Low Energy Printing
Project P09505
Detailed Design Review
Senior Design I
Agenda

- Introduction
- Project Background
- Updated Customer Requirements
- Concept Selection Process
- CR: Fit in Workcentre Pro
- CR: Generate 3.500psi
- CR: Generate Uniform Pressure
- Power Calculations
- Torque Calculations
- Bill of Materials
- Bill of Materials – Budget
- Feasibility Analysis
- Risk Assessment
- Questions
Project Team, Faculty, & Customer

- **Project Team:**
  - **Project Lead:**
    Joshua Jones (ME – Year 5)
  - **Team Members:**
    Whitney Domigan (ME – Year 4)
    Jenna Kilroy (ISE - Year 5)
    Andrzej Lubaszka (EE – Year 5)

- **Faculty:**
  - **Guide:**
    Bill Nowak (ME, Xerox Employee)
  - **Consultant:**
    Marcos Esterman (ISE)

- **Customer:**
  - **Xerox Corp – Marking Elements & Integration Lab**
    John Knapp
Project Background

Xerographic digital printers are very energy intensive, specifically the **fusing sub-system**. This is largely due to the fact that during the fusing process toner is heated to *well above* its *melting point*, to enable heat flow, and allow the toner to adhere to the paper.

- **Senior Design Project as Stated on Edge:**
  “Re-consider the design of an extremely low power, non-thermal fusing system”
Project Scope

The purpose of this project is to develop a fusing sub-system that uses **pressure** instead of thermal energy to fuse toner to paper. The new design should fit into the current Xerox Workcentre 245/55 Pro printer, however if due to design constraints the new design is unable to be fit internally it may be externally attached to the Xerox Workcentre 245/55 Pro printer.
How a Fusing Sub-System Works

Traditional Toner Fusion:

Temperature + Pressure + Heat = Fused, Adhered Toner

Image by: David Thompson, Xerox Corp.
Information by: David Thompson, Xerox Corp. and Dinesh Tyagi, Eastman Kodak Company
**Customer Requirements**

### Updated Customer Needs

<table>
<thead>
<tr>
<th>Number</th>
<th>Need Type</th>
<th>Original Needs</th>
<th>Updated Needs</th>
<th>Customer Weight</th>
</tr>
</thead>
</table>
| 1      | Paper Quality | Paper is not damaged  
|        |            | Image be Xerox quality | Paper can go through system without being damaged | 9 |
| 2      | Compatibility | Fit into current Xerox Workcentre 245/55 Pro | Fuser (minus the motor/drive system) fits into Workcentre Pro | 3 |
| 3      |            | Compatible with other Xerox models | Technology may be able to be used up and down along Xerox stream | 1 |
| 4      |            | Technology can be used up and down along Xerox stream | Standard office paper (8.5 x 11”) fits | 9 |
| 5      |            | Standard office grade paper (20/24 pound paper) | Accept paper in orientation it currently enters fuser (SHF / LHF) | 3 |
| 6      | Cost      | Sub-system cost less then current system  
|        |            | Easy of manufacturing | Sub-system cost less then current system | 3 |
| 7      |            | Use pressure only to fuse toner to paper | Prototype cost less then $5,000.00 to complete | 3 |
| 8      | Pressure   | Low Energy - non-thermal | Use pressure only to fuse toner to paper | 9 |
| 9      |            | User must be able to safely clear jam in fuser | Pressure along the nip needs to be uniform | 9 |
| 10     |            | Fuser last for at least 100,000 prints | User must be able to safely clear jam in fuser | 1 |
| 11     | Misc.     | Fuser last for at least 100,000 prints | Fuser last for at least 100,000 prints | 1 |

**Most Important Customer Requirements:**

- Paper is not damaged
- Uniform pressure along nip
- Fit into current Xerox Workcentre 245/55 Pro
- Use pressure only to fuse toner to paper
Assumptions Made in Concept Selection

- Deflection in bottom roller is negligible.
- By adding additional rollers on top of the bottom roller we will be able to alleviate the deflection of the “top” roller.
- Additional rollers placed on top of the “top” roller will increase the uniformity of pressure.
Concept Selection Process

