



Amphenol TCS Manual Press-Fit Machine Improvement

A Major Qualifying Project Report:
Submitted to the faculty of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science By:

David Nguyen

Bhalayogasthini Sivayoganathan

Simeon MacMillen

In Partnership with
Beijing Jiaotong University
Partners: Yichao Liu, Bin Xi

Date: 14 October 2010

Approved:

Professor Yiming (Kevin) Rong, Major Advisor, WPI
Professor Amy Zeng, Co-Advisor, WPI
Professor Yiping Lu, Co-Advisor, BJTU

Acknowledgements

We would like to recognize the following individuals for their invaluable contribution to this project:

Romen Li, General Manager, Backplane Assembly, Amphenol TCS,

Mark Zhou, Marketing, Backplane Assembly, Amphenol TCS

Michael Li, Logistics, Backplane Assembly, Amphenol TCS

Professor Rong Yiming, Project Advisor, Worcester Polytechnic Institute

Professor Amy Zeng, Project Advisor, Worcester Polytechnic Institute

Professor Lu Yiping, Project Advisor, Beijing Jiaotong University

The operators at the Amphenol, TCS Changzhou facility

Abstract

This project aims at evaluating the machines and proposing solutions to make the process of attaching connectors to Printed Circuit Boards more efficient by reducing the pressing cycle time at Amphenol TCS' Changzhou, China facility. Through ergonomic analysis of the current design, along with a series of interviews and surveys, we developed several solutions to address the shortcomings in productivity and suggested several ergonomic modifications as well new machine design concepts to help improve the operators' working conditions.

Table of Contents

Acknowledgements..... ii

Abstract..... iii

Table of Figures and Tables..... v

 Figures..... v

 Tables..... v

Introduction 1

2. Background 3

 2.1 Amphenol TCS..... 3

 2.2 Press-fit technology 4

 2.3 Automatic vs. manual machines 5

 2.4 Ergonomic Caution Zones 8

3. Methodology..... 9

 3.1. Comparison of various methods..... 9

 3.2. Types of Methods 11

 3.2.1. Interview 12

 3.3 Methodology Summary 14

4. Results and Analysis..... 15

 4.1. Survey..... 15

 4.2 Cycle Time for a Mid-Sized Board 17

 4. 3 Proposed Design Solutions..... 18

 4.3.1 Design Option #1..... 18

 4.3.2 Design Option #2..... 23

 4.3.3 Recommendations for Design Option #3..... 28

 4.4 Comparison 29

 4.4.2 Pair-wise Comparison 30

 4.4.3 Decision Matrix 31

 4. 5 Supplementary Design Modifications 33

6. Conclusions and Recommendations 35

Recommendation:..... 35

References 37

Table of Figures and Tables

Figures

Figure 1 -Structure and sectional view of press fit	5
Figure 2 -Automatic Press Fit Machine	6
Figure 3 -Manual Press Fit Machine.....	7
Figure 4: Operator Feedback	15
Figure 5 -Relationship between Angle and Height	19
Figure 6 -Manual Machine Operation.....	20
Figure 7 - Roller Wheels	21
Figure 8 - Physics Diagram	22
Figure 9- Current Ergonomic Issues	23
Figure 10 -Mechanical Assembly	24
Figure 11 –Example of Electric Press Placement on Toggle Machine.....	25
Figure 12 -Rollers with Electric Motor (for y-axis movement).....	25
Figure 13 -Electric Press Control Unit	26
Figure 14 -Schematic for Electric Press.....	27

Tables

Table 1 -Comparison Table -Modify or Design.....	8
Table 2 -Analysis of Survey Results.....	16
Table 3 - Press Fit Steps (Skilled Worker)	17
Table 4 - Press Fit Steps (Unskilled Worker)	18
Table 5 -Electric Press Parts and Price Estimates.....	28
Table 6 -Pair-Wise Comparison.....	31
Table 7 -Decision Matrix	31
Table 8– Supplementary Cost Analysis	34

Introduction

In the competitive global economy, any advantage a company can get can mean the difference between successful business and failure. As companies try to improve their bottom lines, they may try to improve the quality of their product (selling value), or decrease the cost of their product (production, transit, or other expense areas). It is no secret that a leaner company can better compete economically. As a result, efficiency –a ratio of output to input or the effective use of resources in production (Princeton University, 2010) –has achieved a large significance for many companies, especially in the manufacturing industry. Efficiency gains can be realized in three important areas: time -decreased cycle time or throughput, materials –reduced waste, and quality –reduced defect rate. In addition to business benefits, companies that make efforts to increase efficiency can also reduce their environmental footprint, through improved and responsible use of resources.

Ergonomics is the science studying “the relation between workers and their environments” (Princeton University, 2010). Associated with comfort, ergonomics has traditionally been viewed as a negative factor in the efficiency of a process (Interface Analysis Associates, 2008). Because of this view, companies have been reluctant to invest in ergonomic improvements, where not required (Heine, 1999). However, modern research shows a correlation between ergonomic investment and process efficiency (Ranee, 1996), suggesting that many corporations may have overlooked an important means to increased industrial effectiveness.

In the diversified electronics industry, where large volumes of manufactured products must be balanced with custom orders, efficiency is especially important. In large product orders, any small difference in time or material usage can result in large potential savings (or losses). Likewise, the ability of a company to minimize waste in product changes, such as starting production of a new circuit board, is important to maintaining profitability in an unpredictable market.

Amphenol TCS, a division of Amphenol Corporation, is a “leader in high-speed, high-density connection systems” (Amphenol TCS, n.d.), with products in the high-speed, high-density connector and backplane markets. One component of Amphenol TCS’s backplane production involves the use of machines (manual or automatic) to press-fit connectors onto printed circuit boards (PCBs). The efficiency of Amphenol TCS’s press-fit process is determined by three factors: defect rate (for pressed connectors), press-fit cycle time, and ergonomic conditions for the workers.

The focus of this project was to improve the efficiency of the Amphenol TCS press-fit machine. For their manual press-fit machines, Amphenol’s defect rate was under two percent (Li, Zhou, & Li, 2010), leaving little room for improvement. The cycle time was highly variable, due to the diversity in processed boards. This left ergonomic conditions as a relevant factor influencing press-fit efficiency. By inspecting the factory process and surveying the machine operators, we were able to identify multiple ergonomic issues with the current machine setup. By performing an ergonomic analysis of the current design, we identified several possible areas of improvement in this setup. Through brainstorming and mechanical analysis, we developed a set of possible solutions to address these identified issues. Finally, through decision analysis, we identified and proposed a set of solutions appropriate to the needs of Amphenol TCS. By addressing worker ergonomic concerns, Amphenol TCS can boost worker productivity and efficiency, increasing its competitiveness and profitability.

2. Background

2.1 Amphenol TCS

Our Sponsor for the project is Amphenol TCS (ATCS), a division of Amphenol Corporation (Amphenol). Amphenol TCS was found in 1968 as a division of Teradyne Inc., and was acquired by Amphenol in December 2005. Amphenol TCS is a business unit of Amphenol in Information Technology and Data communication markets (Amphenol Corporation, n.d.).

Amphenol TCS is headquartered in Nashua, NH and has manufacturing sites in Mexicali, Mexico; Penang, Malaysia; Chengdu, Changzhou and Shenzhen, China; Milpitas, California; Nashua, New Hampshire and Winston-Salem, North Carolina.

Amphenol TCS delivers total connection solutions, including designing and manufacturing backplane systems, printed circuit boards and high speed, high density connectors. Amphenol solutions are applied in networking, communications, storage and computer server markets.

Amphenol TCS products can be sorted into three categories as follows.

1. Backplane systems
2. Connectors
3. High-technology Printed circuits

Backplane systems

Amphenol TCS provides solutions that help to meet the need of bandwidth increase by optimizing the full signal path and by boosting channel performance. Amphenol TCS is the most advanced manufacturer of backplane systems with a range of press fit, surface mount and testing capabilities.

Connectors

Amphenol TCS provides innovative technology and reliable high density solutions for backplane, Mezzanine and optical applications.

High-technology printed circuits

Amphenol TCS has printed circuits capabilities in advanced materials, deep micro vias, buried, blind and back drilled vias, sequential lamination, panel sizes up to 24"x 54", layer counts up to 64, board thickness up to .500".

