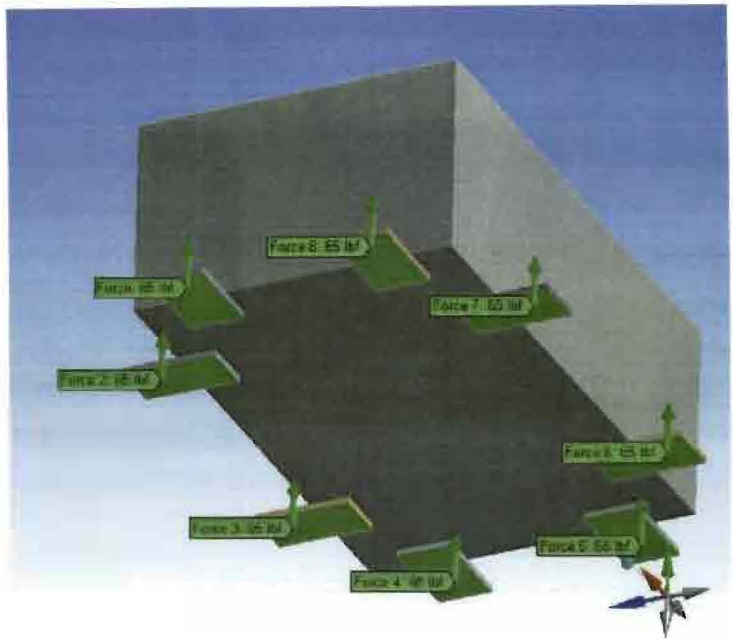
Thus,

$$\sigma = \frac{Mc}{I} = \frac{(260)*(0.125)}{(0.002604)} = 12481 \text{ psi or } \mathbf{12.5 \ kpsi}$$

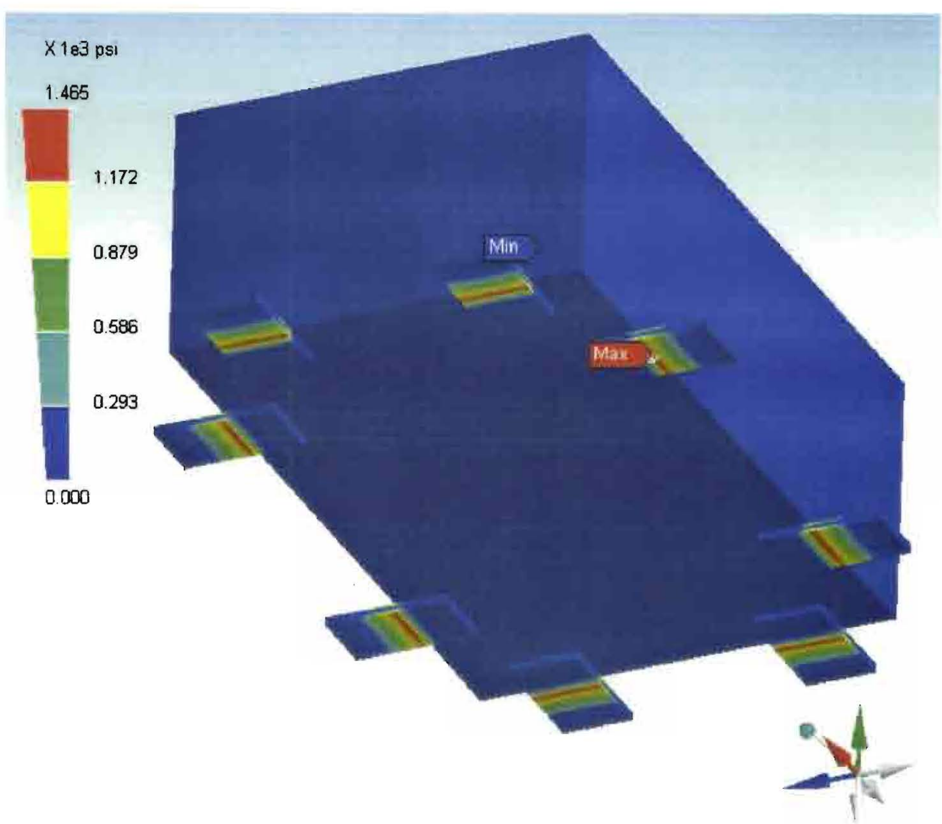
A <u>conservative</u> maximum stress value for steel is σ_{max} = 40 kpsi, thus the pre-loading system concept passed the initial feasibility calculations.

Next, finite element analysis was done using Inventor and DesignSpace. Inventor was used to create 3D models of the load block and the lifting tabs which the air cylinders would push against. Using an estimated load of 520 lb (the actual load was closer to 200 lb), DesignSpace was used to model the stresses and strains in the lifting tabs in order to verify the safe operation of the system. The results are shown in the images below.