PUGH 1 - Week 3
Preliminary Design

PUGH 2 - Week 4
Loading Styles

PUGH 3 - Week 6
How to Mechanically Apply Load

Concept Selection PUGH 1
Concept Selection PUGH 2
Concept Selection PUGH 3

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Design Concept
Flexibility of Design

• Allows for more thorough DOE:
  – Spring tensioned force
    • Can install Belleville washers
  – Adjustable load force
  – Replaceable rollers
    • New sizes
    • New materials
    • Crowning / skew
Flexibility of Design

Module Skew Design
Trade Plate

0°

Skew

Set Screw
Flexibility of Design

Skewed Rollers
CR: Fit in Workcentre Pro

- **Current Fuser System’s Dimensions:**
  - Length: **18.5 inches**
  - Width: **4.5 inches**
  - Height: **6.5 inches**

- **Our Design’s Dimensions:**
  - Length: **13 inches**
  - Width: **3 inches**
  - Height: **4 inches**

*Our system’s dimensions do not take into account the size of the motor or the apparatus necessary to attach the motor to the printer, nor other interfacing apparatus*
CR: Fit in Workcentre Pro
CR: Fit in Workcentre Pro

Top 2 Rollers:
- Length: 13”
- Diameter: 1”

Center Roller:
- Length: 13”
- Diameter: 1.5”

Bottom Roller:
- Length: 13”
- Diameter: 2”
CR: Fit in Workcentre Pro

Top End Plate:
- Length: 3”
- Width: 0.5”
- Height: 2.25”

Bottom End Plate:
- Length: 3”
- Width: 0.5”
- Height: 1.25”
CR: Fit in Workcentre Pro

• Reasoning for initial roller sizes:
  – Length:
    • Rollers must be at least 11” long so they can accept standard office paper in both Long and Short Edge Feed.
    • One inches added to roller lengths for play in paper acceptance.
  – Diameter:
    • **Bottom Roller**: diameter needs to be big enough so deflection in the roller is negligible.
    • **Center Roller**: can be slightly smaller then the bottom roller due to stabilizing top rollers.
    • **Top Rollers**: fit in endplates

• Through analysis, initial design choices were verified.
CR: System Generate 3,500psi

• Assumptions Made:
  – The black box program is correct.
CR: System Generate 3,500psi

Two symmetrical rollers with 3 materials each and applied loads:

- $E_1$ – Material 1 (Outer)
- $E_2$ – Material 2 (Middle)
- $E_3$ – Material 3 (Inner)

- $R_i$ = Inner Radius
- $R_m$ = Mid Radius
- $0.5t$ = Outer thickness

- $R_T = Total Radius = R_m + 0.5t$

- $F = Force Applied$
CR: System Generate 3,500psi

Estimation of Rollers with paper

\[ E_1 - 24 \text{ lb Paper} \]
\[ E_2 - \text{Variable (steel)} \]
\[ E_3 - \text{negligible} \]

\[ R_i = \text{Inner Radius} \sim 0 \text{ in} \]
\[ R_m = \text{Radius Roller} \]
\[ 0.5t_p = \text{Half Paper Thickness} \]

\[ R_T = \text{Total Radius} = R_m + 0.5t_p \]

\[ F = \text{Force Applied} \]
CR: System Generate 3,500psi

- Assumptions:
  - 2-D Model
  - Uniform Loading
  - Unit length of roller

- Materials Used:
  - Steel
  - 24 lb paper

<table>
<thead>
<tr>
<th>Material</th>
<th>Roller</th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>29</td>
<td>0.5</td>
</tr>
<tr>
<td>E (Mpsi)</td>
<td>0.75</td>
<td>--</td>
</tr>
<tr>
<td>Thickness (in)</td>
<td>--</td>
<td>0.0025</td>
</tr>
</tbody>
</table>
CR: Generate Uniform Pressure

• Assumptions:
  – Deflection in the bottom roller is negligible.
  – Additional rollers on top of the center roller will alleviate its deflection.
  – Adding additional rollers to the top of the center roller will increase the uniformity of pressure.
CR: Generate Uniform Pressure