2.2 Press-fit technology

Press fit technology is the only solder-less method used in PCB application to ensure electrical connection and mechanical attachment. Press fit technology is made through pressing in contact pin into printed circuit board (PCB) through a hole (IMS Connector Systems GmbH, n.d.).

By using press fit the following can be avoided

1. Thermal stress on PCB
2. Fumes/gases that may reduce contact reliability of the connector
3. cold solder joint
4. shorts as a result of solder bridging

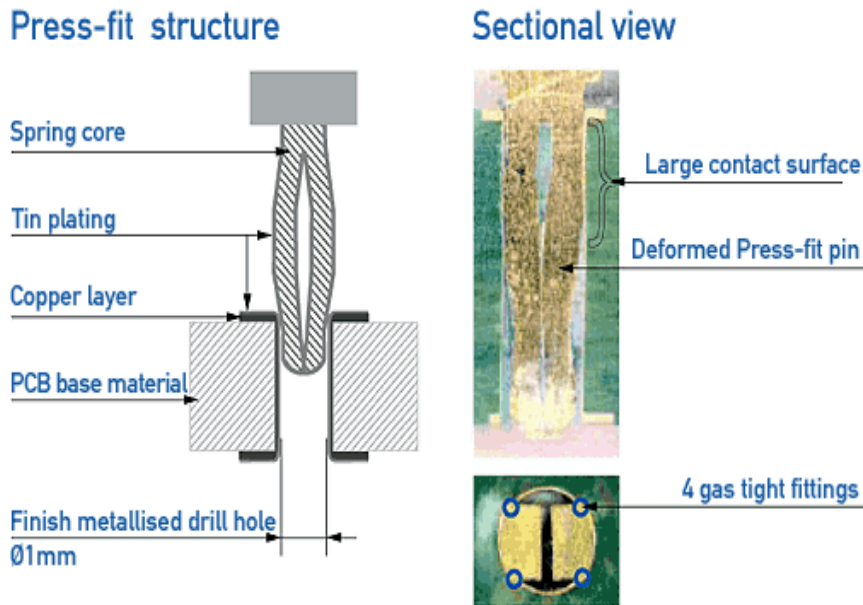


Figure 1 -Structure and sectional view of press fit

(IMS Connector Systems, n.d.)

Compared to soldering, press fit technology is convenient, cost efficient, reliable, environmentally friendly and the connectors can be replaced. When compared with soldering, press fit technology is an efficient and an effective solution for backplane and PCB assembly manufacturing.

2.3 Automatic vs. manual machines

Amphenol uses both manual and automatic press fit machines for production. Automatic press fit machine is utilized for uniform, mass production and manual machine is used for low volume production and to rectify the faulty board of the automatic machine.

Our group decided to work on the manual machine for the following reasons

- A reduction in manual machine defects could allow Amphenol to reduce testing time. (Currently, the testing processes take a significant amount of time (personal communication, Michael Li, August 25, 2010).

- Improved efficiency of manual machine would allow Amphenol to shift more work from the automatic machines to the manual machines, balancing the entire work flow (personal communication, Michael Li, August 2010).
- The complexity of the automatic machine rendered it beyond the scope of our project, with both skill level and time required to effect a useful change.
- The Amphenol project liaisons strongly recommended a focus on a manual machine (personal communication, Mark Zhou, et. al, August 23-27, 2010)
- Although manual machines press a small percentage of connectors on each board, any defects caused by them would require Amphenol to rework an entire board, slowing down the entire work flow.

Manual press fit machine had more avenues of improvements compared to Automatic and thus we chose the manual design to make the most impact for the company.



Figure 2 -Automatic Press Fit Machine



Figure 3 -Manual Press Fit Machine

Based on the reasoning given above, we decided to focus on manual machine along with the recommendation of our sponsors.

We analyzed ways to improve the efficiency of the manual machine and outlined the following avenues:

1. Reduce defects
2. Reduce cycle time
3. Improve the ergonomics of the machine

We were told by the Amphenol TCS Changzhou team that the current defect rate for the manual machine is approx. 2% (personal communication, Mark Zhou, Michael Li, August 23, 2010). Because this defect rate is very small, we felt that a mechanical design to improve the defect rate would be difficult to achieve. We started focusing on the other two avenues and determined that both reduction in cycle time and improvement of the ergonomics of the machine are operator related. Therefore, we proceeded to gather information from operators to improve the efficiency of the manual press fit machine.

Table 1 -Comparison Table -Modify or Design

Improve old machine design	Design a new machine
Easier to make changes to the current design	Current design will be scrapped and a completely new design will be used
Have limitations, restrictions to work with the current design	Open ended and very few restrictions as team has the choice to design whatever is needed.
Cost effective as only requires improvements to current design, minimum or no retraining at all	Could be expensive as it has to be designed from scratch, operators need to be trained again
The current issues could be pinpointed and solutions can be developed as needed	Solutions can be developed from the current design but new design could bring in unexpected problems.

2.4 Ergonomic Caution Zones

Ergonomics is “the science and practice of designing jobs or workplaces to match the capabilities and limitations of the human body” (Keween, n.d.). In the work area, there are certain ergonomic issues which are referred to as “Caution Zones.” Caution Zones refer to an issue which has a significant negative ergonomic impact, and has a number of indicators including:

- Awkward Postures
- High Hand Force
- Highly Repetitive Motion
- Heavy, Frequent or Awkward Lifting

Any work situation which exhibits the above traits for more than two hours is a “caution zone” job. In our project, it was important for us to identify any ergonomic issues to improve, to enhance worker safety, and increase long-term process efficiency. (A more comfortable operation can be performed with greater ease and therefore, more quickly.)

3. Methodology

The goal of our project and research question is to gather data needed to improve the efficiency of the manual press fit machine at Amphenol TCS in Changzhou. We identified manual machine operators as our main source of information as they are the direct users of the manual press fit machine. We were looking for potential solutions to improve the cycle time of the process and to improve the ergonomics of the machine through the Operators feedback. Our objectives were as follows.

Objective 1 - Gather information of the current issues of the manual press fit machine

Objective 2 – Based on the feedback, brainstorm potential solutions and get more support data for solutions

In order to collect information there are several methods available such as surveys, in person interviews, telephone interviews, document reviews, focus groups etc. We compared various methods to find the best method(s) for our situation. Regardless of the method, we had language barrier as one of our main challenges. Although we had our project partners from Beijing Jiaotong University conversing with the workers, we had to be attentive to ensure that information was not lost in translation between languages and people.

3.1. Comparison of various methods

The following chart compares various information collecting methods available and lists both advantages and the challenges of every method. We considered all the method listed below and chose the best methods for our situation after much discussion.

Method	Overall Purpose	Advantages	Challenges
<i>Questionnaires, surveys, checklists</i>	when need to quickly and/or easily get lots of information from Operators in a non threatening way	<ul style="list-style-type: none"> -can complete anonymously -inexpensive to administer -easy to compare and analyze -administer many workers -can get lots of data 	<ul style="list-style-type: none"> -might not get careful feedback - wording can bias respondent's responses -are impersonal - doesn't get full story
<i>Interviews</i>	Useful when in-depth answers are needed.	<ul style="list-style-type: none"> -get full range and depth of information -can be flexible with subject 	<ul style="list-style-type: none"> -can take much time -can be hard to analyze and compare -can be costly -interviewer can bias respondent's responses
<i>Documentation review</i>	To get an impression of how efficient the manual machine is; from review of applications, finances, memos, minutes, etc.	<ul style="list-style-type: none"> -get comprehensive and historical information -doesn't interrupt measure taken -information already exists -few biases about information 	<ul style="list-style-type: none"> -often takes much time -info may be incomplete -need to be quite clear about what looking for -not flexible means to get data; data restricted to what already exists
<i>Observation</i>	In order to gather accurate information about how efficient the machine/operator is.	<ul style="list-style-type: none"> -view consequences of a measure as they are actually occurring -can adapt to events as they occur 	<ul style="list-style-type: none"> -can be difficult to interpret seen behaviors -can be complex to categorize observations -can influence behaviors of program participants -can be expensive
<i>Focus groups</i>	explore avenues to make manual machine efficient- in depth through group discussion, e.g., about reactions to an experience or suggestion, understanding common complaints, etc.;	<ul style="list-style-type: none"> -quickly and reliably get common impressions -can be efficient way to get much range and depth of information in short time - can convey key information about issues 	<ul style="list-style-type: none"> -can be hard to analyze responses -need good facilitator for safety and closure -difficult to schedule 6-8 people together - can be expensive to have a meeting with operators during work time

<i>Case studies</i>	to fully understand or depict respondent's experiences in a measure, and conduct comprehensive examination through cross comparison of cases	-fully depicts respondent's experience in program input, process and results -powerful means to portray program to outsiders	-usually quite time consuming to collect, organize and describe -represents depth of information, rather than breadth
---------------------	--	---	--

(Adapted from McNamara, 1997)

(Table 3a)

After evaluating the various methods that are available to us, we decided that focus groups, case studies, documentation review etc. would not really work for us well. The manual press-fit machines process connectors on nearly every board. Therefore, we could not use focus groups to speak with operators, as this would interrupt the entire factory process. Documentation review was not a feasible alternative as there were no historical data or information on efficiency of the manual press fit machine in Amphenol TCS.

