# Stator Winding Machine Manual

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# Table of Contents

# Table of Figures

# I. Start-up Instructions

## Specifying No. of Winding Turns

1. The machine is set to do 8 winding turns. It cannot currently specify otherwise.

## Starting the Machine

1. BEFORE starting the machine, the IAI slide with the winding apparatus must be far in enough from the loading system to give clearance for stator loading, AND must also be far out enough that the spool of wire will not hit the slide.
2. Be sure the red arrows line up on the lower stator loading shaft.
3. Be sure that all input switches (X120, X121, etc…) on the PLC are OFF.
4. Be sure the track for feeding in and out is clear of any objects.
5. Turn on E-Stop (big red button).
6. Switch PLC from off to Run Mode.

## Loading the Machine

1. Place stators on the feeding track.
2. For the first winding, a manual feed of wire must be made. After the wire is placed between the grippers, switch on X121 (input 2) on the PLC. This will continue the sequence.

## Clearing Jams

1. If the machine jams, immediately push the E-stop. If the machine is in the process of winding, move the big IAI slide out of the way of the stator.

# II. Machine Operation

## Feeding

The assumption used for this machine is that a separated machine would be employed prior to this machine such as a vibratory feed bowl or pick and place system to initially feed the stators. Thus feeding is accomplished by hand feeding the stators onto the conveyor system. The feeding system consists of a conveyor system, a pneumatic cylinder stop, and an optical sensor. On either side of the conveyors precisely spaced rails guide the stator movement along the continuously running conveyor system. Only if the emergency stop is actuated will the conveyors stop. Advancing stators move passed the retracted pneumatic cylinder stop and interrupts the optical sensor beam. This triggers the extension of the cylinder, which is positioned to stop all the stators behind the tripping stator by blocking the track. The first stator continues down the in feed conveyor and stops once it reaches a loading platform where the stator positioning is to take place. Once the stator is wound and placed back on the loading platform, the pneumatic cylinder is retracted and one more stator is sent through. The next stator takes the wound stator's place and pushes the wound stator onto the next out feed conveyor.

## Stator Positioning

When the stator is positioned on the loading platform, a loader, consisting of a pneumatic cylinder and a stepper motor, pushes the stator from below through the bearing-tube hole and lifts the stator to the correct height for winding. Specially machined pieces that fit over the pneumatic cylinder and stepper motor shafts ensure stator stability and positioning. The stepper motor allows for the rotational positioning of the stator. An inductive sensor detects stator teeth and provides accurate positioning of the stator teeth for winding. Before winding, the stepper motor rotates the stator until a gap is present, indicating a tooth is in position to be wound. This positioning is repeated for the winding of subsequent teeth. After the winding is completed, the pneumatic cylinder retracts and the wound cylinder is left on the loading platform.

## Stator Winding

The adopted stator winding process closely follows the shed winding method. A linear actuator moves the winding fixture toward the stator from the home position. As the wire is being fed, the linear actuator moves for precise wire placement on the stator teeth. The wire is fed by rotating the wire spool around a specially machined part that is precisely a slope to guide the wire onto the stator tooth. The spool rotates on a shaft under the power of a pulley system connected to a smart motor, which is programmed to rotate the desired number of revolutions to accommodate the wire size. A bolt was mounted on the end of the rotating shaft for an inductive sensor to detect the position of winding fixture directly. Due to the design of the winding apparatus the wire spool is attached to and rotates with the fixture. To counteract the imbalance of the rotating spool a counter weight was attached to the opposite side of the winding fixture from the spool.

### Gripping/Clipping the Wire

The wire gripper and clippers are mounted on a linear actuator that serves to move them into position and out of the way when needed. One closes the clippers when the wire is to be cut. The other two control the grippers, one for gripping the wire, the other for swinging the grippers into position around the upper stator positioning shaft. In the initial setup of the machine, the wire is hand fed to the grippers. After this the wire will be in position and programmed for the grippers to automatically grab.

## III. Machine Specifications

### Restrictions on Windings

- Wire Size – The machine can wind 22-28 gage wire. Some of the programming constants, though, would need to be changed to accommodate for the change.
- Number of Turns – Due to the stator restriction, the machine is capable of 10-20 turns per tooth.
- Stator Specs – The machine is restricted to 9-pole, 22.7mm stators. The bearing tube hole on the stators is restricted to 8mm in order to fit on the loading shaft.

## IV. Suggestions for Improvement

1) Offset stepper motor with belt drive so that more force can be applied on loader shaft.
2) Add limit switches to the pneumatic cylinders so that timers in the programming are not necessary.
3) Shorter slide for the winding apparatus.
4) Make the angle larger on the conveyor railing to provide for better clearance for the wire.
5) Better grip on the wire grippers.
6) Use a stepper motor that can do absolute positioning for the stator rotations.

