Plastic Hose Forming System
The Team

Hashem Behbehani  ME

Walter Evans IV   ME

Lauren Fandl     ME

Ian Wogan        ME
The Team Continued.....

Sponsor: Transfer Flow, Inc.

Contact: Todd LaPant
Mike Larocco
Joseph Baldi

Advisor: Dr. Joe Greene
About Transfer Flow Inc.

• Located in Chico, CA
• Manufactures:
  • Aftermarket fuel tanks
  • OEM fuel tanks
  • Custom work
The Problem

- 500,000 feet of fuel line per year
- Want to move to a different material
  - Cheaper/ more cost effective
  - Can be used in more applications
Need Statement: Transfer Flow Inc. needs a thermoforming process to form plastic hose for fuel tanks.

Goal Statement: Design, build, and test a plastic hose forming machine that will lower Transfer Flow Inc’s costs.
The Customer

Customer/ Sponsor: Transfer Flow Inc.

- Thermoforming machine will be used at Transfer Flow Inc’s warehouse.

Stakeholders:

- Todd LaPant, Chief Engineer
- assembly workers
- maintenance workers
Customer Requirements

- Safe
- Efficient
- Cost effective
- Versatile
- Easy setup/maintenance
- Take up small space
## Requirements

<table>
<thead>
<tr>
<th>Must Do</th>
<th>Should Do</th>
<th>Would Be Nice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verify thermoforming process for tubes</td>
<td>Short set up time</td>
<td>Form all three types of hose</td>
</tr>
<tr>
<td>Be versatile (accommodate multiple shapes)</td>
<td>Fit in small area</td>
<td>Complete work center</td>
</tr>
<tr>
<td>Be operated by an unskilled laborer</td>
<td>Forms hose quickly</td>
<td></td>
</tr>
<tr>
<td>Form at least one of the three types of hose</td>
<td>Repeatable</td>
<td></td>
</tr>
<tr>
<td>Be controlled by PC</td>
<td>Reliable</td>
<td></td>
</tr>
<tr>
<td>Be cost effective</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualitative</td>
<td>Quantitative</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
<td></td>
</tr>
<tr>
<td>Thermoform process</td>
<td>Short setup time</td>
<td></td>
</tr>
<tr>
<td>Be versatile (accommodate multiple shapes)</td>
<td>Fit in a small area</td>
<td></td>
</tr>
<tr>
<td>Process must form at least 1 of the 3 types of hose</td>
<td>Forms hoses quickly</td>
<td></td>
</tr>
<tr>
<td>Operated by an unskilled laborer</td>
<td>Repeatable</td>
<td></td>
</tr>
<tr>
<td>Controlled by PC</td>
<td>Reliable</td>
<td></td>
</tr>
<tr>
<td>Form all 3 of the 3 types of hoses</td>
<td>Cost Effective</td>
<td></td>
</tr>
<tr>
<td>Complete work center</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Quantitative Requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Engineering Specifications</th>
<th>Metric</th>
<th>Method/Device</th>
<th>Target</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short set-up time</td>
<td>Time</td>
<td>Minutes to setup</td>
<td>Stop watch</td>
<td>&lt;5 minutes</td>
<td>Unskilled laborer</td>
</tr>
<tr>
<td>Fit in small area</td>
<td>Area</td>
<td>Feet squared</td>
<td>Tape Measurer</td>
<td>10'x15'</td>
<td>Includes the entire workstation</td>
</tr>
<tr>
<td>Forms hoses quickly</td>
<td>Units/Time</td>
<td>Units/hour</td>
<td>Count units with stopwatch</td>
<td>60 hoses per hour</td>
<td>From start to finish</td>
</tr>
<tr>
<td>Repeatable</td>
<td>Tolerances for Key Product Characteristics (KPC)</td>
<td>Inches</td>
<td>Checking Fixture</td>
<td>±2σ variation of bend angle</td>
<td>Includes all hoses formed</td>
</tr>
<tr>
<td>Reliable</td>
<td>Mean Time between Failures</td>
<td>Weeks</td>
<td>Endurance Test</td>
<td>1000 hoses</td>
<td>Under normal factory conditions</td>
</tr>
<tr>
<td>Cost effective</td>
<td>Money</td>
<td>US Dollars</td>
<td>Cost Analysis</td>
<td>&lt;current cost</td>
<td>Operational costs</td>
</tr>
</tbody>
</table>
Proof of Concept

• Differential Scanning Calorimetry for Thermal Testing (DSC)
  - Heat flow is measured in relation to temperature change
  - Finds phase change temperature
**DSC Results:**

![Differential Scanning Calorimetry Graph](image)