Roller Deflection Calculations

- \(2b = \text{nip width}\)
- \(F = \text{force needed to achieve desired pressure.}\)
- \(Y_{\text{max}} = \text{maximum deflection in top roller}\)

\[ b = \sqrt{\frac{2F}{\pi l} \left( \frac{1}{d_1} + \frac{1}{d_2} \right)} \]

\[ F = \frac{\pi P_{\text{max}}}{2} \sqrt{\frac{1}{\pi l} \left( \frac{1}{d_1} + \frac{1}{d_2} \right)} \]

\[ y_{\text{max}} = \frac{-Dl^3}{384 \times E \times I} \]
CR: Generate Uniform Pressure

Deflection in Rollers

Roller size paired with 2" Roller [in]

Deflection [in]

- 2.0857E-05
- 5.8362E-06
- 2.68932E-06
- 6.37469E-07
- 2.2411E-07
- 4.98023E-08

Roller Deflection Calculations
CR: Generate Uniform Pressure

ANSYS Results: Loading Method

http://edge.rit.edu/content/P09505/public/Final%20Ans%20Results
CR: Generate Uniform Pressure

ANSYS: Deflection Results

With Side Plates

Without Side Plates

http://edge.rit.edu/content/P09505/public/Final%20Ansys%20Results
CR: Generate Uniform Pressure

ANSYS Results: Uniformity at Nip

Top Rollers

Bottom Rollers

http://edge.rit.edu/content/P09505/public/Final%20Ansys%20Results

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Senior Design I – Detailed Design Review
CR: Generate Uniform Pressure

ANSYS Results: Stress

Rollers

End Plate

http://edge.rit.edu/content/P09505/public/Final%20Ansys%20Results
CR: Generate Uniform Pressure

Deflection Over Nip

ANSYS Deflection Over Nip Results
Power Calculations

- Assumptions:
  - Each page requires 1.5 page lengths to include a gap between the pages, in order to print one page, 16.5” of roller will have to pass through the nip.
  - Roller diameter of 2”, passing 1.5 page lengths through the printer requires 2.54 revs of the roller.

To achieve 35 pages per minute, a rotational velocity of 88.9 rpm would be required.

\[
35[\text{ppm}] \times 2.54 \frac{\text{rev}}{\text{printed page}} = 88.9[\text{rpm}]
\]

Using an estimation of 17 Newton-meters for the torque required to turn a steel roller system, a very rough calculation for power can be obtained.

\[
\text{Power [watts]} = \text{Torque [N} \cdot \text{m]} \times \omega \left[\frac{\text{rad}}{\text{s}}\right]
\]

\[
P = 17 \times 88.9
\]

\[
P = 156 [\text{Watts}]
\]
Torque Calculations

- Due to the complexity of the interactions of the deflecting rollers, we have found it difficult to calculate the torque that this assembly would require. However, we have identified the major forces in play that would affect the torque
  - Inertia of the rollers.
  - Loss from the rolling friction of the Bottom roller on paper-
    - Loss from the deformation of the paper.
  - Loss from the rolling friction of the paper on the Center roller.
  - Loss from the rolling friction of the Top rollers on the Center roller.
  - Loss from each of the 8 bearings.
  - Loss from backlash from the input drive.
# Bill of Materials

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Description</th>
<th>Part Dimensions</th>
<th>Part Material</th>
<th>Req. Quantity</th>
<th>Quantity Units</th>
<th>Part Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bottom A Roller</td>
<td>Diameter: 2</td>
<td>316/316L Stainless Steel</td>
<td>1</td>
<td>Inches</td>
<td>[Image]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length: 13 - 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Center B Roller</td>
<td>Diameter: 1.5</td>
<td>416 Stainless Steel</td>
<td>1</td>
<td>Inches</td>
<td>[Image]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length: 13 - 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Stabilizing C Roller</td>
<td>Diameter: 1</td>
<td>416 Stainless Steel</td>
<td>2</td>
<td>Inches</td>
<td>[Image]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length: 13 - 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Shell Cup Needle Ball Bearing</td>
<td>Outter: 11/16</td>
<td>Steel</td>
<td>8</td>
<td>Inches</td>
<td>[Image]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inner: 0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Bill of Materials

