Brushless Motor Stator Winding Machine

Operations Manual

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1. Introduction

The following is a project completed as a requirement for a manufacturing engineering class from *Walla Walla University's Edward F. Cross School of Engineering*. The focus of this class was to become familiar with the design, fabrication, assembly, programming, wiring, testing, and documenting of an automated production machine. The project objective was to design and build the *2008 Model Brushless Outrunner Winding Machine*. The machine winds wire onto stators that are used in brushless motors, which are commonly used in remote controlled aircraft. The stators are from a brushless kit supplied by gobrushless.com.

2. Specifications

Stator

- 9 poles
- Outside Diameter: 22.7mm
- Inside Diameter: 8.0mm
- Thickness: 4.5mm
- Insulation: High-temp heavy epoxy coating
- 5-11 turns per pole

Machine

- 22 to 26 AWG enameled magnet wire
- Capable of specifying the number of wire turns per pole

3. Operation

3.1 Starting the Machine

1. Reset the big red E-Stop button by twisting it and wait until the linear slides finish homing.

2. Press the black "go" button and wait for the red light to turn on.

3.2 Loading the Machine

When the red light illuminates, do the following:

1. Load stators onto the track so they line up behind the air cylinder gate.

2. Position the wire between the jaws of the gripper. For maximum grip, place it near the rear of the jaws. To avoid injury, do not put any part of your body between the jaws of the gripper. To close the jaws and resume machine operation, press the black "go" button.

3.3 Finishing Winding Sequence

1. Once the pole has been wound the machine will stop. When this happens, flip the toggle switch X120 on the PLC. This initiates the cutting operation. After the wire is cut, the machine will eject the stator.

2. Push the E-Stop button to reset the machine.

3.4 Clearing Jams

If a jam occurs, press the red E-Stop button to deactivate the linear sliders, motors, and air cylinders. Carefully remove the jammed part, then start the machine as normal.

3.5 Specifying the Number of Turns per Pole

1. Enter the desired number of turns per pole into the following formula to calculate the number of steps per pole.

   $S = 4290*(t - 1)$, where S = steps per pole and t = turns per pole

2. Open the Smartmotor program SMI.sms and enter the number of steps per pole in the first "if" statement under "c1".

3. Write the program to the Smartmotor.

4. Start operation as normal.

4. Major Section Operations

4.1 Loading and Ejecting System

The loading and ejecting system is completely gravity fed. The stators slide from the beginning of the track and are singulated by the air cylinder gate system. They then slide into position to be picked up by the stator shaft. After winding, the ejector removes the stator from the shaft as it moves down. There

are no controlled parts involved in the ejection process. The beauty of this system lies in its utter simplicity.

4.2 Stator Positioning System

The stator shaft picks up the stator from the track and positions it translationally by coupling the upper and lower parts of the shaft together with the stator in between. To position the stator rotationally, the lower part of the shaft is turned by a stepper motor. An inductive sensor senses the poles of the stator and tells the motor to stop turning when they are in the correct position.

The stators are wound using three phases. Since the stators have 9 poles, there will be 3 teeth per phase. Each phase will be wound one at a time. Thus 3 teeth will be wound, then the wire will be cut and the next 3 teeth will be wound and so on until all three phases are complete.

4.3 Stator Winding System

The winding system uses a smart motor to turn a shaft that is connected to the winder arm. The shaft is hollow so the wire can be fed through it. At the beginning of the winding sequence, the winder arm is positioned near the grabber which holds the end of the wire. The winder then makes one revolution slowly, then speeds up and completes the rest of the revolutions. The stator shield deflects the wire around certain parts of the stator so it can be wound around one pole at a time. As the wire is wound, it pushes the previous turn toward the back of the pole. This system works well when the turns can be positioned in a single layer. However, after the first layer is filled, it tends to stack successive turns near the front of the pole.

4.4 Wire Tensioning System

In order to wind the stator correctly, there needs to be tension on the wire. This machine uses a tensioning system that applies even tension and takes up any slack that may be in the wire. The tensioning system uses a compression spring that presses a friction disk against a metal surface to resist the turning of the spool and thus provide tension. It also uses a torsion spring to remove any slack from the wire. This system works, but to perform optimally, the machine needs a controllable variable tension system.