# V. Appendix

## Annotated Photos

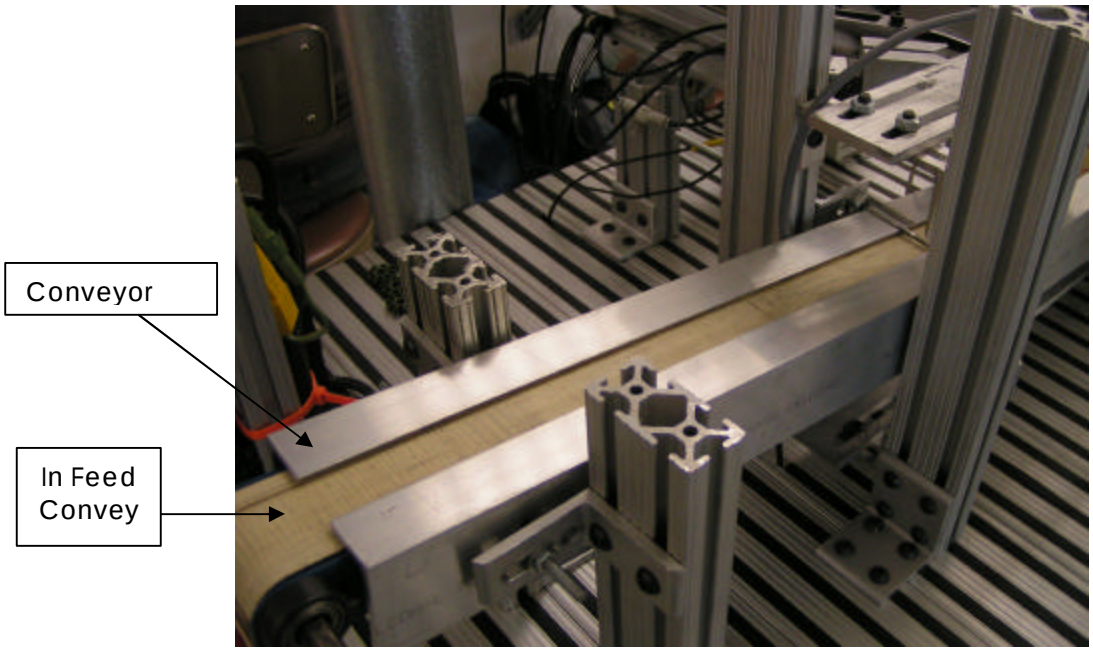



**Figure 1: Beginning of Feed System**