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Description</th>
<th>Part Dimensions</th>
<th>Part Material</th>
<th>Req. Quantity</th>
<th>Quantity Units</th>
<th>Part Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Top End Plate</td>
<td>3 x 0.5 x 1.25</td>
<td>304 Stainless Steel</td>
<td></td>
<td>2 Inches</td>
<td><img src="image1.png" alt="Top End Plate" /></td>
</tr>
<tr>
<td>6</td>
<td>Bottom End Plate</td>
<td>3 x 0.5 x 2.25</td>
<td>304 Stainless Steel</td>
<td></td>
<td>2 Inches</td>
<td><img src="image2.png" alt="Bottom End Plate" /></td>
</tr>
<tr>
<td>7</td>
<td>Socket Cap Screw</td>
<td>L: 2.25</td>
<td>Steel</td>
<td>8</td>
<td>Inches</td>
<td><img src="image3.png" alt="Socket Cap Screw" /></td>
</tr>
<tr>
<td>8</td>
<td>Drive Motor</td>
<td>N/A</td>
<td></td>
<td>1</td>
<td></td>
<td><img src="image4.png" alt="Drive Motor" /></td>
</tr>
</tbody>
</table>
# Bill of Materials

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Description</th>
<th>Part Dimensions</th>
<th>Part Material</th>
<th>Req. Quantity</th>
<th>Quantity Units</th>
<th>Part Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>End Plate Support Bar</td>
<td>Length: 14-15 Width and Height: 0.5</td>
<td>Steel</td>
<td></td>
<td>2 Inches</td>
<td><img src="image1.png" alt="Part Picture" /></td>
</tr>
<tr>
<td>10</td>
<td>Pan Head Machine Screw</td>
<td>0.5</td>
<td>18-8 Stainless Steel</td>
<td></td>
<td>25 Inches</td>
<td><img src="image2.png" alt="Part Picture" /></td>
</tr>
<tr>
<td>11</td>
<td>Retaining E Ring</td>
<td>Diameter: 0.5</td>
<td>PH 15-7 MO Stainless Steel</td>
<td></td>
<td>8 Inches</td>
<td><img src="image3.png" alt="Part Picture" /></td>
</tr>
</tbody>
</table>
### BOM – Budget

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Description</th>
<th>Part Supplier</th>
<th>Req. Quantity</th>
<th>Quantity Units</th>
<th>Mat'l Cost ($)</th>
<th>Labor Cost ($/hr)</th>
<th>Tlt. Labor Cost ($)</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bottom A Roller</td>
<td>McMaster Carr</td>
<td>1</td>
<td>Inches</td>
<td>$274.52</td>
<td></td>
<td></td>
<td>$274.52</td>
</tr>
<tr>
<td>2</td>
<td>Center B Roller</td>
<td>McMaster Carr</td>
<td>1</td>
<td>Inches</td>
<td>$98.79</td>
<td></td>
<td></td>
<td>$98.79</td>
</tr>
<tr>
<td>3</td>
<td>Stabilizing C Roller</td>
<td>McMaster Carr</td>
<td>2</td>
<td>Inches</td>
<td>$29.58</td>
<td></td>
<td></td>
<td>$59.16</td>
</tr>
<tr>
<td>4</td>
<td>Shell Cup Needle Ball Bearing</td>
<td>Bearings Direct</td>
<td>10</td>
<td>Inches</td>
<td>$4.98</td>
<td></td>
<td></td>
<td>$49.80</td>
</tr>
<tr>
<td>5</td>
<td>8992K961 Side Plate Stock</td>
<td>McMaster Carr</td>
<td>1</td>
<td>Inches</td>
<td>$57.60</td>
<td></td>
<td></td>
<td>$57.60</td>
</tr>
<tr>
<td>6</td>
<td>Socket Cap Screw</td>
<td>McMaster Carr</td>
<td>8</td>
<td>Inches</td>
<td>$4,77 per pack of 25</td>
<td></td>
<td></td>
<td>$47.77</td>
</tr>
<tr>
<td>7</td>
<td>Drive Motor</td>
<td>Xerox</td>
<td>1</td>
<td>N/A</td>
<td>$400.00</td>
<td></td>
<td></td>
<td>$400.00</td>
</tr>
<tr>
<td>8</td>
<td>End Plate Support Bar</td>
<td>McMaster Carr</td>
<td>1</td>
<td>Inches</td>
<td>$10.70</td>
<td></td>
<td></td>
<td>$10.70</td>
</tr>
<tr>
<td>9</td>
<td>Pan Head Machine Screq</td>
<td>McMaster Carr</td>
<td>1</td>
<td>Inches</td>
<td>$5.71</td>
<td></td>
<td></td>
<td>$5.71</td>
</tr>
<tr>
<td>10</td>
<td>Retaining E Ring</td>
<td>McMaster Carr</td>
<td>1</td>
<td>Inches</td>
<td>$6.12</td>
<td></td>
<td></td>
<td>$6.12</td>
</tr>
<tr>
<td>11</td>
<td>Pressure Sensitive Paper</td>
<td>Xerox</td>
<td>2</td>
<td></td>
<td>$600.00</td>
<td></td>
<td></td>
<td>$1,200.00</td>
</tr>
</tbody>
</table>

