1. Machine Description

Bottle capping machines are one of the last pieces of equipment a liquid-filled container will pass through prior to shipping. The bottles of liquid, in this particular application shampoo bottles, are passed via conveyor from the filling station to the capping station. At the capping station, a capping head is accelerated to match speed with the bottles on the conveyor. Once at matched speed with the bottle, an output fires which crimps the cap onto the bottle. The capping head then decelerates, and rapidly returns to the beginning of the cycle for the next bottle. To maintain high throughput, the conveyor is never stopped during the cycle.

Occasionally in a capping application, the bottles on the conveyor feeding from the previous process may not be perfectly spaced. This results in caps not being placed properly on the bottles. This is a situation for which the machine must constantly monitor and correct.

Galil’s DMC-2123 Ethernet controller will be used in this application to apply the bottle caps. The electronic cam mode (ECAM) will be used for the cyclical motion of the capping head. A special feature of the ECAM mode which allows the slave CAM table to be shifted on the fly will be used to insure caps are placed correctly on the bottles.

This machine uses one axis to apply the bottle caps to the bottles. The conveyor is run by an open loop AC motor controlled by a PLC. This motor has an encoder which is read by the Y-axis encoder input of the controller, and is used as the master for the ECAM. The X axis is a servo motor which moves the capping head horizontally. This axis is responsible for accelerating and matching speed with the bottles on the conveyor. Once they have matched speed, an output fires a solenoid, which crimps the caps onto the bottle tops. After the caps are applied, the X axis retracts to its initial position, and the cycle repeats.

A mechanical diagram of the machine follows:

![Figure 1. Bottle Capping Machine.](image)

2. Requirements

This section summarizes the requirements for the machine described above:

1. One servo axis (X) for capping head motion.
2. One axis (Y) to read the position of the bottle conveyor encoder.
3. Electronic CAM mode to simulate the motion of a mechanical cam.
4. Input position latch (Y) for homing and phase alignment correction.
5. Dynamic adjustment of capping head position with relation to the bottle conveyor.
6. Digital output (100 mA required) to apply cap to bottle.
7. Forward/Reverse limit inputs and index pulse on X axis.
8. 2 digital inputs for coordination with PLC; one to indicate conveyor is moving, another for cycle start signal.
9. Stand alone operation.

3. Components Selected

This section describes the Galil hardware and software products chosen to implement the machine’s control system. Below is a complete bill of materials followed by a description of major components.

**Table 1. Bill of Materials for Automated Bottle Capping Machine**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Unit Price (U.S.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMC-2123-DC24-BOX</td>
<td>Econo series 2-axis Ethernet motion controller</td>
<td>$1095 / $810</td>
</tr>
<tr>
<td>ICM-20105</td>
<td>Opto-isolated interconnect module</td>
<td>$195 / $145</td>
</tr>
<tr>
<td>WSDK Servo Tuning Software</td>
<td>Servo Tuning and Analysis Software</td>
<td>$195 (one time)</td>
</tr>
</tbody>
</table>

Galil Motion Control, Inc.  3750 Atherton Road • Rocklin, CA 95765 USA • 800-377-6329 • Phone: 916-626-0101 • Fax: 916-626-0102 • www.galilmc.com
Controller: DMC-2123-DC24-BOX

To provide Ethernet functionality along with low cost, the DMC-21x3 series controller was selected. This controller has a 10BaseT Ethernet port, on-board I/O and an ECAM feature for camming slave axes to a master axis. The -DC24 option allows the controller to be powered off a single 18-36VDC power supply. The -BOX option mounts the controller in a metal enclosure to allow easy mounting out in the system. The DMC-21x3 was chosen for it’s higher powered outputs on the ICM-20105, which can drive the capping mechanism directly.

Interconnect

The ICM-20105 opto-isolated I/O module provides signal interconnection for the DMC-21x3 series controllers. It has four 15-pin Male D-Sub connectors for individual axis signals. There is one 37-pin D-Sub for the 8 digital inputs, 8 high-side drive 500 mA digital outputs, home switches, limit switches and one 25-pin D-Sub for 4 axes of auxiliary encoders.

WSDK Software

WSDK (Windows Servo Design Kit) is a development tool which aids in setup and troubleshooting of the Galil motion control system. The WSDK tuning methods and storage scopes are extremely helpful in selecting the proper PID parameters and motion profiles. In addition to simplifying the tuning and motion programming, WSDK also offers basic setup tools, spreadsheet parameter entry, and system diagnostics.