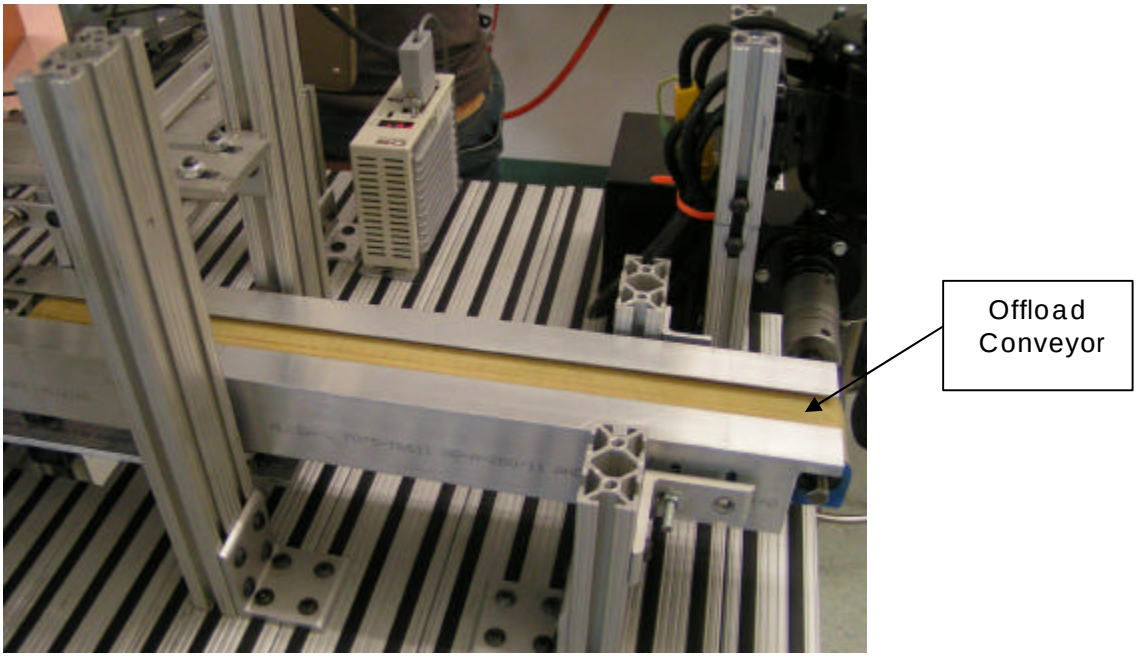



**Figure 2: End of Feed System**

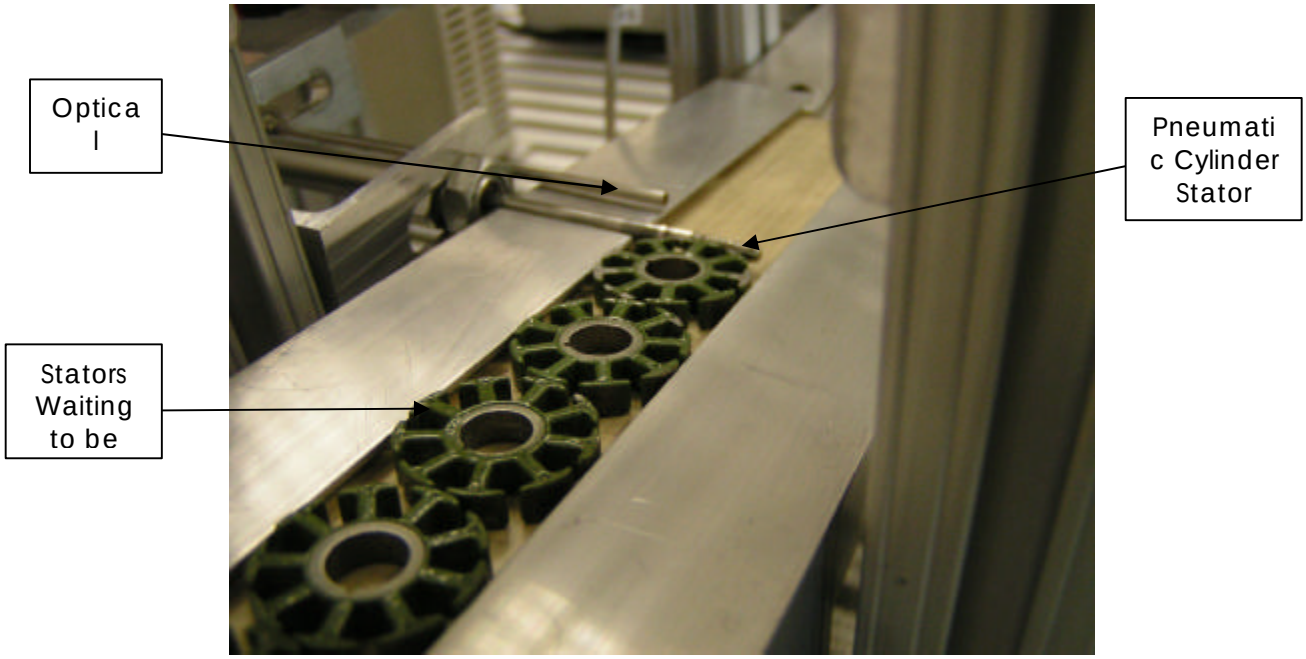



**Figure 3: Stators Halted on In Feed