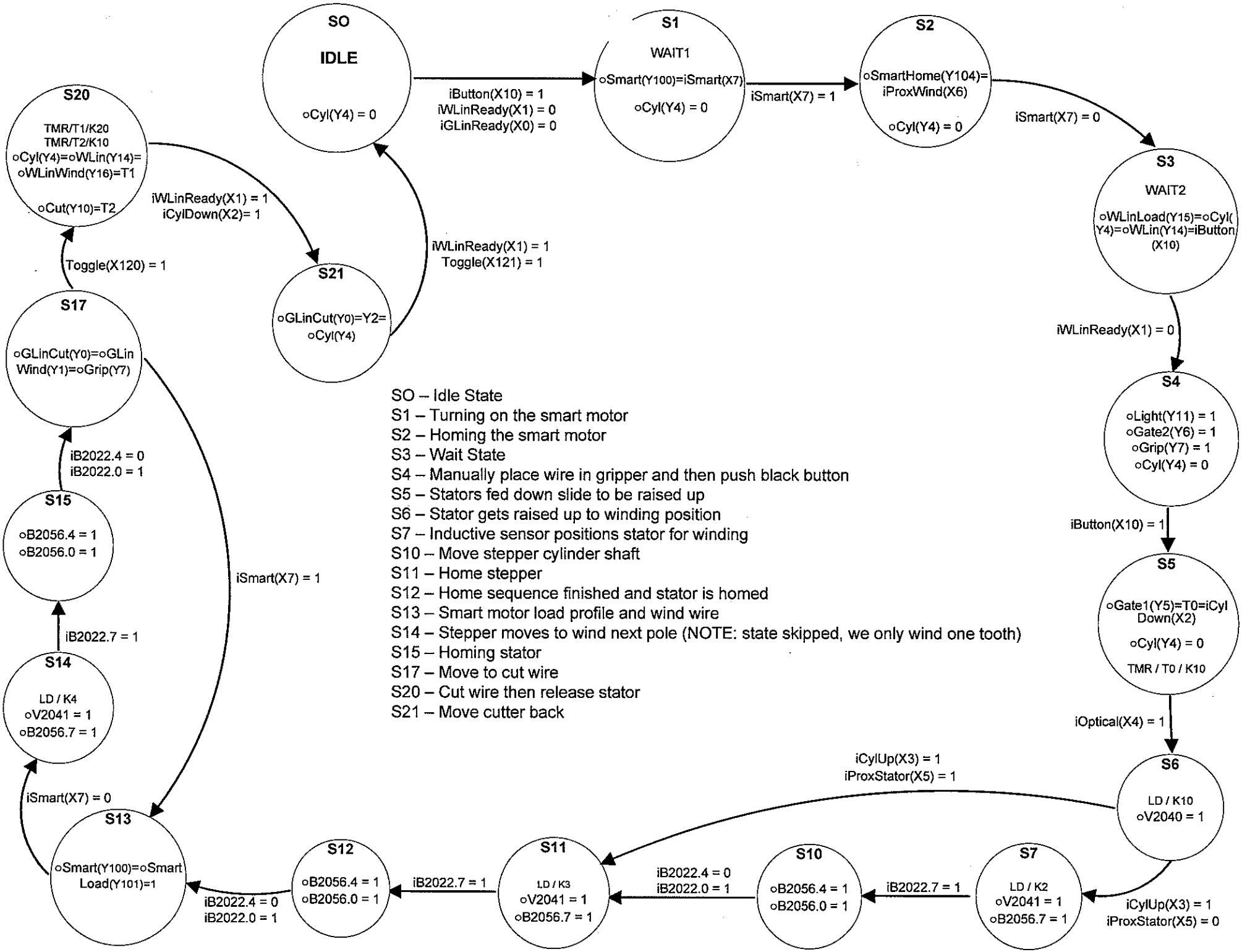
Suggestions for Future Improvements

There are some areas of this machine that could use improvement.

1. One of the issues with this machine is its ability to wind multiple poles with the same section of wire. After a pole is wound, the stepper motor tries to turn the stator to position another pole for winding. The problem is that in order to keep the wire tails out of the winder arm's way, the gripper must keep holding them. But the gripper holding the wire tails inadvertently keeps the stator from turning.

2. The gripper/cutter assembly can't move forward far enough to actually cut the wire because the gripper jaws interfere with the winder arm. This could easily be fixed with some modification of the jaws.

3. The stator shield sometimes malfunctions and causes the wire not slip into the space between the poles. This might be fixed by modifying the geometry of the stator shield. Being able to control the tension on the wire would also help.