Electronic Cam

There are two keys to this application; the ECAM mode and the ability to change the slave phase relationship of that mode on the fly. With ECAM, any slave axis or set of slave axes can be linked to a master axis to simulate the motion of a mechanical cam. This enables periodic synchronization of one or more axes of motion to one master. The master axis can be any motor-driven axis or encoder. Galil motion controllers treat the ECAM function as a table-based relationship of master positions versus slave positions over one cycle. This allows the X axis capping head to synchronize with the bottle conveyor during the capping, then rapidly return for the start of the next cycle.

The other feature of the ECAM which is critical for this application is the ability to adjust the phase relationship between the master and its slaves on the fly. In this way, if the spacing of the bottles on the conveyor is something other than nominal, an adjustment may be made without stopping the machine or ruining any product. The EP command is used to add an offset to the slave table to account for this out of phase scenario. For example, if the bottle lags behind the capping head by 200 master counts, the command “EP,200” will phase shift the slave axis by that amount to re-align the system. This correction is maintained for every cycle thereafter.
The following sections show how these features and others are implemented for proper machine operation.

**Motion Specifications**

This bottle capping machine has the following motion requirements:

1. **Conveyor speed** – 4 inches/second
2. **Nominal bottle spacing on conveyor** – 6 inches
3. **Bottle conveyor (Y) resolution** – 1000 encoder counts/inch.
4. **Capping head (X) resolution** – 1000 encoder counts/inch
5. **X axis time required to apply cap (while at matched speed)** – 0.5 seconds

This gives the following values for the ECAM routine.

- **1 cycle = 6 inches/bottle = 6 inches/master cycle = 6,000 counts/master cycle**
- **4 inches/second @ 6 inches/cycle = 1.5 seconds/cycle**

**X axis capping head**

To increase throughput of the machine, the return speed of the capping head will be faster than the forward motion. Based on the above specifications, the capping head must be at matched speed for a total of 0.5 seconds. The capping head must be returned to the start position within the 1.5 seconds.

Using these guidelines, a velocity profile for the X-axis capping head would look as follows:

With this velocity profile, we see that the slave profile may be divided up into 0.25 sec intervals, for a total of 6 intervals over the 1.5 second cycle. Using this, Table 2 is developed to define the final ECAM table to be used (shown graphically in Figure 6).

The slave counts shown in Table 2 are then entered as the ECAM table within the Galil program. The next section will discuss the program structure.

**Program structure**

There are three major sections to this bottle capping machine; initial setup (including homing), ECAM table setup, and correction mechanism. Those three sections are detailed below:

**Initial setup**

The initial homing of the X axis capping head and Y axis conveyor is critical for operation of this machine. The X axis must start its cycle ahead of any given bottle such that they match speed when the bottle and cap are perfectly aligned. The key therefore is proper mechanical positioning of the X axis home input.

The X axis capping head has a reverse limit switch and index mark for homing. A forward limit switch is also mounted for safety, but is not used for homing. The homing of the X axis takes place in two parts. First, the axis is

<table>
<thead>
<tr>
<th>Interval</th>
<th>Time (sec)</th>
<th>Δ Master Position (in)</th>
<th>Δ Slave Position (in)</th>
<th>Cumulative Master position (in)</th>
<th>Cumulative Slave position (in)</th>
<th>Master counts</th>
<th>Slave counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.5</td>
<td>2000</td>
<td>1500</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2.5</td>
<td>3000</td>
<td>2500</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>1</td>
<td>0.5</td>
<td>4</td>
<td>3.0</td>
<td>4000</td>
<td>3000</td>
</tr>
<tr>
<td>5</td>
<td>1.25</td>
<td>1</td>
<td>-1.5</td>
<td>5</td>
<td>1.5</td>
<td>5000</td>
<td>1500</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>1</td>
<td>-1.5</td>
<td>6</td>
<td>0</td>
<td>6000</td>
<td>0</td>
</tr>
</tbody>
</table>

**Figure 5. Velocity profile for X axis capping head.**

**Figure 6. The electronic cam table specified in Table 2.**
moved at rapid speed in the reverse direction to the reverse limit switch. The motor decelerates and stops. Second, the axis is moved forward at low speed to find the index mark. The position is then defined as zero, which is the start of the capping cycle.

```csharp
#Xhome
JG -10000 ;' Jog at rapid speed to the reverse limit switch
BGX ;' Begin jog to reverse limit
AMX ;' Wait until motor crosses switch and stops
JG 500 ;' Jog motor slowly towards encoder index
FIX ;' Find index
BGX ;' Begin find index move
AMX ;' Wait until index is triggered. Position is defined as zero.
EN ;' End routine
```