We resolved to gather some initial data about the issues of the machines and its efficiency from experienced operators of the manual press fit machine at Amphenol TCS's Changzhou facility. It was decided that we would interview the experienced operators and based on the feedback, we would be able to brainstorm some potential solutions. We hoped to observe the operators to get a better understanding of the problem to brainstorm. Once we brainstormed some solutions, we believed that a survey of the operators would enable us to gather the supporting information needed.

3.2. Types of Methods

We resorted to use interview, survey and observation as our tools to gather the necessary information and data we need to improve the efficiency of the manual press fit machine. We felt that interviews would enable us to get specific questions answered, observation would provide strength to available information from interviews, and survey would help us confirm our assumptions and beliefs.

Since our data gathering methods utilize human subjects, IRB approval was obtained for the survey and interview questions.

3.2.1. Interview

Interview is defined by Merriam-Webster online dictionary as “A meeting at which information is obtained (as by a reporter, television commentator, or pollster) from a person or a report or reproduction of the information obtained.”

There are various types of interviews depending on the goals of the interviewer and the information interviewer wishes to gather. Types of interviews include

1. Initial introduction
2. Familiarization or background
3. Fact gathering
4. Verification of information gathered from different sources
5. Confirmation of the information gathered from interviewee
6. Follow-up, amplification or clarification

(Modell 2007)

The type of interview that we conducted is a fact gathering interview to get answers to our questions and find some information. Questions that can be asked with the information gathering method can be either close ended or open ended questions. Questions which require participants to use their own words are known as open questions. The questions which have preselected answers for the participants to choose are known as closed questions (Fink, 1995). For our interview questions, we created various open ended questions to analyze the situation and to get optimal feedback from operators.

As per IRB requirement, machine operators were informed that

1. Participation is voluntary
2. As a participant, they may end the survey at any time
3. As a participant, they don't need to answer every single question in the interview.

Interview questions helped us gather the necessary information for initial analysis. All interview questions were direct and most of them were open such as, "What are the problems that you experience in the current toggle machine?" and "If there is anything we could modify to make it efficient, what do you think it would be?" etc.

As noted in Table 3.(a), the survey is a useful tool for quickly and inexpensively gathering data from a large number of people while protecting their privacy. Because of these advantages, we decided to use a survey to collect feedback from the manual press operators on the ergonomic impact of the current work station setup.

We created an eight-question questionnaire composed of close-ended questions for simplicity. We submitted the survey for Worcester Polytechnic Institute's Institutional Review Board to ensure that we satisfy all the regulations and ethical guidelines on conducting research which involves human subjects. The Institutional Review Board of Worcester Polytechnic Institute reviews and approves all surveys involving human subjects performed under auspices of WPI under federal mandate (The Common Rule, 45 CFR 46) and WPI policy. Our survey got approved and the project was exempt from further IRB review and supervision. Just as it was in the interview, the workers were briefed about the survey, their rights and the data was collected in an anonymous fashion.

There are currently four workers who operate the manual press machine (over both shifts). We surveyed these four operators, as well as four other factory workers who had previously used the

machine. Because our total population of workers was so small (four current operators), we could not obtain a high level of accuracy for our survey results. (According to Morris, for small populations, the resolution is limited to 100% $(1-1/N)$, where N is the total population size.) Regardless of this limitation, the survey results provided a valuable perspective on areas of potential improvement, from the current (and past) machine operators.

3.3 Methodology Summary

The time frame for the entire project was eight weeks. However, the time needed to conduct the interviews, surveys, and observation varied. Once administered, the interview and survey process was fairly short, being completed within twenty minutes or less. The variability factor all, however, was that the time that the workers complete each task depended on whenever they were present in the factory. Because not all the workers were in the factory at the same time, it took us a few days to conduct interviews and request surveys of all the workers needed. As with the interview process, the observation of the worker and machine process varied because operators used the machines on different days for different boards. Thereby, to view the machines at several states of use, it took a few days of observation.

The anticipated cost of the project depended on the fabrication method chosen to make the final design and specific supplementary modifications chosen by our Sponsor to implement. In order to determine specific costs of each modification, a cost analysis was performed on each separate component. Detailed cost explanation can be found along with the design ideas in the Results and Analysis Section. Labor was not factored into the cost.

4. Results and Analysis

This chapter contains the raw data collected to analyze and propose the major design modifications of the press fit machine. First, the results of the survey from 3.2.2 in the Methodology Section (see Appendix A) are compiled. Next, the details of the major designs are outlined. Also in this section, the efficiency of each design concept is estimated and a decision matrix is created to measurable compare each design option against the design specifications. These results are analyzed and used to provide recommendations for Amphenol to increase the efficiency of their manual press fit machines.

4.1. Survey

The results of the survey outlined in the Methodology section are seen in Figure 4.

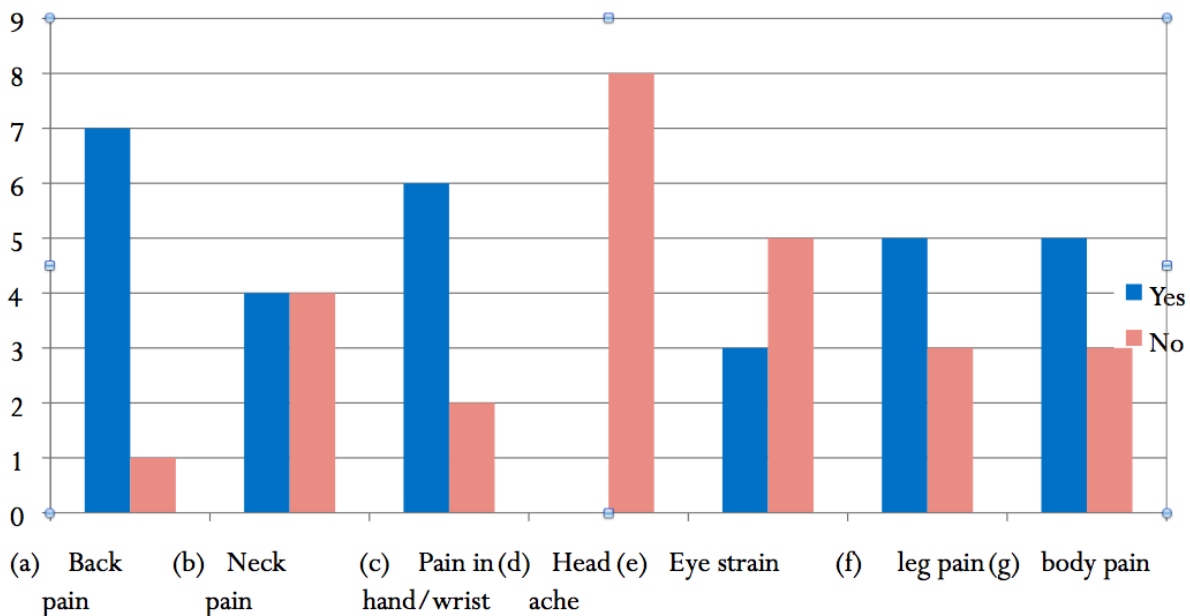


Figure 4: Operator Feedback

A total of eight operators were surveyed. None of the surveyed operators suffered from headaches. However, at least one third of the operators expressed that they suffered from all the remaining pains, especially back pain. Although the sample size was small, the survey was administered to all the

workers who operate the manual press fit machines during the morning shift. It is alarming therefore, that all these workers suffered from multiple symptoms which they believe resulted from operating the manual press fit machines. Based on our observations and ergonomic research, we compiled a table of possible causes and ergonomic solutions for the work discomfort (see Table 3).