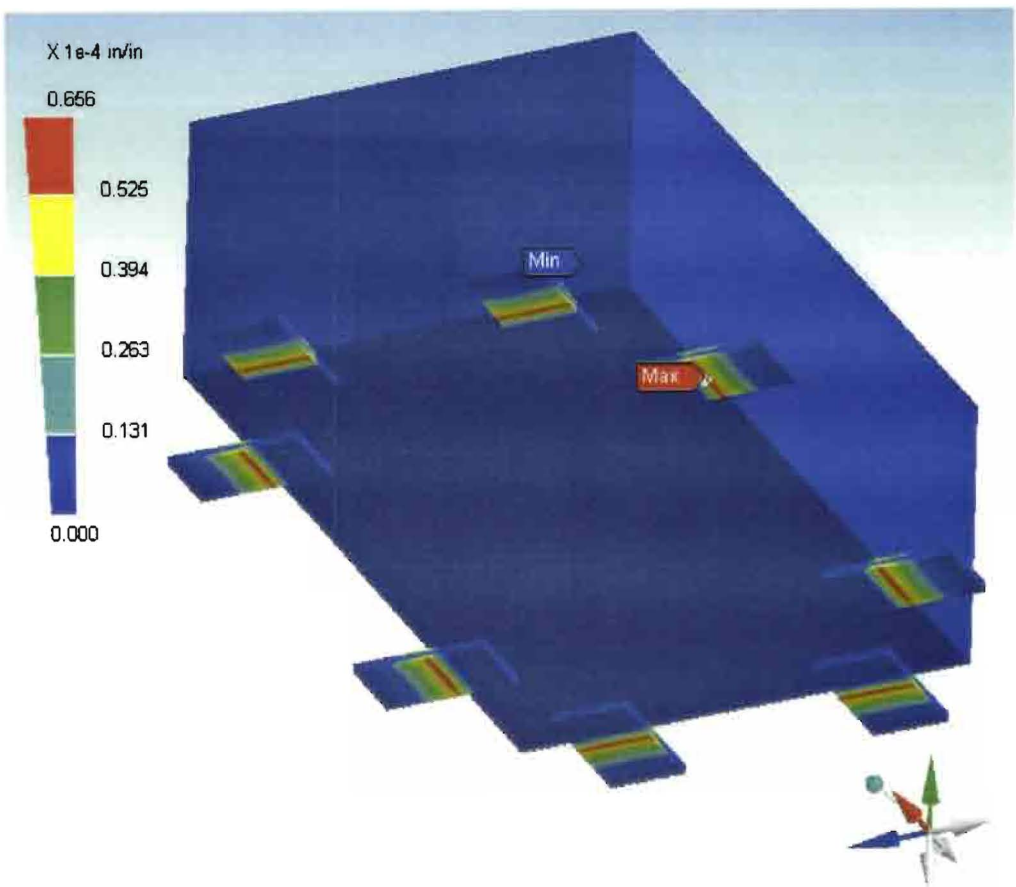


The first simulation tested the design for stresses in the tabs, which again using a conservative value for steel could not exceed 40 kpsi. The results are shown below.



The resulting maximum stresses in the lifting tabs was only 1465 psi or 1.4 kpsi, well below the maximum value of 40 kpsi.

The next analysis was for strain in the tabs. The image below resulted.



The maximum strain which resulted from the simulated loading was 6.56*10-5, or 0.0000656 inches per inch, an acceptable value.

Thus, the pre-loading system was deemed to be reasonable and safe, was pursued in the final design, and was successful.

h. Individual Perspective and Contributions: Joshua Woods

The Eastman Bale Straightener has been my senior capstone design project for the 2003-2004 school year, and by completing this project, I am completing my Bachelor's Degree in Mechanical Engineering. The structure of the Mechanical Engineering program at UT requires that the capstone projects be performed in teams. Thus, while working on this project, I have been a member of a three person team, with the other members being Kirk Lowe and Ian Gilliam.

Working as a team on a large project such as this one presents various advantages; however it also brings certain challenges along with it. Teamwork is valuable in that when designing a system such as the Bale Straightener, a wide range of ideas are input from various sources, rather than drawing the creative potential from one source. Also, a large project such as this requires an extensive amount of time, energy, and work. When working on a team, much more time, energy, and work can be put into the project than can be when only one person bears the full burden. Being so, it would seem at first that working on a team would decrease the amount of work or effort that an individual would need to put into the project and decrease the amount of knowledge, experience, and benefit that an individual would gain from the completion of the project.