**Tabulated Results from DSC Machine:**

<table>
<thead>
<tr>
<th>Hose</th>
<th>$T_{\text{melt}}$</th>
<th>$T_{\text{malleable}}$</th>
<th>Can hose be formed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markel</td>
<td>165 °C / 329 °F</td>
<td>125-145 °C / 257-293 °F</td>
<td>Yes</td>
</tr>
<tr>
<td>Cooper Standard</td>
<td>155 °C / 311 °F</td>
<td>100-125 °C / 212-257 °F</td>
<td>Yes</td>
</tr>
<tr>
<td>Kongsberg</td>
<td>N/A</td>
<td>N/A</td>
<td>No</td>
</tr>
</tbody>
</table>
Design Solution

• Design consists of:
  – work table and fixturing system
  – heating loop
  – cooling loop
  – Control System

• Primary manufactured components are designed using sheet metal

• The majority of the other components were purchased
Propylene Glycol

- high boiling temperature
- relatively low toxicity when compared to other heat transfer fluids
Fixtures

- Corner fixtures securely hold the hose during forming
- Fixture corners utilize the availability of sheet metal and tooling resources at Transfer Flow Inc.
Work Bench and Fixturing

Positioning Arm and Corner Fixtures

- Work bench: sheet metal surface welded to steel tubing
  - steel surface used to mount the fixturing system using magnetic bases
The process must be versatile
  • It can accommodate many different shapes of hoses.

Setup for a new hose shape:
  • Use the example shape (with corner fixtures attached) to set the positioning arms in the correct locations
  • Remove the metal example shape
Heating Cycle

Consists of:

- High temperature pump
- Insulated hot reservoir
- Immersion heater
- Adjustable flow control valve
- High temperature solenoid valve

Operation Conditions:

- Kept under pressure to prevent the propylene glycol from vaporizing
- Propylene glycol heated to 250 degrees Fahrenheit
- Flow rate of 2.1 gallons per minute
Cooling Cycle

Consists of:
- Pump
- Cold reservoir
- Adjustable flow control valve
- Solenoid valve

Operation Conditions:
- Flow rate of 2.1 gallons per minute
Hose Forming System
Schematic

Heating Cycle Operation:
Turn the pump on
Heat the hose
Turn off the pump
Purge hose with pressurized air, returning all heated propylene glycol to the hot reservoir.

Cooling Cycle Operation:
Turn the pump on
Cool the hose
Turn off the pump
Purge hose with pressurized air, returning all cool propylene glycol to the cold reservoir.
<table>
<thead>
<tr>
<th>Must Do</th>
<th>Should Do</th>
<th>Would Be Nice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard operation module</td>
<td>Maintenance module</td>
<td>Debugging Module</td>
</tr>
<tr>
<td>Display/Store data from sensors</td>
<td>Maintenance log</td>
<td>Override/Force Step</td>
</tr>
<tr>
<td>Emergency shutdown protocol</td>
<td>Leak Detection Protocol</td>
<td>Adjust System Variables</td>
</tr>
</tbody>
</table>

Easy to read dialogue boxes and menus

**Diagram:**

- **Main Menu**
  - Turn on System
    - Mode Select
      - Maintenance Module
      - Standard Operations Module
      - Debug Module
      - Shut Down Protocol
Operating System

• Indicators
  – Lights
  – Gauges
  – Dialogue boxes
• Switches
  – Solenoid Valves
  – Motor
  – Heating Element
Control Panel

- Power Supply
- Lab Jack
- Relays
  - AC
  - DC
- Fuse Panel
- On/Off Safety Switch
Safety

- Stop Button
- Signage
- Emergency Pressure Release Valve
- Coalescing Air Filter
Design Changes

Original Design

Fabricated Design
• We made changes in the following areas:
  – Distribution manifolds and valves and tubing
• Tank Design
  – Size
  – Location
Parameter Optimization

• Taguchi Test Plan
  – Uses statistical methods to improve the quality of manufactured goods
  – Used to optimized parameters prior to performing test plan
The Taguchi experiment helped us determine:

- What parameters have the biggest impact
- Compared results from the Copper Standard and the Markel
- Possible values for machine parameters including
  - Heat Time, Cool Time, Pressure

Design of Experiment

- 3 parameters at 2 levels (low and high)
What we learned from Taguchi

- **Markel Cycle Time Level Averages**
- **Markel Bend Angle Level Averages**
- **Markel Quality Level Averages**

- **Cooper Standard Cycle Time Level Average**
- **Cooper Standard Bend Angle Level Average**
- **Cooper Standard Quality Level Averages**
Test Plan

• We will use the validation data from the Taguchi experiment as our test data
• The test plan includes experiments to test the following parameters

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set-up Time</td>
<td>≤ 5 minutes</td>
</tr>
<tr>
<td>Machine Footprint</td>
<td>≤ 150 square feet</td>
</tr>
<tr>
<td>Repeatability</td>
<td>± 2σ variation</td>
</tr>
<tr>
<td>Cycle Time per Hose</td>
<td>≤ 1 minute</td>
</tr>
</tbody>
</table>
Funding and Labor

• Funding came from our sponsor Transfer Flow Inc.