System**

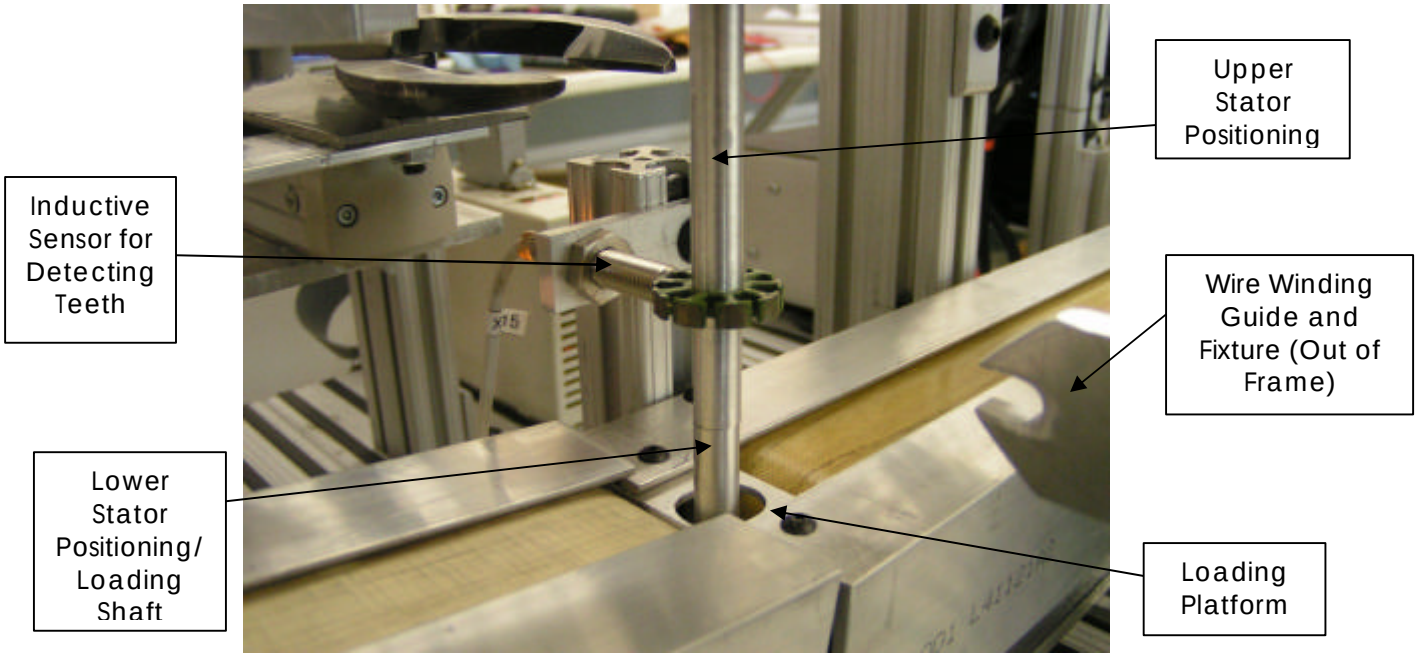



**Figure 4: Loader Holding Stator in Position**

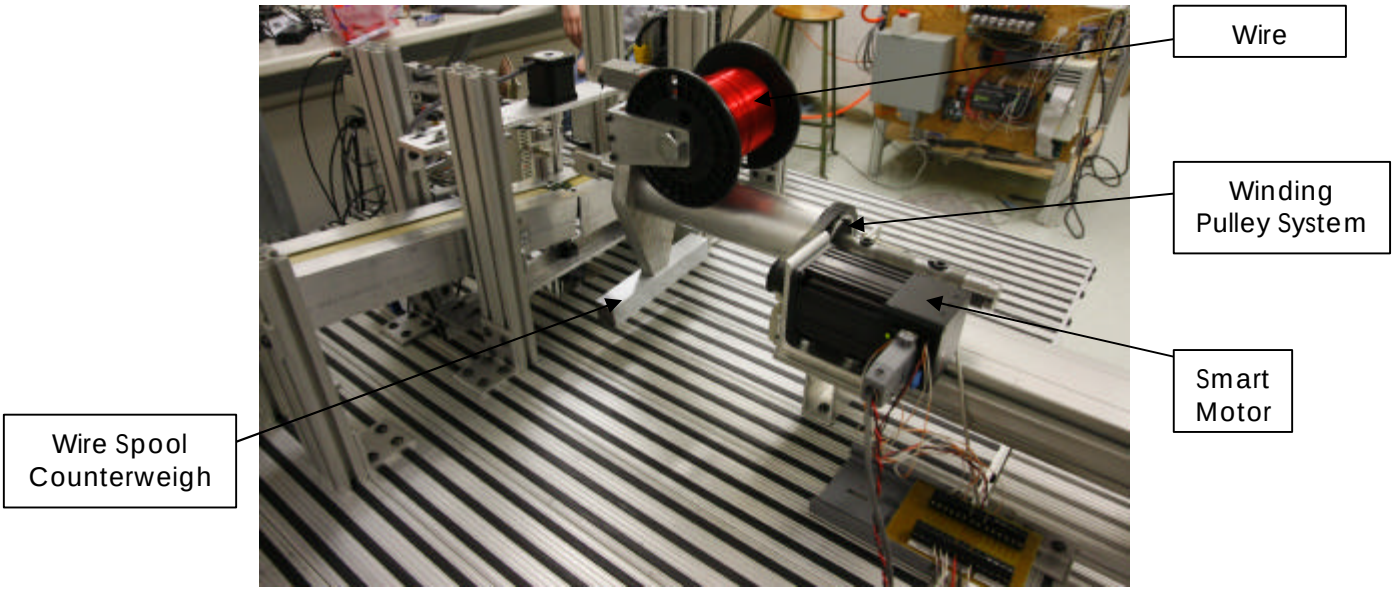



