CNC Retrofit of Mandrel Tube Bender
Team Members

Jordan Schwarz  
Mechatronic / Mechanical

Jared Berry  
Mechatronic

Brendan Green  
Mechatronic

Tyler Watson  
Mechanical

Daniel Cliffe  
Mechanical
Sponsored By:
Transfer Flow Inc. (TFI)

Director of Engineering
Todd LaPant, P.E.

Professor Nick Repanich
Problems with the Original System

- Imprecise linear movement
- Imprecise rotational movement
- Slow manufacturing process requires too many man hours
- Time-consuming to program
- Difficult to operate
# Customer Requirements

<table>
<thead>
<tr>
<th>Must Do</th>
<th>Should Do</th>
<th>Would Be Nice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain a linear positional accuracy of ±0.025 inches at any position.</td>
<td>Form tube 1.25 to 2.00 inches in diameter.</td>
<td>Be aesthetically pleasing.</td>
</tr>
<tr>
<td>Maintain a rotational positional accuracy of ±0.5° at any position.</td>
<td>Require less than 5 minutes for an operator to set up.</td>
<td>Does not require a change of clamps for different-diameter tubes.</td>
</tr>
<tr>
<td>Load job information from TFI’s network server.</td>
<td>Improve ease of use for operators and TFI’s engineering team.</td>
<td>Monitors current stage of operation and relays warnings to operator.</td>
</tr>
<tr>
<td>Utilize interface software familiar to TFI personnel.</td>
<td>Monitor important aspects of the job and relay status to the operator.</td>
<td>Reduces minimum length of stock required for operation.</td>
</tr>
<tr>
<td>Allow the user to run the machine manually if the need arises.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Include a safety device to ensure operator oversight of the machine.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not increase the minimum length of stock required for operation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>Specification</td>
<td>Metric</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>---------------</td>
<td>--------</td>
</tr>
<tr>
<td>Linear positional tolerance</td>
<td>Length</td>
<td>Inches</td>
</tr>
<tr>
<td>Rotational positional tolerance</td>
<td>Angle</td>
<td>Degrees</td>
</tr>
<tr>
<td>Maximum setup time for equivalent-diameter tubing</td>
<td>Time</td>
<td>Minutes</td>
</tr>
<tr>
<td>Maintain or reduce minimum stock length</td>
<td>Length</td>
<td>Inches</td>
</tr>
</tbody>
</table>
Design Solution

Linear Motion System:
• Two-stack NEMA 34 stepper motor
• Rack and pinion integrated solution

Rotational Motion System:
• Two-stack NEMA 34 stepper motor
• Belt and pulley linkage

Motion Control System:
• MACH3 with KMOTION plugin
• KFLOP, SNAPAMP and KONNECT
Linear Motion System

Components:

• Two-stack NEMA 34 stepper motor from Applied Motion Products

• Rack and pinion integrated solution from CNC Router Parts
  • Provides mount for motor
  • Includes 3.2:1 gearing ratio from belt
  • Designed for flexible deployment
  • Precision assembly not required
Rotational Motion System

Components:

• Two-stack NEMA 34 stepper motor from Applied Motion Products
• 25:1 two-stage planetary gearhead from Anaheim Automation
• Two 48-tooth GT3 timing belt pulleys
• GT3 timing belt
Motion Control System

Components:

- KFLOP motion controller
  - Can control two stepper motors
- SNAPAMP amplifier
  - Up to 12.5 amps continuous per axis
- MACH3 G-code processing package
  - KMOTION plugin for communicating with the KFLOP
- KONNECT I/O expansion board
  - Optically isolated outputs communicate with original machine
  - Opto-isolated inputs for limit switches
Methods:

- CNC Laser Table
  - Cut all sheet metal parts
  - Steel and aluminum
- Press Brake
  - Formed all angles
  - 14 gauge aluminum to 0.25 in steel
- CNC Mill
  - Cut aluminum motor mounting block
- Engine Lathe
  - Modified mounting block
Fabrication

Features:

- Slotted Holes
  - Allowed for dimensional variation
  - Adjustable position for rotational axis
- Bolted Connections
  - Multiple assembly/disassembly
  - Less manufacturing time
- Sheet Metal
  - Readily available at TFI
  - Affordable
  - Leverages TFI knowledge base
Required Tests:

• Linear Positional Accuracy
• Rotational Positional Accuracy
• Setup Time
Specification:
Feed length ±0.025 inches

Parameters:
Normal shop environment

Results:
Linear inaccuracy ±0.0035 inches

SPECIFICATION MET
Rotational Positional Accuracy Test

Specification:
Part rotation ±0.5°

Parameters:
Normal shop environment

Results:
Rotational inaccuracy ±0.25°

SPECIFICATION MET
Specification:
Less than 5 minutes without changing dies

Parameters:
One trained operator

Results:
Setup time 1 minute

SPECIFICATION MET
Expenditures:

- **Design Solution:** $6,205
  - Including cost of purchased parts, tooling, hardware and software
- **Transfer Flow Labor:** $17,022
  - Opportunity cost
  - Transfer Flow employees are estimated to cost $180 an hour
- **Design Team Labor:** $68,224
  - Estimate the cost of the design solution, $40 per hour
  - No actual cost to Transfer Flow

---

**Estimated Budget:** $121,000
Complications

Linear Motion System:

• Far greater friction than expected
• Motor theoretically had sufficient torque
  • Verified by actual measurement
  • Probable driver issue

Solution: Larger NEMA 34 stepper

• Provides enough torque
• Documentation not available
Hindsight is Perfect

Things we might have done differently:

• Purchase a motion controller with actual documentation
  • Saving money on aspirin
• Check critical dimensions before ordering components
  • Notably the gearbox
• Redesign the entire carriage assembly
  • New pneumatic chuck
• Nickel plate the rack upon delivery
Future Suggestions

Shop Operations:
• Place CNC Tube Bender in production
• Market precision tubing capabilities
• Expand formed tube product line

Intellectual Property:
• Sell retrofits based on this design
• Retrofit and sell other tube bender
Practical Engineering Knowledge

- Motor Sizing
- Motion Control
- Wiring Diagrams
- Wiring
- Data Communications
- Programming (C++ and G-code)
- Design for Manufacturability
- Finite Element Analysis
- Project Planning
- Computer Aided Design
- Geometric Dimensioning and Tolerance
- Manufacturing Processes
- Design for Sheet Metal
- Systematic Troubleshooting

- Control Systems
- Digital Input/Output
- Feedback Systems
- Machine Design
- Electronic Components Integration
- Motion Mechanics Integration
- Gearing and Coupling
- Vibration and Resonance
- Inertia Matching
- Interface Programming
- Life Cycle Assessment
- Hazard Mitigation
- Powertrain Stiffness
- Electrical Noise Management
Questions?