Table 2 -Analysis of Survey Results

Problem	Ratio	Possible Cause(s)	Potential Solution(s)
Back Pain	7/8	<ul style="list-style-type: none"> -Workers hold their head in front of their body (tightens the upper back and shoulder muscles and causes numbness in the hands and arms/ restrict blood flow -Jobs involving prolonged standing (almost 8hours/day) will lead to back pain -Shoulders are elevated for a prolonged time 	<ul style="list-style-type: none"> -Ergonomic chairs to adjust the worker's operating position -Position the monitor approx. 20-26 inches (arm's length) from user so arms hang relaxed from shoulders and elbows are bent at approximately a 90° angle
Neck Pain	4/8	<ul style="list-style-type: none"> -Awkward viewing angle to align the press fit head -Forearm tension. 	<ul style="list-style-type: none"> -Ergonomic chairs that support the neck -Position the monitor directly in front of user to avoid excessive twisting of the neck
Hand/Wrist Pain	6/8	<ul style="list-style-type: none"> -Flexed wrists (i.e., hand curled towards forearm) -Gripping tools too tightly for precision when aligning head 	<ul style="list-style-type: none"> -Fingers, hands, wrists should be in a neutral position when idle -Modify the handle and the button position
Headache	0	<ul style="list-style-type: none"> -Constant change of head postures to align press head 	
Eye Strain	3/8	<ul style="list-style-type: none"> -Far viewing distance -Changing viewing angles -Prolonged screen viewing 	<ul style="list-style-type: none"> Height of handle should be at about eye level, or slightly lower to avoid neck extension -Take eye breaks do eye exercises

Leg Pain	5/8	-Standing too long -Legs are unequally bent	-Suitable space for legs under the table
-----------------	-----	--	--

4.2 Cycle Time for a Mid-Sized Board

To gather a reference of how long the workers needed to manually press a board, several operators were timed over a prolonged period at different intervals throughout a working day. However, there was not a conclusive aggregate achieved for the entire process as operators pressed several different boards throughout the day. The following references apply to operators with different skill levels working on a particular board.

The results listed in Tables 4 and 5 show the results of the process time. There are seven different connectors (comprised of three distinct types) on the board pressed by a toggle machine. The skilled operator can operate a toggle to finish one board in fifty seconds, while an unskilled operator can finish the same job in one minute and ten seconds.

Table 3 - Press Fit Steps (Skilled Worker)

Big Connector		Time for Each Step (s)		Middle Connector	
<i>Left Hand</i>	<i>Right Hand</i>			<i>Left Hand</i>	<i>Right Hand</i>
Match the back plate	Match the back plate	2	1	Free	Press air valve switch
Grab the edge of the back plate	Grab the joystick	2	1	Grab the edge of the back plate	Grab the joystick
Grab the edge of the back plate	Adjust the press-head	1	2	Grab the edge of the back plate	Adjust the press-head
Grab the handle	Move down	1	3	Grab the edge of the back plate	Grab the joystick
Press	Press	0	3	Grab the edge of the back plate	Adjust the press-head
TOTAL		6	10		

Table 4 - Press Fit Steps (Unskilled Worker)

Big Connector		Time for Each Step (s)		Middle Connector	
Left Hand	Right Hand			Left Hand	Right Hand
Grab the handle	Grab the joystick	2	1	Free	Press air valve switch
Grab the handle	Move down	2	3	Grab the handle	Grab the joystick
Grab the handle	Adjust the press-head	3	7	Grab the handle	Adjust the press-head
Press	Press	1	3	Grab the handle	Grab the joystick
Free	Free		4	Grab the handle	Adjust the press-head
TOTAL		8	18		

Tables 4 and 5 also serve as functional decomposition diagrams of the process, divided into 6 steps for the skilled workers and 5 steps for the unskilled worker. Analyzing the cycle time for each table, there are several things to be noted. The first thing is that for small connectors, there is not much time difference (less than 2 seconds). The reason is the head on the machine is flat, which makes it easy to aim at the connectors below. Next, for the big connector it is difficult for the operator to control the muscle to move the back plate conveniently so that they can simultaneously grab the left-handle; location is difficult. Lastly, because the middle connector does not rely on pneumatic pressure, the workers must use complete manual force to press the toggle, making it physically difficult to align the head.

4.3 Proposed Design Solutions

Based on our observations of current ergonomic issues, we came up with two major machine designs and a third option for improving the manual press-fit machine.

4.3.1 Design Option #1

The first design option that we are proposing for the manual press fit machine is a hand lever configuration. The hand lever design is a simple and straightforward design to make the machine more

ergonomically friendly. We propose that the attachment be adjusted so that the angle between the hand lever and the horizontal axis adjacent to the ground is decreased. By decreasing the angle of the hand lever attachment, we can bring the height of the hand lever down making it easier for the operator. As a result of the trigonometry, a relatively small reduction in the angle near the pivoting point would produce a significant amount of height reduction. Since the motion of the hand lever assembly is similar to a partial circular motion, we assume the following assumption to be true: when an angle is reduced by theta degrees, the height of the circle is reduced by $r \sin \theta$. See Figure 5 below.

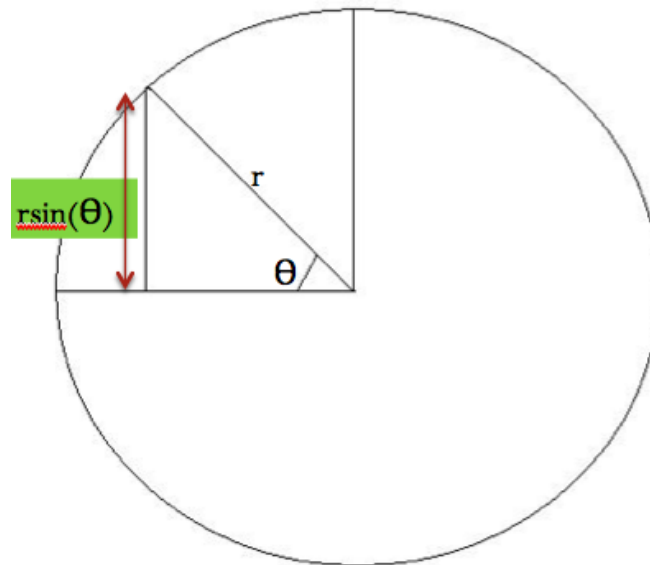


Figure 5 -Relationship between Angle and Height

An advantage of the hand lever design is that a prototype or test modification of the actual machine with the angled lever can be performed on an old toggle machine that is not being used. Thus, modification could be done internally with simple milling, lathe machining, or by a contractor for a relatively small cost. In addition to being inexpensive, this design is also simple, configurable without changing the current machines or equipment, and does not require worker retraining as the process is the same. Also advantageous about the simplicity of the hand lever modification is that it allows for

further customizations to be made to the rest of the manual press machine because the other parts stay intact and remain unchanged (see Figure 6 below). Thus, independent changes of the press head for the manual machine can still be altered even after the new hand lever is configured.