**Figure 5: Winding Fixture**

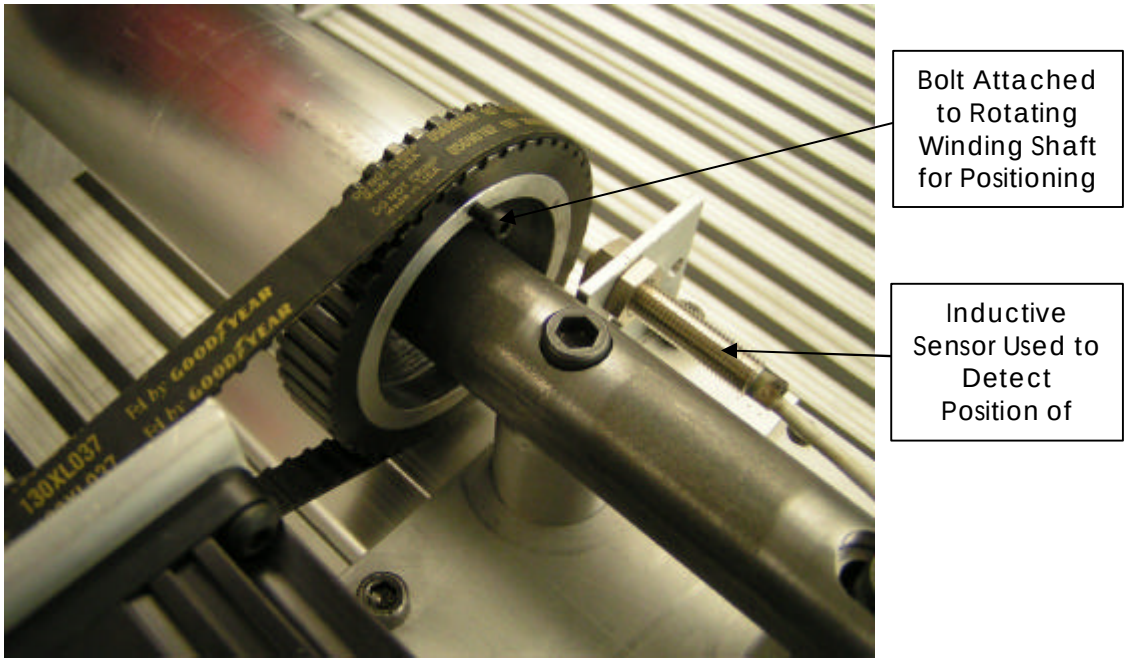



**Figure 6: End of Winding Fixture**

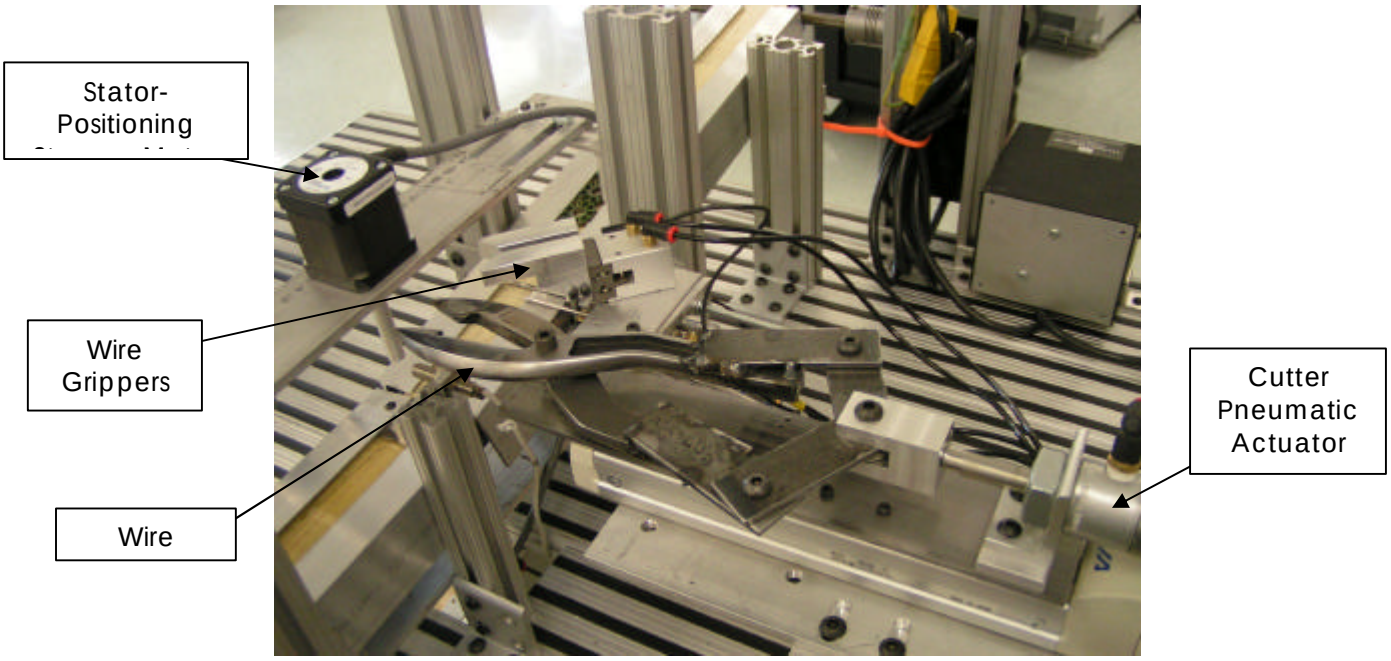