• Labor was donated from:
  – Transfer flow personnel
    • Todd LaPant
    • Michael Larocco
    • Joseph Baldi
    • Ignacio Saucedo
    • Steve Nannini
  – California State University, Chico personnel
    • Dr. Joe Greene
    • Steve Eckart
    • Dave Gilson
    • Hashem Behbehani
    • Walter Evans
    • Lauren Fandl
    • Ian Wogan
## Budget

### Total Budget

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased Parts</td>
<td>4,128.04</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>360.00</td>
</tr>
</tbody>
</table>

### Fall Semester

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Cost/Hour</th>
<th>Benefit and Overhead Factor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Time</td>
<td>525.5</td>
<td>36.54</td>
<td>1.77</td>
</tr>
<tr>
<td>Labor and Machining</td>
<td>40</td>
<td>30.00</td>
<td>1.77</td>
</tr>
</tbody>
</table>

### Spring Semester

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Cost/Hour</th>
<th>Benefit and Overhead Factor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Time</td>
<td>626.5</td>
<td>36.54</td>
<td>1.77</td>
</tr>
<tr>
<td>Labor and Machining</td>
<td>78</td>
<td>30.00</td>
<td>1.77</td>
</tr>
</tbody>
</table>

**Estimated Total Cost:** 85,260.36
## How did we do?

<table>
<thead>
<tr>
<th>Engineering Specifications</th>
<th>Target (for Quantitative)</th>
<th>Target Met?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Must Do:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verify a thermoforming process</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Be Versatile</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Operated by an unskilled Laborer</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Form at least one type of hose</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Controlled by PC</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Cost Effective</td>
<td></td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Should Do:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short set-up time</td>
<td>≤ 5 min</td>
<td>TBD</td>
</tr>
<tr>
<td>Fit in a small area</td>
<td>≤ 150 feet squared</td>
<td>Yes</td>
</tr>
<tr>
<td>Cycle time per hose</td>
<td>≤ 1min</td>
<td>No</td>
</tr>
<tr>
<td>Repeatable</td>
<td>± 2 σ</td>
<td>TBD</td>
</tr>
<tr>
<td>Reliable</td>
<td>1000 hoses (MTBF)</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Would be Nice:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Form all three types of hose</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Complete work center</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>
Things We Didn’t Expect

• **Purge time required**
• **Fluid transfer from tank to tank**
  – **Heat transfer to cold tank**
• Accuracy when using the plasma cutter
• Solenoid performance
• Accuracy of thermocouples
• Heat loss of the system
• Importance of automated safety systems
• Minimum bend radius
Ready for Market?

• Successfully proved that a thermoforming process is a viable design solution

• This product needs:
  – More testing
  – More safety systems
  – Improved cycle time
Future Testing

- Future testing is recommended
- Need to complete the set of validation tests
- Future experiment recommended to determine the required over-bend with respect to desired bend angle
  - Example:
    - Suggested over-bend for a 90 degree Markel hose is ≈20 degrees.
    - Suggested over-bend for a 45 degree Markel hose is ???
    - Suggested over-bend for a 135 degree Markel hose is ???
Future Design Considerations

• Functionality
  – *Quick connect fittings for different types of hose*
  – *Thermocouple position*
  – Hooks for hoses

• Cycle Time Improvements
  – *Smaller manifolds*
  – Proportional control solenoid valves
  – Fixture design
• Temperature Control
  – *Heat sinks*
    • *Coalescing filter*
    • *Cold Tank*
  – *Hot tank fluid agitation*
  – Thermocouple placement
  – Distribution manifold size

• Safety
  – *Shielding on table*
  – *Eyewash station for hot fluid (OSHA: Title 8)*
  – Work station hoses rated to a higher pressure
  – Quick connect fittings
  – Pressure check system
  – Air filtration system
Special Thanks

Thank you California State University, Chico
A special thanks to our sponsor Transfer Flow Inc.
  Todd LaPant
  Mike Larocco
  Joseph Baldi
And to our project advisor
  Dr. Joe Greene
Questions?
Questions?