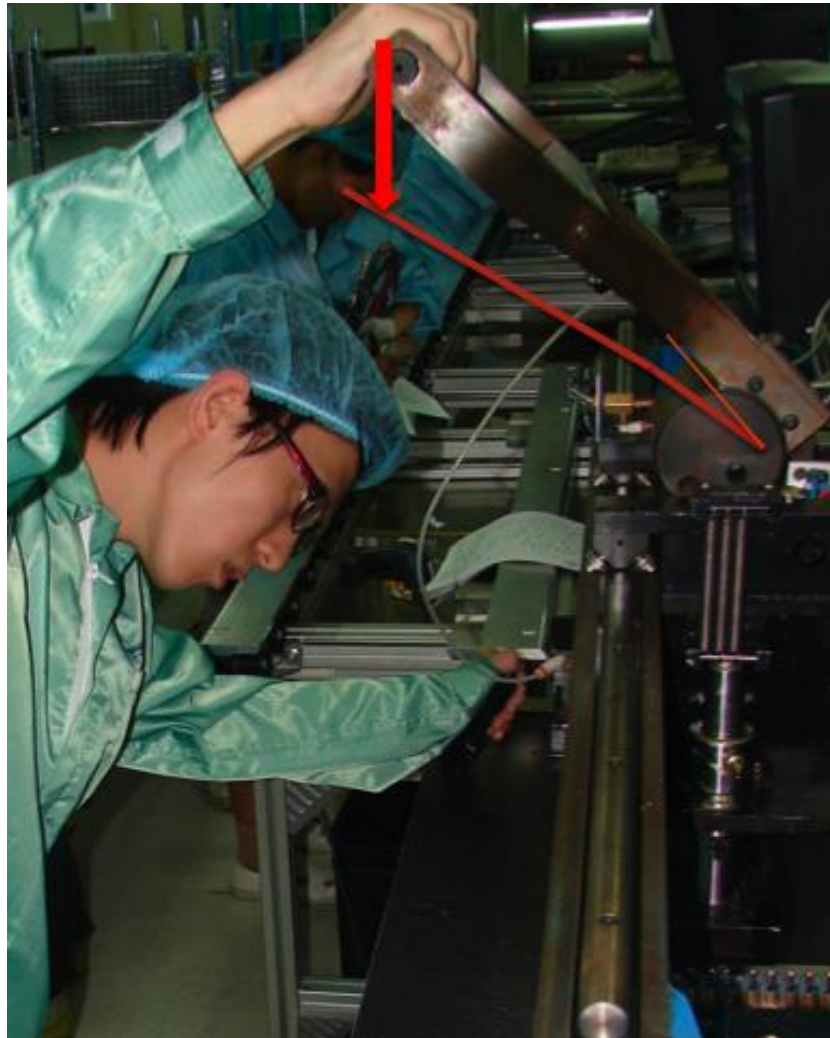


Figure 6 -Manual Machine Operation

One supplementary modification that we would like to implement is to increase the friction in the roller wheels of the press head (see Figure 7 below). Increasing the friction in the rollers would help the operators to stop the machine at a desired spot without much stumbling. This will improve the workers' precision. Frictional forces that are needed to be dealt with are rolling and static friction.

Under normal circumstances, rolling friction is much less than static friction, so it requires less force to keep it moving than to move it from rest.

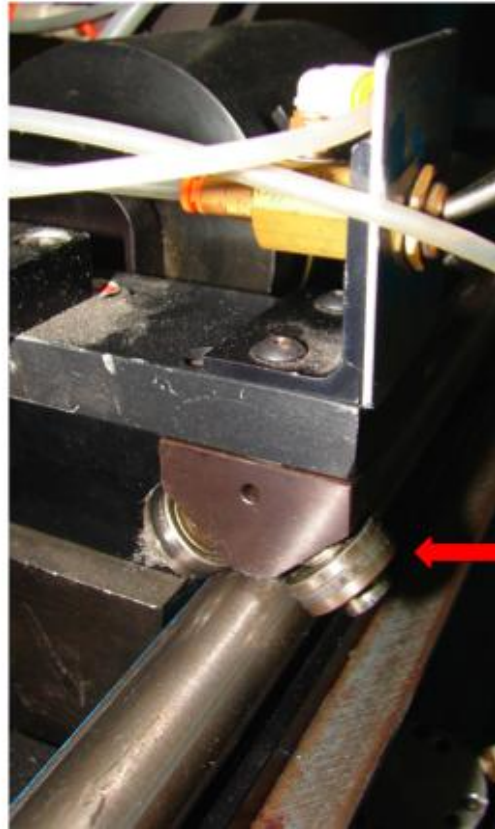


Figure 7 - Roller Wheels

However, a balance needs to be reached to make rollers easy to move, and also than easy to stop. To ensure that the manual machine can be stopped at one place without much stumbling, we can increase traction in the rollers, or increase friction in the path of the rollers. But a balance has to be reached to ensure that rolling unit can be moved with relative ease (see Figure 8 below). We could find a comfortable medium level through experimentation, if it needs to be implemented.

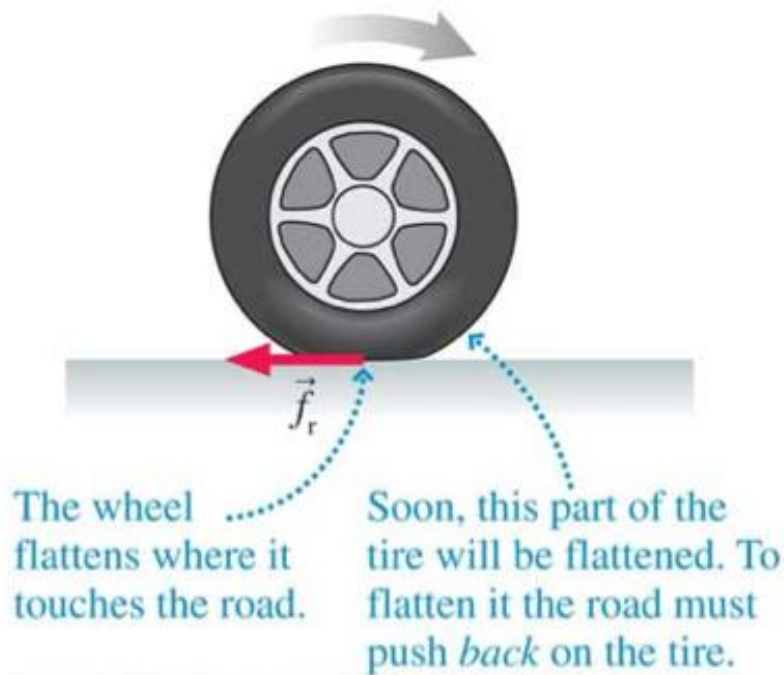


Figure 8 - Physics Diagram

By making these modifications to the manual press-fit machine, we hope to improve the ergonomics by reducing the amount of time spent in the “caution zone” outlined in the background. Modifying the lever position, and thus changing the height to reach the handle, we hope to have workers be able to keep their head above their hands when working as to not fall into the caution zone. Altering the height also changes the position of the elbow relative to the shoulder and this would also eliminate another caution zone. Additional changes that we hope will result as a change with this design include reducing the neck and back position angle so that they are bent less than thirty degrees. See Figure 9 below.

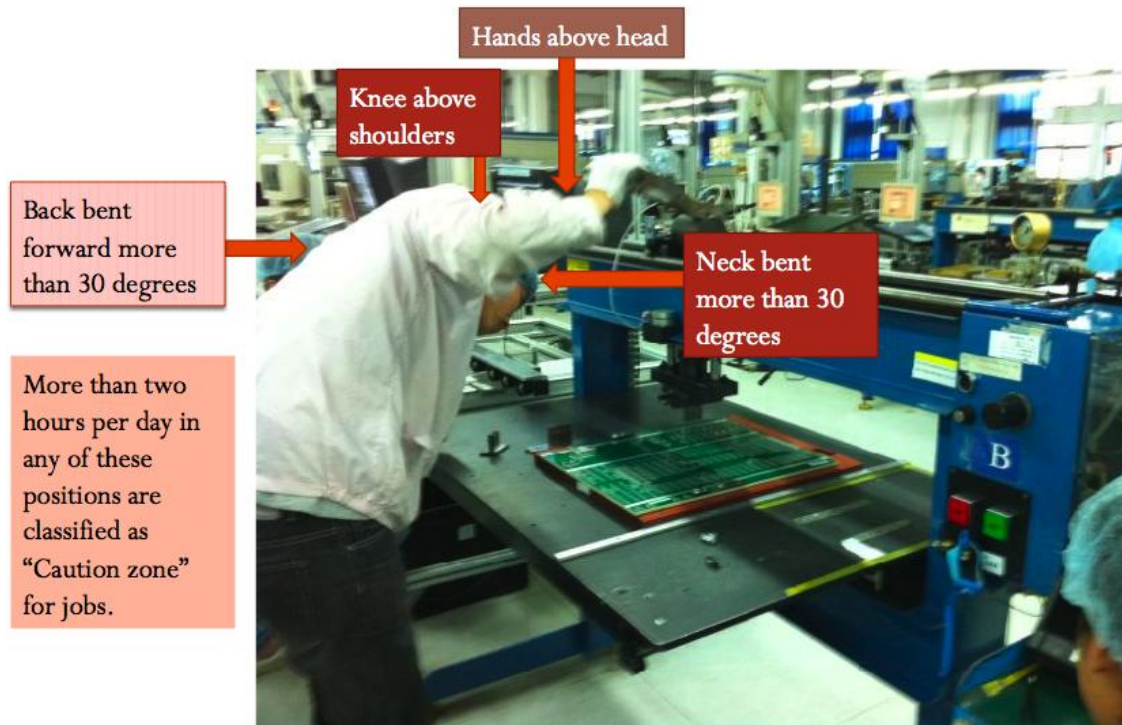


Figure 9- Current Ergonomic Issues

4.3.2 Design Option #2

Another design consideration was an electrically controlled press unit. This would consist of two parts, the operator control unit, and the electrically powered press unit, which would integrate into the current Toggle Press design.