**Figure 7: Cutters and Grippers**

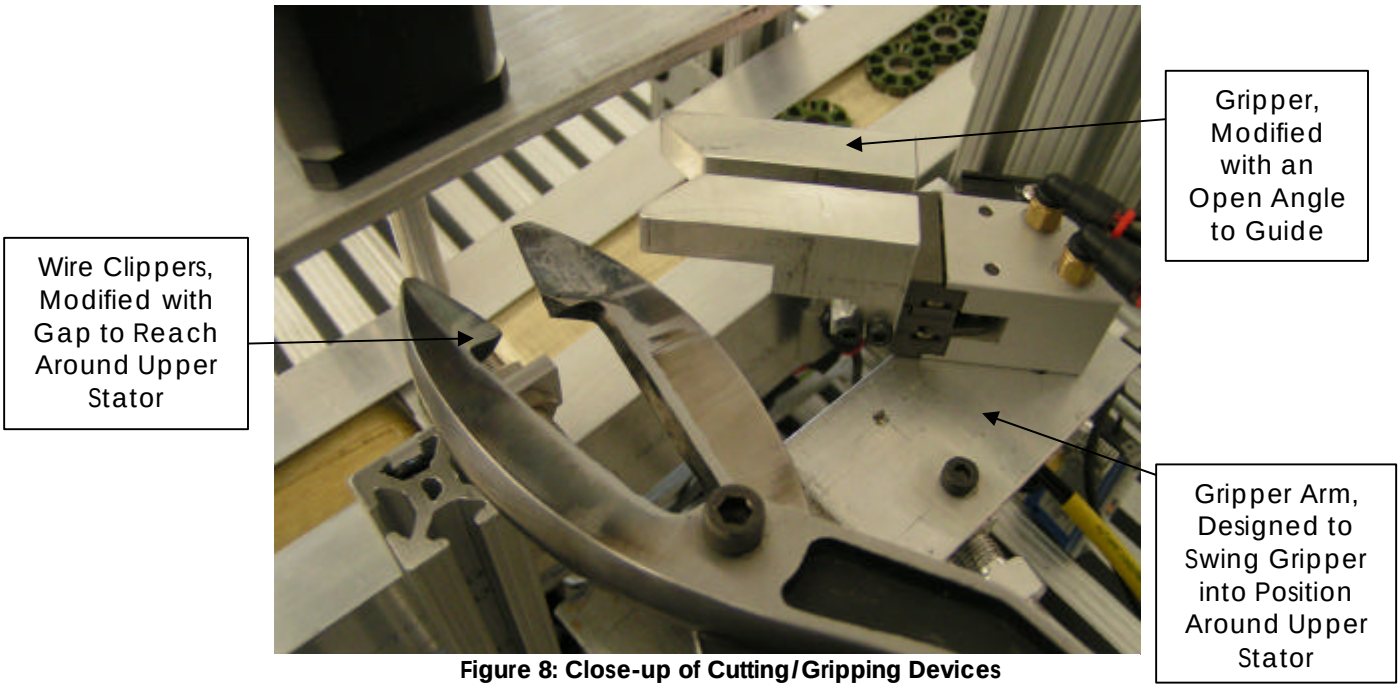
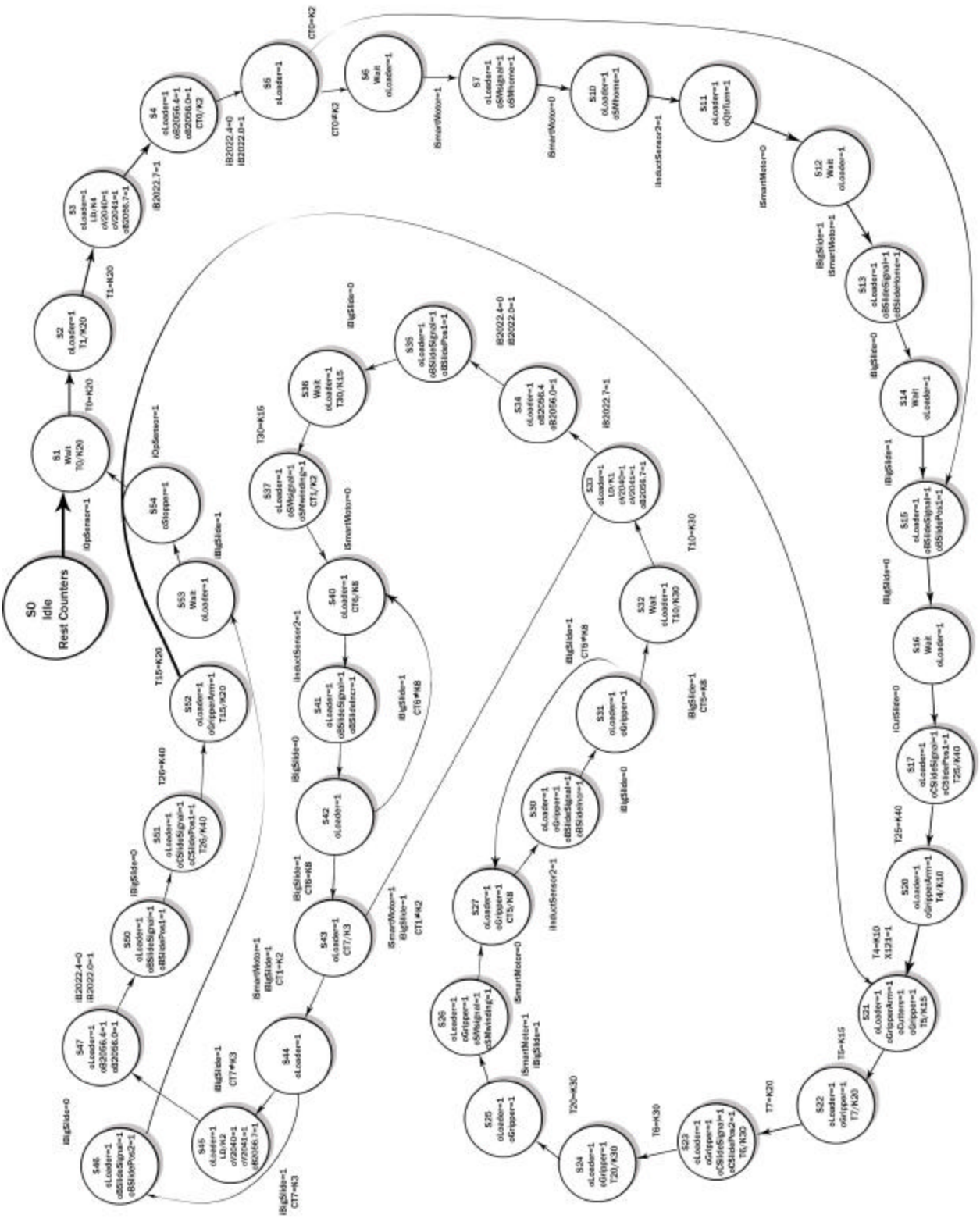