- Machining cost have not been calculated yet
- Total does not include the price of the motor or pressure sensitive paper because they were donated by Xerox

**Total:** $570.17
# Project Feasibility Checklist

<table>
<thead>
<tr>
<th>Task</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do we have the knowledge to complete the required engineering analysis?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>2. Have we verified that our calculations are accurate?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>3. Do we have a plan to prototype or simulate our design?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>4. Do we have the ability/resources to manufacture our design?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>5. Are we within budget (&gt;$5,000)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>6. Have we fulfilled our customer requirements?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>7. Do we have complete engineering drawings?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>8. Do we have a complete BOM (including part costs)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>9. Are we prepared to purchase parts and build our design?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>10. Are we prepared for SD2?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

**Total Of Each Column**: 5 3 2

**Total Score**: 37/50

*Scoring:*
- 5: Task has been completed.
- 4: Task is relatively easy to complete.
- 3: Task is somewhat easy to complete.
- 2: Task will be difficult to complete.
- 1: Task is not complete or is going to be very difficult to complete.
Risk Assessment

- Risk Assessment Excel Document:
  - Risk Tracking
  - Example of Risk Tracking Document:

<table>
<thead>
<tr>
<th>Risk #</th>
<th>Risk Item</th>
<th>Risk Level</th>
<th>Mitigation strategy/ progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.x</td>
<td>Pressure Calculations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>We Don’T Know What The Black Box Program Is Doing, Could Be Wrong</td>
<td>Medium</td>
<td>This is potentially our most accurate way to calculate required pressure - ensure the design can deliver a wide variation of pressure</td>
</tr>
<tr>
<td>1.2</td>
<td>Deflection Calculations Could Be Off, Considering The Scale</td>
<td>Low</td>
<td>we will have to construct a device to definitively check the deflections - the design allows for modification to improve deflection</td>
</tr>
<tr>
<td>1.3</td>
<td>Don’T Have A Model For Calculating Material Interaction</td>
<td>Medium</td>
<td>rely on black box program</td>
</tr>
<tr>
<td>1.4</td>
<td>How Do We Apply Load To Rollers?</td>
<td>Low</td>
<td>concept selection - screw driven methods won for easy, size and flexibility of load - keeping the moment down is important to minimize deflection</td>
</tr>
<tr>
<td>2.x</td>
<td>Torque Requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Cannot Calculate Load Torque Of Assembly</td>
<td>Medium</td>
<td>checked various texts, cannot pin down any figures for losses due to friction and deflection - can account for inertia - bearings are difficult to account for - deflection of rollers is difficult to account for - deflection of paper is difficult to account for - use a measurement of existing device as a rough estimate of load torque</td>
</tr>
<tr>
<td>2.2</td>
<td>Cannot Accurately Measure Torque</td>
<td>High</td>
<td>attempted to measure starting torque with torque wrench, but device required less than 35Nm minimum measure - contacted labs on campus, RIT does not possess a capable test rig - given test bench motor, with 6:1 gearing, but coupling did not fit - given machinable coupling, need to construct bench apparatus to hold fixtures in place - since device obviously cannot be driven with existing drive train, must be driven externally - we can use the bench motor we already have. - this may be out of scope of project, not a priority for week 9</td>
</tr>
</tbody>
</table>
Questions