The electric press unit would consist of a pair of rack-and pinions, with the racks parallel to each other and the two pinions interlocked on the interior of the racks. One of the pinion shafts would have an additional gear, which would be connected to a worm gear, which would in turn, be connected to a motor (see Figure 10 below). The second pinion would follow the first, powered one.

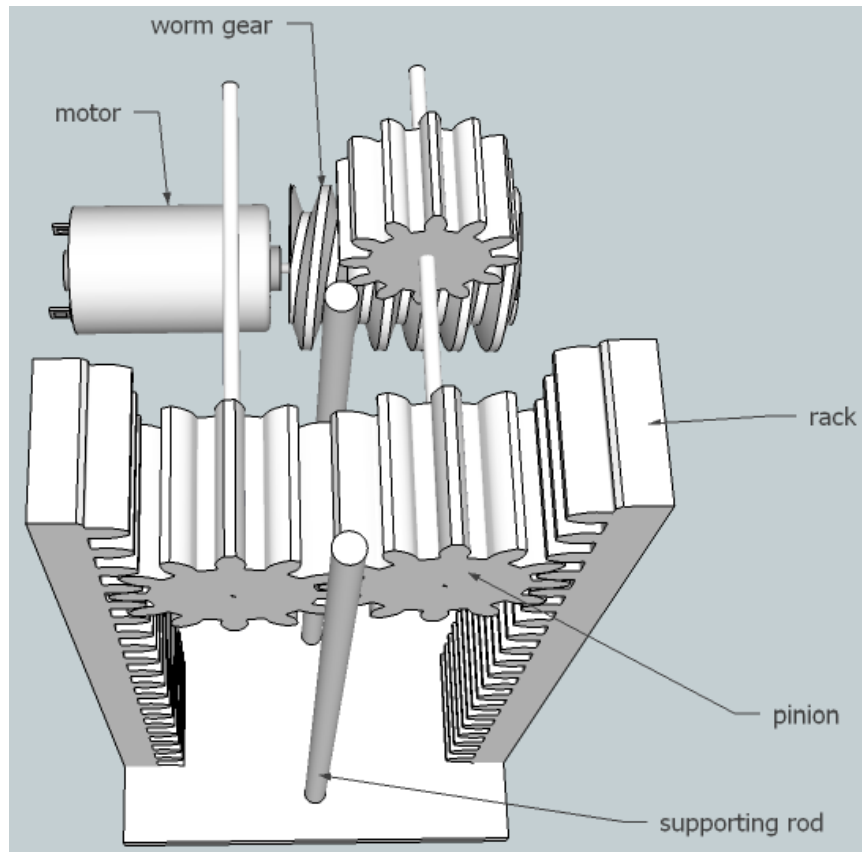


Figure 10 -Mechanical Assembly

The above mechanical assembly would replace the entire press-head assembly in the current Toggle Machine, as illustrated in Figure 11:

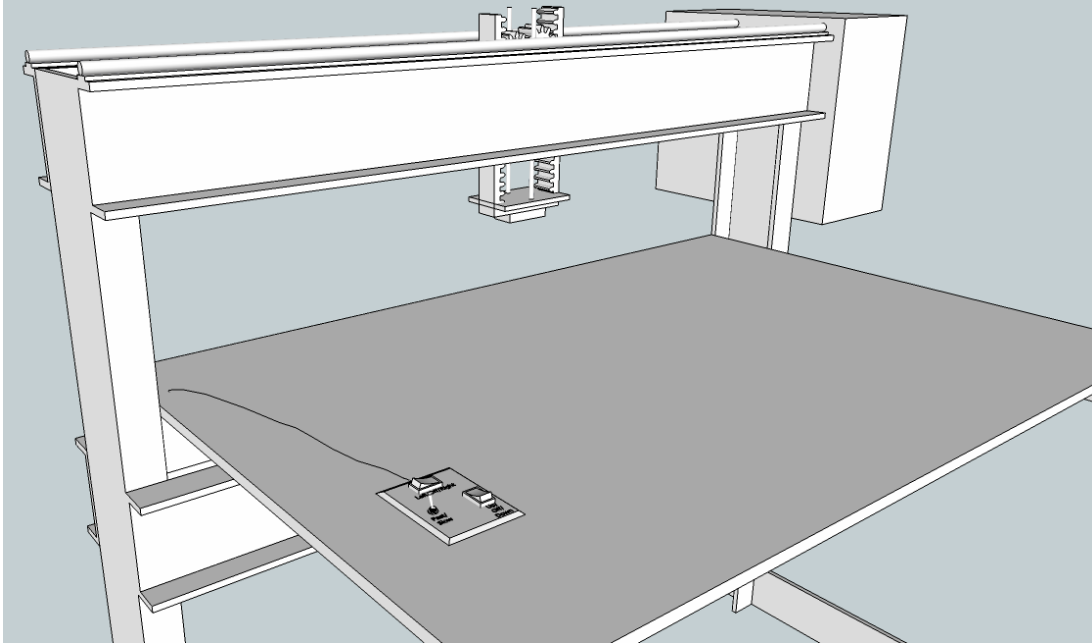


Figure 11 –Example of Electric Press Placement on Toggle Machine

For control of the y-axis (side-to-side movement), the unit would add a powered rubber or hard plastic wheel to the existing slide-assembly for the press-head (see Figure 12)

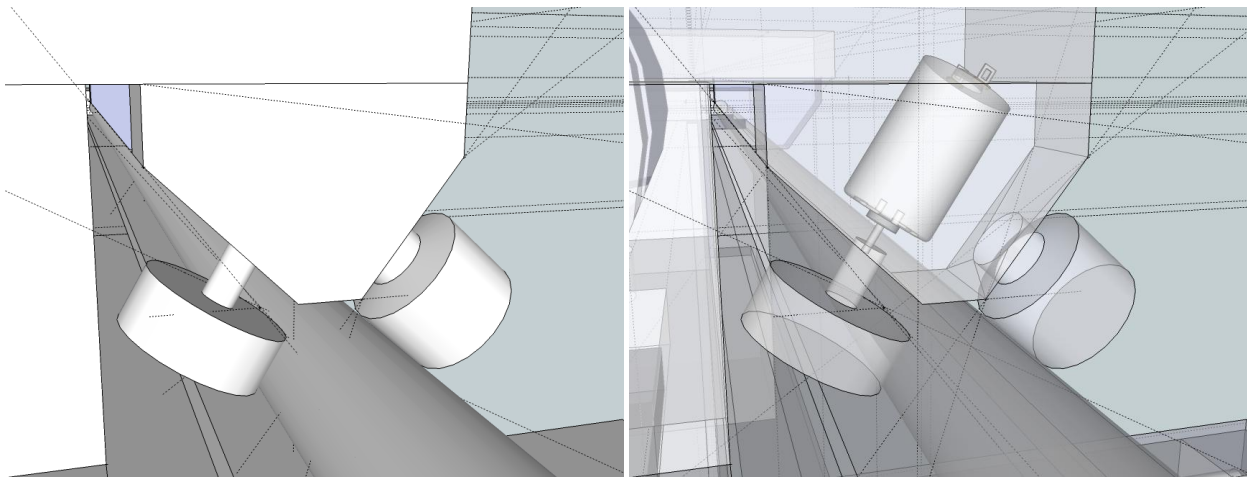


Figure 12 -Rollers with Electric Motor (for y-axis movement)

This motor could provide direct power to a roller (as shown in above Figure) or use gears to set up or down the power as required.

The control unit for this design option would consist of a simple plate with three embedded switches (see Figure 13). One switch would control the speed of the press (for both axes) and the other two switches would each control one axis of movement for the press (y and z). Each of the switches for controlling movement would have three positions: center (off), up (positive z) and down (negative z), or right (positive y), and left (negative y). The movement switches would be momentary; the operator would have to hold the switch in the desired direction for as long as he or she wanted the press to move in that direction. Once the operator released the switch, the press would stop moving.