**Figure 8: Close-up of Cutting/Gripping Devices**

## State Machine Diagram



## State Machine Diagram (Continued…)

S0: Idle state – Waiting for stators
S1: Close stopper when stator enters
S2: Load stator for winding
S3: Home stator into position
S4: Continue homing stator
S5: Skip homing of SmartMotor and Big Slide after the first stator winding
S6: Wait state
S7: SmartMotor homing sequence
S10: Stop homing if inductive sensor is activated
S11: Do quarter turn
S12: Wait state
S13: Homing sequence of big slide
S14: Wait state
S15: Winding position of big slide
S16: Wait state
S17: Cutting position of cutter slide
S20: Bring in gripper arm and wait for manual feed of wire
S21: Close gripper and cutter
S22: Bring back gripper arm
S23: Bring back cutter slide
S24: Timer state
S25: Wait state
S26: Begin first winding
S27: Looping sequence of big slide
S30: Back up slide for every revolution
S31: If 8 revolutions are done, continue to next pole winding
S32: Wait state
S33: Rotate stator 120 degrees
S34: Continue rotating 120 degrees
S35: Bring big slide into position for winding
S36: Timer state
S37: Begin winding sequence of 2nd and 3rd poles
S40: Looping sequence of big slide
S41: Back up slide for every revolution
S42: If 8 revolutions are done, continue to next pole winding
S43: If third pole is wound, move to next phase winding
S44: If 3 phases are wound, move to end sequence
S45: Rotate stator for next phase winding
S46: Pull out winder before completed stator drops
S47: Continue rotating stator for next phase
S50: Winding position of big slide
S51: Cutting position of cutter slide
S52: Bring in gripper arm
S53: Drop complete stator
S54: Wait for next stator

The following section contains the PLC Ladder Logic for this machine using DirectSoft 5 Programming.

**Cutter Slide Program**

| Step | Command | Operand 1 | Operand 2 | Comment |
|---|---|---|---|---|
| 1 | BTOF | 302 | | Turn off input |
| 2 | SVON | 1 | | Turn on servo |
| 3 | ACC | 1 | | Set acceleration |
| 4 | VEL | 25 | | Set velocity |
| 5 | HOME | 1 | | Home |
| 6 | BTON | 302 | | Tell PLC READY |
| 7 | TAG | 1 | | Loop back point |
| 8 | WTON | 11 | | Wait for PLC |
| 9 | IN | 12 | 14 | Input bits |
| 10 | BTOF | 302 | | Tell PLC NOT READY |
| 11 | IFEQ | 99 | 1 | Pos 1 – Cutting |
| 12 | MOVP | 1 | | |
| 13 | EDIF | | | |
| 14 | IFEQ | 99 | 4 | Pos 2 – Pull Away |
| 15 | MOVP | 2 | | |
| 16 | EDIF | | | |
| 17 | BTON | 302 | | Tell PLC DONE |
| 18 | WTOF | 11 | | Be sure PLC saw |
| 19 | GOTO | 1 | | Loop to TAG1 |

**Cutter Slide Position Table**

| No. | Acceleration | Velocity | Axis |
|---|---|---|---|
| 1 | 1 | 100 | 65 |
| 2 | 1 | 20 | 10 |