The Y axis conveyor is homed by an initial jog of the conveyor, which is commanded by the PLC. A latch input on the conveyor watches for the leading edge of a bottle, and that position is then defined as zero. The following code would accomplish that:

```csharp
#Yhome
AI 3 ;' PLC sets input 3 to indicate conveyor moving
ALY ;' Arm Y axis positional latch
#Ywait;JP#Ywait,_ALY=1 ;' Wait for latch to trigger
DPY = _TPY - _RLY ;' Define conveyor as current position minus latch position
EN
```

**ECAM table setup**

The ECAM table is set up once at power up, and then is not run again during normal operation. Once the motors have been homed and the CAM table setup, the code simply waits for the signal from the PLC (Input #1) that the cycle should begin.

```csharp
#CAMInit
EAY ;' Select Y axis as CAM master
EM 0,6000 ;' Slave modulus 0, master modulus 6000
EP 1000,0 ;' 1000 master counts per interval for 6 total CAM intervals
'The slave CAM positions derived in Table 2.
ET[0] = 0
ET[1] = 500
ET[2] = 1500
ET[3] = 2500
ET[4] = 3000
ET[5] = 1500
ET[6] = 0
EB 1 ;' Enable ECAM mode
AI 1 ;' Wait until run signal from PLC
EG 0 ;' Engage ECAM when master reaches position 0
EN
```

**Correction Routine**

As mentioned earlier, the unique feature to this ECAM routine is the ability to adjust the phasing between the bottle conveyor and capping head. If at any time the bottles are not spaced a nominal distance apart, the code will calculate the positional error and apply a correcting offset to the slave axis.

Specifically, a sensor is mounted which reads the position of a bottle as it passes on the conveyor. This sensor is located such that the bottle is read at the nominal zero position of the cycle. The high-speed positional latch reads the actual bottle position as it crosses the sensor. The code determines if the bottle is leading or lagging the ECAM cycle. Based on the difference between the actual position and theoretical zero position, a correctional move is then applied to the slave axis to re-phase the axes.

(Continued next page)
#AUTO ; Routine starts automatically on power up
JS#Xhome
JS#Yhome
JS#CAMInit
JS#Correct
EN
\`
'X axis home routine
#Xhome
  JG -10000 ; Jog at rapid speed to the reverse limit switch
  BGX ; Begin jog to reverse limit
  AMX ; Wait until motor crosses switch and stops
  JG 500 ; Jog motor slowly towards encoder index
  FIX ; Find index
  BGX ; Begin find index move
  AMX ; Wait until index is triggered. Position is defined as 0.
EN
\`
'Y Home routine
#Yhome
  AI 3 ; PLC sets input 3 to indicate conveyor moving
  ALY ; Arm Y axis positional latch
  #Ywait;JP#Ywait, _ALY=1 ; Wait for latch to trigger
  DPY = _TPY - _RLY ; Define conveyor as current position minus latch position
EN
\`
'Initialize ECAM table and parameters
#CAMInit
  EAY ; Select Y axis as CAM master
  EM 0,6000 ; Slave modulus 0, master modulus 6000
  EP 1000,0 ; 1000 master counts per interval for 6 total CAM intervals
    'The slave CAM positions derived in Table 2.
  ET[0] = 0
  ET[1] = 500
  ET[2] = 1500
  ET[3] = 2500
  ET[4] = 3000
  ET[5] = 1500
  ET[6] = 0
  EB 1 ; Enable ECAM mode
  AI 1 ; Wait until run signal from PLC
  EG 0 ; Engage ECAM when master reaches position 0
EN
Correction routine

ALY ;’ Arm Y-axis (conveyor) positional latch
MF,0 ;’ Wait until conveyor crosses zero position of ECAM cycle
IF _ALY=0 ;’ If latch has triggered, ie. bottle leading cycle
  Diff = _RLY - 6000 ;’ Calculate difference
  EP,Diff ;’ Apply lead phase correction to X-axis capping head
ELSE
  #AL;JP#AL, ALY=1 ;’ Wait until latch triggers
  Diff = _RLY ;’ Calculate difference
  EP,Diff ;’ Apply lag phase correction to X-axis capping head
ENDIF
MF 500 ;’ Wait until motors are at matched speed
SB 1 ;’ Fire output 1 to set cap
MF 2500 ;’ Wait until motors have completed matched speed section
CB1 ;’ Clear output 1 to retract capping head
JP#Correct,@IN[1]=1 ;’ Loop while input 1 high
EQ 0 ;’ Disengage slave if input 1 low
EB 0 ;’ Disable ECAM mode
EN ;’ End program