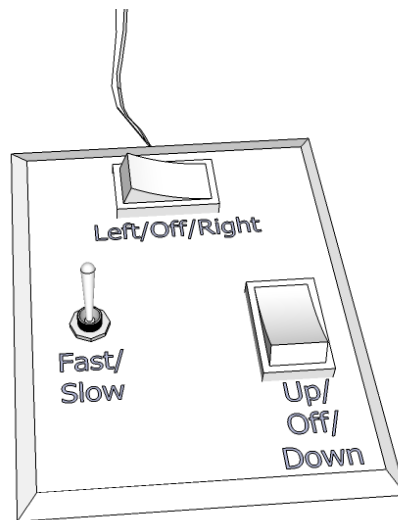


Figure 13 -Electric Press Control Unit

The electric circuit for this model is shown below:

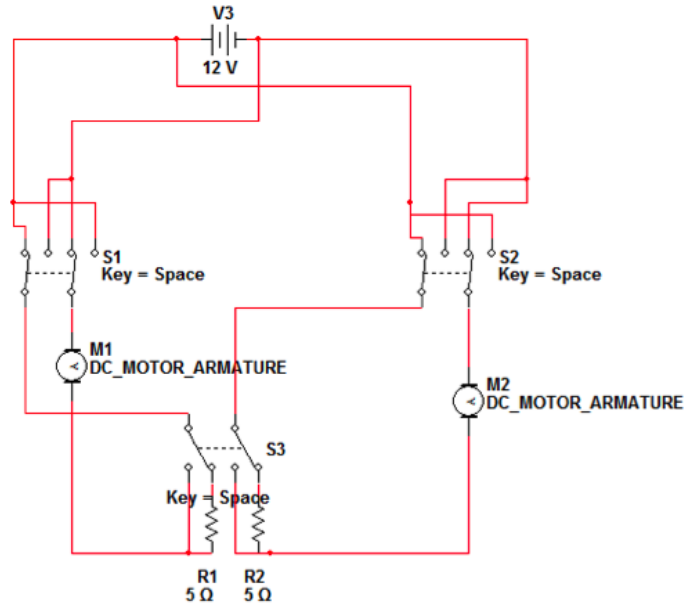


Figure 14 -Schematic for Electric Press

(schematic created using Multisim)

As can be seen in Figure 14, two motors, M1 and M2, are controlled by one DPDT switch each (one set of poles for each motor direction), S1 and S2, and the speed for both motors (see R1 and R2) is controlled by a single DPDT toggle switch, S3.

The electrically controlled Press Machine would need the following parts at a minimum (see Table 6). According to a simple price evaluation, this solution would cost around 2783 元 to produce. Note that for two prices listed in the table (supporting structure and racks), we were not able to find an actual product for price comparison, and estimated these costs. A more detailed cost analysis was not done, as this design was eliminated from consideration during the project (in favor of a simpler one).

Table 5 -Electric Press Parts and Price Estimates

Item	# Items	Unit Cost	Total Cost	Source
Electric Motors	2	150 元	300 元	Taobao
Spur Gears	4	40 元	160 元	Taobao
Worm Gear	1	30 元	30 元	N/A
DPDT Mom Rocker Switch	2	\$5=33.35 元	66.7 元	RadioShack
DPDT Toggle Switch	1	\$4=26.7 元	26.7 元	RadioShack
220VAC/12VDC Convertor	1	120 元	120 元	Taobao
Racks	2	\$50=333.5 元	667 元	N/A
Stability cylinders	2	\$.4=2.7 元	5.4 元	Alibaba
Supporting Structure (machined parts)	1	\$200=1334 元	1334 元	N/A
Resistors	2	\$.24=1.6 元	3.2 元	Parts-express
Plastic/hard rubber wheels	2	35 元	70 元	Taobao
Total Cost	20		2783 元 (\$ 417 USD)	

Please note that prices shown were current as of September 2010, and may be different from those found today. All prices displayed were used to obtain an estimate, and should not be relied on for final, accurate costs.

4.3.3 Recommendations for Design Option #3

Design Option #3:

Based on identified issues with the current press-fit machine, ergonomic research, and specifications from Amphenol, TCS, we identified a list of desired elements in a new machine design:

Improvements:

- Base on average worker dimensions for Chinese population (see Appendix B)
- Limit the human effort required to operate the press-fit assembly
- Reduce operation steps (complexity)
- Increase control of machine for small precision
- Smaller size than Toggle machine (Amphenol design specification)

In addition to the above improvements, we recommend that the new design incorporate the following existing good design considerations:

- Require two-handed operation (safety issue)
- Minimize investment
- Board size: 415mm x 415mm x 4mm (Amphenol design specification)

Designing a new press-fit machine would allow Amphenol TCS to improve each of the identified machine issues. This option is the most comprehensive solution to efficiency improvement of the ATCS press-fit operation. However, this design solution would likely be the most expensive, involving design, fabrication, and material costs.

4.4 Comparison

When making the decision of which model we would choose for our final design, we compared each design option on several categories, including usability, cost, maintenance, and practicality. We found that, while the electric motor press design was new in that it could be controlled with an electric

motor, its uniqueness ultimately was a disadvantage. Looking at the cost analysis of each design and taking into consideration that we do not have a set cost for the hand lever modification, it still is more economical to implement that versus the electric motor. If we were to assume that the initial cost of the electrically-controlled press head were less of that than the manual hand lever, the maintenance and lifetime cost of the electric motor design would surpass that of the hand lever in the long run. Also, there are fewer parts needed to modify the press fit machine, one for the hand lever versus an entire system needed to operate the motor, mechanical components for the rack and pinions, as well as the control pad.

4.4.2 Pair-wise Comparison

We utilized a pair-wise comparison to evaluate and compare our design specifications. This allowed us to determine the design specifications that were most important to our group. We used a 10, 5, 0 scale for our ratings with a 10 signifying that a design specification was of more importance when compared to another. A rating value of 5 signified equal importance between the two categories, while 0 was less important in relation to the second category. We used a 10, 5, 0 scale so that the resulting total would result in a whole number and could easily be ranked. We found that Safety is the most important design specifications for our group (a value of 30), followed by Ergonomics (26.67), Precision (20), Cost (16.67), Risk Factor (6.67), and Size (0). While Size was one of our design specifications, we felt that it was the least important constraint as opposed to the others when considering possible design options. This made it easier to compare and evaluate the design specs. We used this information to help determine which design satisfied our needs specification the best. The pair-wise comparison allowed us to measure the importance of our design specification, with the total also serving as the weighted value for each category in our decision matrix.

Table 6 -Pair-Wise Comparison

	Safety	Cost	Size	Ergonomics	Precision	Risk Factor	TOTAL	TOTAL as %
Safety	-	10	10	5	10	10	45	30.00
Cost	0	-	10	0	5	10	25	16.67
Size	0	0	-	0	0	0	0	0.00
Ergonomics	5	10	10	-	5	10	40	26.67
Precision	0	5	10	5	-	10	30	20.00
Risk Factor	0	0	10	0	0	-	10	6.67

4.4.3 Decision Matrix

We used a decision matrix to come up with a numerical value of each design option to help evaluate the design choices (see Table 8).

Table 7 -Decision Matrix

	Safety	Cost	Size	Ergonomics	Precision	Risk Factor	TOTAL Score
Weight	30.00	16.67	0.00	26.67	20.00	6.67	100
Design 1	5	5	5	5	4	5	480.00
Design 2	4	2	5	5	3	1	353.33

The total value for each design option was calculated by multiplying a weight (calculated in 4.4.2) by a numeric value for each decision category (described below). The design option with the highest total value was the preferred design, according to our project preferences (weights). As shown in Table 8, both design choices received identical scores, rendering them equally viable.

Decision Categories

Each design category was evaluated based on appropriate factors. We used values between 1 and 5 to represent the strength of a design choice for each category. One represented the least favorable outcome for the category, while 5 represented the most favorable outcome.

Each Category of the decision matrix was calculated as follows:

Safety – no obvious safety concerns were identified with either design. The major stipulation, that both hands be used for operation, was satisfied by both designs. Design 1, thus, received the maximum outcome of 5, while Design 2 received a score of 4, due to uncertainties with electrical safety considerations.

Cost –An estimated total cost was calculated for each Design choice to determine the best economical choice. Design Option 2 was significantly more expensive than Design Option 1, so Design 2 received a value of 2, while Design 1 received a value of 5.

Size –As neither design option modifies the size of the Toggle machine, they received identical scores. The current toggle machine has a large footprint, and can process large boards, so both design options receive a score of 5.