**Winder Slide Program**

| Step | Command | Operand 1 | Operand 2 | Comment |
|---|---|---|---|---|
| 1 | BTOF | 302 | | Turn Off input |
| 2 | SVON | 1 | | Turn on servo |
| 3 | ACC | 1 | | Set acceleration |
| 4 | VEL | 25 | | Set velocity |
| 5 | BTON | 302 | | Tell PLC READY |
| 6 | TAG | 1 | | Loop back point |
| 7 | WTON | 15 | | Wait for PLC |
| 8 | IN | 16 | 18 | Input bits |
| 9 | BTOF | 302 | | Tell PLC NOT READY |
| 10 | IFEQ | 99 | 1 | Home |
| 11 | HOME | 1 | | |
| 12 | EDIF | | | |
| 13 | IFEQ | 99 | 2 | Pos 1 – Winding |
| 14 | MOVP | 1 | | |
| 15 | EDIF | | | |
| 16 | IFEQ | 99 | 3 | Pos 2 – Increment back |
| 17 | MOVP | 3 | | |
| 18 | EDIF | | | |
| 19 | IFEQ | 99 | 4 | Pos 3 – Pull Away |
| 20 | MVPI | 2 | | |
| 21 | EDIF | | | |
| 22 | BTON | 302 | | Tell PLC DONE |
| 23 | WTOF | 15 | | Be sure PLC saw |
| 24 | GOTO | 1 | | Loop to TAG1 |

**Winder Slide Position Table**

| No. | Acceleration | Velocity | Axis |
|---|---|---|---|
| 1 | 1 | 200 | 175 |
| 2 | 1 | 50 | -0.460 |
| 3 | 1 | 200 | 155 |

```
‘Declare variables

UAO ‘READY signal to PLC
UBI ‘Trigger input
UCI ‘input #1
UEI ‘input #2

‘Setting tuning parameters

KP=250
KI=28
KD=200
KL=20
KS=10
KV=0
KA=0
KG=0
F

‘Loop infinitely
WHILE 1

‘Loop back point
C1

‘Signal PLC READY
UA=A

   ‘loop until B signal
   WHILE UBI==0 LOOP

   c=UCI
   d=UEI*2
   e=c+d

‘e=1 – Y11
‘e=2 – Y12
‘e=3 – Y11+Y12

   ‘homing’
   ’------‘
   ‘do one full revolution
   IF e==1
         UA=0
         A=50
         V=5000
         D=6285
         G

         ‘while doing revolution
         WHILE Bt

               ‘stop if inductor sees
               IF UEI
                     UA=0
                     S
                     O=0
                     V=8000
                     P=1670
                     G
                     TWAIT
                     BREAK
```

## Smart Motor Program (Continued…)

```
    ENDIF
          LOOP
    ENDIF


    ‘8 rotations’
    ’-----------’
    IF e==3
    UA=0
          A=25
          V=100000
          D=50286
          G
          TWAIT
          BREAK
    ENDIF

    ‘Wait for next signal
    WHILE UBI==1 LOOP
    UA=1

LOOP
GOTO1
END
```

| Profile | 60 Degree Rotation | Phase Rotation |
|---|---|---|
| **Curve** | S-curve | S-curve |
| **Total Pulses** | 3333 | 1111 |
| **Start Frequency** | 40 Hz | 40 Hz |
| **Position Frequency** | 4000 Hz | 4000 Hz |
| **End Frequency** | 40 Hz | 40 Hz |
| **Acceleration Time** | 500 ms | 300 ms |
| **Deceleration Time** | 500 ms | 300 ms |

| Profile | Homing sequence |
|---|---|
| **Type** | Run to limit @ frequency 1 |
| **Frequency** | 1000 Hz |
| **Limit** | Ch1C |
| **Event** | Rising Edge |

*Configured at 10000 pulses/per revolution

| Wiring Diagram | | | |
|---|---|---|---|
| | **COMMON NAME** | **PLC OUTPUT** | **PLC INPUT** |
| **PNUEMATIC CYLINDERS** | WIRE CLIPPERS | $Y_0$ | |
| | STOPPER | $Y_1$ | |
| | LOADER | $Y_2$ | |
| | GRIPPER ARM | $Y_3$ | |
| | GRIPPER | $Y_{13}$ | |
| **SEL CONTROLLER** | PORT 015 | $Y_4$ | |
| | PORT 016 | $Y_5$ | |
| | PORT 017 | $Y_6$ | |
| | PORT 018 | $Y_7$ | |
| | PORT 302 | | $X_3$ |
| **SMART MOTOR** | PORT B | $Y_{10}$ | |
| | PORT C | $Y_{11}$ | |
| | PORT D | $Y_{12}$ | |
| | PORT A | | $X_4$ |
| **DS CONTROLLER** | PORT 011 | $Y_{14}$ | |
| | PORT 012 | $Y_{15}$ | |
| | PORT 013 | $Y_{16}$ | |
| | PORT 014 | $Y_{17}$ | |
| | PORT 302 | | $X_5$ |
| **SENSORS** | INDUCTIVE(conveyor) | | $X_0$ |
| | OPTICAL | | $X_1$ |
| | INDUCTIVE(winding) | | $X_2$ |