However, that was not the case on this project. By working on a team, we enhanced the educational quality of the project and created difficulties that helped us to grow individually and as a team. In the diverse, fast-paced, high-technology world of today, and especially in engineering, communication, collaboration, and teamwork are essential to productivity. When collaborating with others, enhanced communication and social skills are needed to promote a positive, productive work environment. Also, the ability to synthesize ideas and information from various sources into a single result is crucial to success in the professional world. The team environment of this project provided an excellent opportunity to sharpen these skills in a relatively safe academic environment before they were needed in professional life. By working together, we learned how to manage professional issues without being distracted by personal issues. We also learned how to create realistic schedules and maintain overall team progress accordingly. We learned how to divide a large, complex problem or task into smaller, manageable tasks, and to combine the results of the smaller pieces into a large, unified solution. We learned the importance of responsibility, integrity, and trust. By working on a team, we were able to obtain a more robust result than if we had worked individually, and in the process of the completing the project together, we obtained experience that will greatly aid us in the pursuit of our careers and further education.

As with any team that truly works together, it would impossible to differentiate the results of this project and determine if one member of the team were more valuable or more responsible for the results than the others. Each member of the team worked hard and contributed a great deal to the project, and at the end of the year all members share the satisfaction and responsibility for the successful completion of the project. Even so, it is possible to point out certain small contributions made by each member throughout the process of completing this project. The following is my attempt to provide a perspective on my individual contributions to this team effort.

During the month of August 2003, we formed our team in order to begin work on the project. Initially, we visited Eastman several times in order to gain insight into the situation for which we were to design a solution. During the fall semester, we analyzed the problem, wrote a work statement, generated design specifications and concepts, and began to construct our report. We met regularly in class to discuss our progress and obtain direction from our faculty advisor, Dr. Don Dareing. Also, we met outside of class in order to discuss our progress among the team members and continue work on the design. As a member of the team, I attended these trips and meetings in order to contribute. Each member, including myself, submitted a draft of the work statement and their own list of design specifications. Once each member had completed their draft, we met and combined our results in order to obtain a well-rounded outcome. My specifications list concentrated heavily on the specifics of aligning the bale, available space, availability of compressed air, and the requirement not to damage the cardboard packaging of the bale. I contributed adequately at design concept generation meetings, including playing key creative roles in the formulation of the digital caliper concept and the idea to utilize air bearing technology. The prospect of moving a 2000 lb bale without damaging the cardboard packaging was a frustrating problem, and during a concept generation meeting I remarked that it would be great if we could simple construct a large air hockey table and float the bale. At the time, I was not aware of air bearing technology, however Dr. Dareing was. Upon hearing that comment, he suggested that we research air bearing technology in order to see if we could apply it to our project. We did, and in the final design of the project, the key feature of our design that allows it to function within the design specifications is an air bearing system. During the initial construction of the report, I contributed sections detailing the work statement and the various design concepts, and I constructed Inventor 3D models and CAD drawings in order to visually communicate the design concepts. Also, I revised and added graphics to the PowerPoint presentations used at our meetings with Eastman staff.

By Christmas break we had chosen a design concept to pursue, and we divided the system into three main systems: the fixture, the air bearing system, and the bale alignment system. I spent Christmas break researching my particular portion of the project, the bale alignment system. I generated various design concepts, and researched each one. I then evaluated each concept and constructed a concept evaluation chart in order to facilitate my decision. My recommendation to the team was to pursue the air cylinder concept for straightening the bale, and this concept was successfully implemented in the final design. Once the system had been chosen, I researched various companies from which to purchase air cylinders and the related support equipment such as connectors, adaptors, hoses, an air filter/pressure regulation unit, etc. Based on inventory, speed of delivery, customer support, and pricing I chose McMaster-Carr, and we ordered all components except for the bearings from McMaster-Carr. I selected the required air cylinders based on the design specifications of the project and collaboration with the other members concerning integration with their portions of the project. During the construction of the prototype, I was involved in every aspect of building the system, as well as making design decisions concerning the bale alignment system. This involved hands-on work including measuring, cutting metal, using various hand and power tools, drilling and tapping threaded holes (a new experience for me), etc. The testing process was intermingled with the construction of the system, and I also contributed in testing the system. Once testing had commenced, it became necessary to design a pre-loading system for the air bearings. We decided to use air cylinders to pre-load the air bearings, at which point I took charge of designing the pre-load system to be integrated with the existing pneumatic system. In doing so I performed feasibility calculations on the design concept, as well as Finite Element Modeling analysis in order to be confident in the system implementing it. Once the system was decided upon, I ordered all of the necessary equipment, measured the placement of the air cylinders, and drilled and tapped most of the holes needed to mount the cylinders to the system. During testing I also operated the controls for the pre-loading system and the bale aligning system. During the final weeks of the project, I collaborated on finishing the report, provided final materials for the bale alignment and pre-load systems, as well as placed all graphics and pictures in both the report and PowerPoint presentation. During all presentations to Eastman, I presented an equal share of the material and again operated the controls during the final demonstration.

I am satisfied with the completion and the success of our project. I know that I have learned a great deal about applying engineering knowledge to obtain practical solutions to real problems, and I have broadened my engineering experience base. Also, I have sharpened my communication and collaboration skills, and gained valuable team experience. I feel that as a result of completing this project I am more prepared and capable to enter the professional world of engineering, and I look forward to putting my knowledge and experience to use.