Ergonomics- We considered the ease of operation of the machine and determined that Design 1 has significant operating ease, while Design 2 has an advantage in reduced/eliminated worker manual force required. Based on these considerations, we gave both designs a value of 5.

Precision –the ability of an operator to precisely control the machine was important, since this was an issue raised by the operators. Design Option 1 has improved control (through increased roller friction), so it received a value of 5. Design Option 2 can offer greater fine control (through tunable low-speed electric operation), but the level of actual operator control (using the electric circuit) is undefined. Therefore, this design received a value of 3.

Risk Factor –refers to the level of unpredictability of a design (leading to potential monetary loss). We evaluated this factor using three issues: Does the design involve a large number of new/additional parts? (The amount of parts involved is one measure of complexity. The more complex a design, the

more opportunity there is for failure.) Is there worker training involved? Any change in operating method could result in operator error during the initial usage period. Is the new design significantly different than the old design? A radically different design could incur unseen costs, due to unforeseen complications. Using these metrics, Design Option 1 has the smallest risk factor, since none of these conditions are met, so it receives a value of 5 and Design Option 2 receives a value of 1 because of its high level of unpredictability.

4.5 Supplementary Design Modifications

To develop a list of smaller modifications to supplement the major proposed designs, we applied reverse engineering using feedback from the operators and brainstormed a list of modifications that we could implement. The modifications are divided into three categories that cater to a specific, operator-identified problem.

CATEGORIES

- *Stability: Tool is shaky and not stable, very hard to pin down at one location*
 - Single-handed locking mechanism for rollers
 - Manual Hand Adjustment for rollers
 - Increase friction on the roller track
 - Elbow rest on table for stable movement
- *Comfort: Cumbersome, awkward to use and tiring*
 - Adjustable handles for workers
 - Lower handle height and increase height of eye level
 - Make handles and switches ergonomic
 - Alternate hand use of handle on press head
- *Ease of Use: Complicated, difficult to learn/use, confusing*
 - Reduce # of Buttons from 3 to 2/1

- Put switch on the side of handle instead horizontally
- Adjust height for various boards by using pneumatic press
- Single Pneumatic Trigger Handle
 - Trigger/Button Swap
 - Move location of button

Although a cost analysis can be performed on many modifications listed in the list of possible solutions, there are a number of changes that cannot be analyzed numerically. Such modifications as removing a button, swapping a switch with a handle, or remapping a button location are adjustments that may not necessarily yield a cost as opposed to adding a physical part (like an elbow pad). We calculated the cost of several parts using the purchase price for each item found on the Internet, as shown in Table 14, excluding labor. These prices may slightly vary depending on where it was bought, or the brand manufacturer of the component. The prices listed in the cost analysis are thereby dependant on the time and location of access during the writing of this report.

Table 8– Supplementary Cost Analysis

Product	Estimated Cost
Elbow Pad Table	\$342.21
Telescopic Handle	\$25
Pneumatic Press Knob	\$33.40
Increased Roller Friction Track (Bearing)	\$22.03
Ergonomic Handle Cushion	\$4.92
TOTAL COST	\$427.56

6. Conclusions and Recommendations

The objective of our project was to improve Amphenol TCS `s press fit machines. After performing two weeks of research in Changzhou, we focused our direction to manual machine because it was essential for the whole working process, was simple to modify, and could had high potential for adding value to the press-fit process. Based on our mechanical and survey data, we came to three designs:

- Design #1--Hand Lever. This design is more simple and straight to make the machine ergonomically friendly, benefiting Amphenol TCS and the machine operators. Additionally, the cost and variation is the least for this design. Implementing this design change could bring much efficiency and comfort to workers.
- Design #2--Electrically Controlled Press-head. This design requires the addition of electric components to control motors and switches, and may be a challenge as operators need to learn new skills. However, if implemented, it has the potential to greatly increase worker comfort.
- Design #3—New Design. This option would involve the manufacturing of a new design, based on the known issues with the current design. As a completely new design, this option could incorporate the most improvements to the machine, but would also involve the greatest cost and variability.

So based on our findings from cost, mechanical design, and company requirements, we recommend the improvement of manual machine by Design#1-Hand Lever Press.

Recommendation:

Amphenol TCS's project objective was to maximize efficiency (profit) at minimal cost, while increasing operator comfort. Additionally, any change should not require a large investment to retrain workers. Based on these requirements, Design#1 is the best solution, meeting company demands.

A secondary objective introduced by Amphenol TCS during the project was to create a new machine design. For this objective, we recommend Design #3 as a more comprehensive solution to the current machine issues. As an alternative, for a medium cost solution, Design #2 can provide additional

working comfort using the existing manual machine. Based on the strengths and weaknesses of each design choice, Amphenol TCS can select the option which is most suitable to their needs.

References

- Amphenol Corporation. (n.d.). *About Amphenol TCS* . Retrieved 10 09, 2010, from Amphenol TCS : http://www.amphenol-tcs.com/about_tcs/index.html
- Ankrum, D. R. (n.d.). *DeMystifying all those chair adjustability options*. Retrieved 10 09, 2010, from Ankrum Associates : http://www.office-ergo.com/ergonomic_seating.htm
- Das, B. (1996). Industrial workstation design: A systematic ergonomics approach. *Applied Ergonomic* , pp. 157-163.
- Ergonomics—Principles for determining dimensions of work places in manufacturing areas and the dimensions. (n.d.). *GB/T 14776-1993* . China National Standard.
- Fink, A. (1995). *How to ask survey questions: A step-by-step guide*. London: Sage Publications.
- General ergonomics requirements for controller. (n.d.). *GB/T 14775-1993* . Standardization Administration of China.
- Heine, H. J. (1999). Ergonomics - A Neglected Science. *Foundry Management & Technology* , 28-30.
- Human dimensions of Chinese adults. (n.d.). *GB 10000-88* . Standardization Administration of China.
- IMS Connector Systems GmbH. (n.d.). *PCB mounted connectors*. Retrieved 10 09, 2010, from IMS Connector Systems: <http://www.imsconnectors.com/pcb-mounted-connectors.html>
- Interface Analysis Associates. (2008). *Ergonomics*. Retrieved 10 06, 2010, from Usernomics: <http://www.usernomics.com/ergonomics.html>
- Keweenaw, E. (n.d.). *Proposed Ergonomics Rule: Preventing Injuries at Work*. Retrieved 10 12, 2010, from Florida Department of Environmental Protection: www.dep.state.fl.us/admin/safety/Presentations/Ergo_Keweenaw.ppt
- Li, R., Zhou, M., & Li, M. (2010, 08 23). Initial Meeting. (S. MacMillen, D. Nguyen, B. Xi, & Y. Liu, Interviewers)
- Lin, J.-S., & Tsai, S.-Y. (2007). Ergonomic design and research of a force saving bucket. *International Association of Societies of design Research Conference* . Hong Kong.
- McNamara, C. (n.d.). *Overview of Basic Methods to Collect Information*. Retrieved 10 09, 2010, from Free Management Library: <http://managementhelp.org/research/overview.htm>
- Merriam-Webster Online Dictionary. (2010). Retrieved 10 09, 10, from <http://www.merriam-webster.com/dictionary/interview>

Modell, M. E. (2007). *The Interview And Other Data Gathering Methods*. Retrieved 10 09, 2010, from martymodell.com: <http://www.martymodell.com/pgsa2/pgsa07.html>

Morris, E. (n.d.). *Sampling from Small Populations*. Retrieved 10 09, 2010, from University of Regina: <http://uregina.ca/~morrisev/Sociology/Sampling%20from%20small%20populations.htm>

Patkin, M. (2001). A checklist for handle design. *Ergonomics Australia On-Line* , 15.

Princeton University. (2010, 09 20). *WordNet Search*. Retrieved 10 06, 2010, from WordNet -A Lexical Database for English: <http://wordnet.princeton.edu/perl/webwn?s=efficiency>

Ranee, A. (1996). Ergonomics way to improved profits and worker satisfaction. *New Straits Times (Malaysia)* , 5.

The Institute of Ergonomics & Human Factors. (n.d.). *What is Workspace?* Retrieved 10 09, 2010, from Ergonomics4Schools: <http://www.ergonomics4schools.com/lzone/workspace.htm>

Weining, F. (2010). *Ergonomics*. Beijing, China: Beijing Jiaotong University.