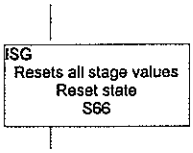


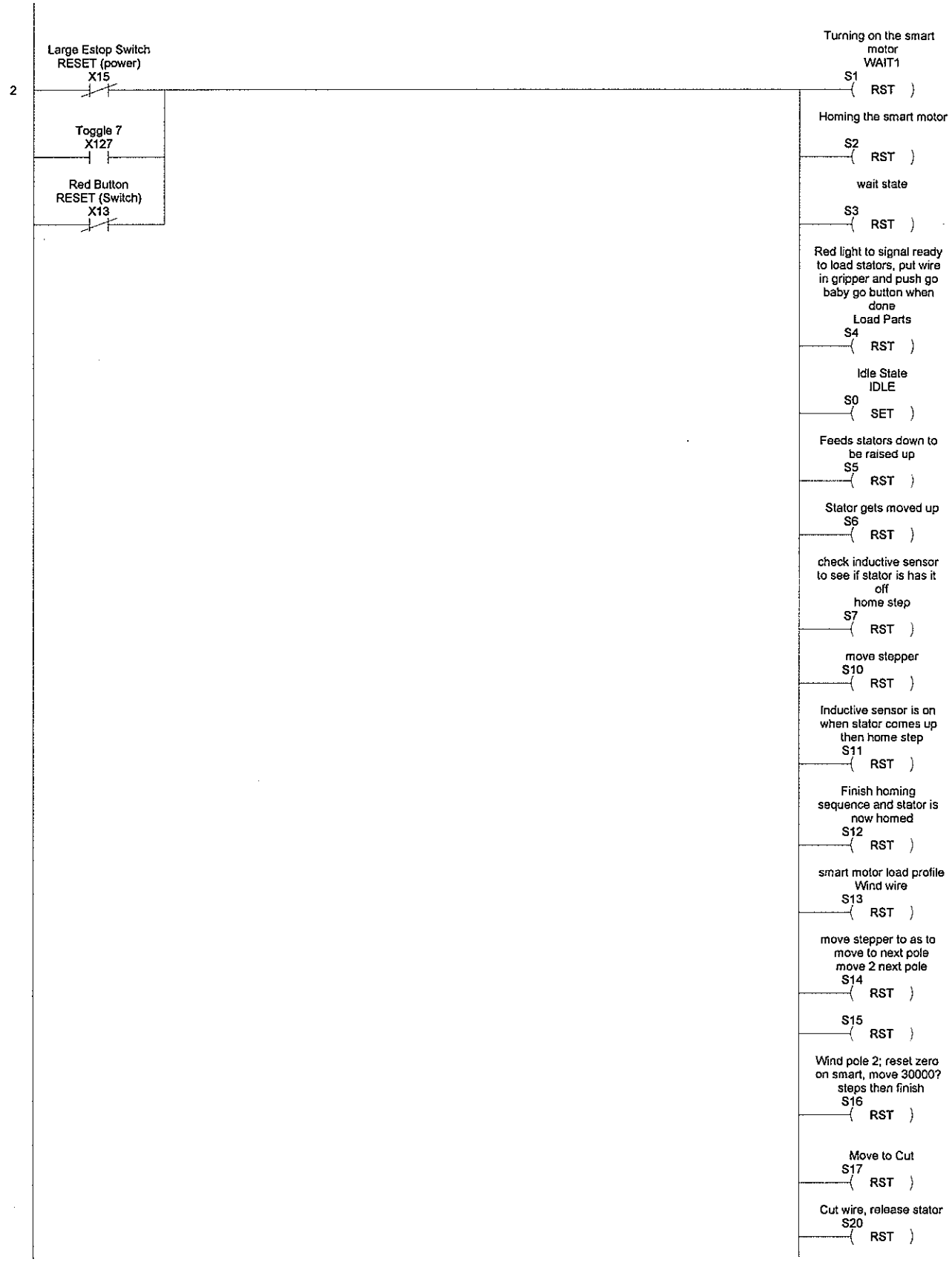
SO – Idle State
S1 – Turning on the smart motor
S2 – Homing the smart motor
S3 – Wait State
S4 – Manually place wire in gripper and then push black button
S5 – Stators fed down slide to be raised up
S6 – Stator gets raised up to winding position
S7 – Inductive sensor positions stator for winding
S10 – Move stepper cylinder shaft
S11 – Home stepper
S12 – Home sequence finished and stator is homed
S13 – Smart motor load profile and wind wire
S14 – Stepper moves to wind next pole (NOTE: state skipped, we only wind one tooth)
S15 – Homing stator
S17 – Move to cut wire
S20 – Cut wire then release stator
S21 – Move cutter back

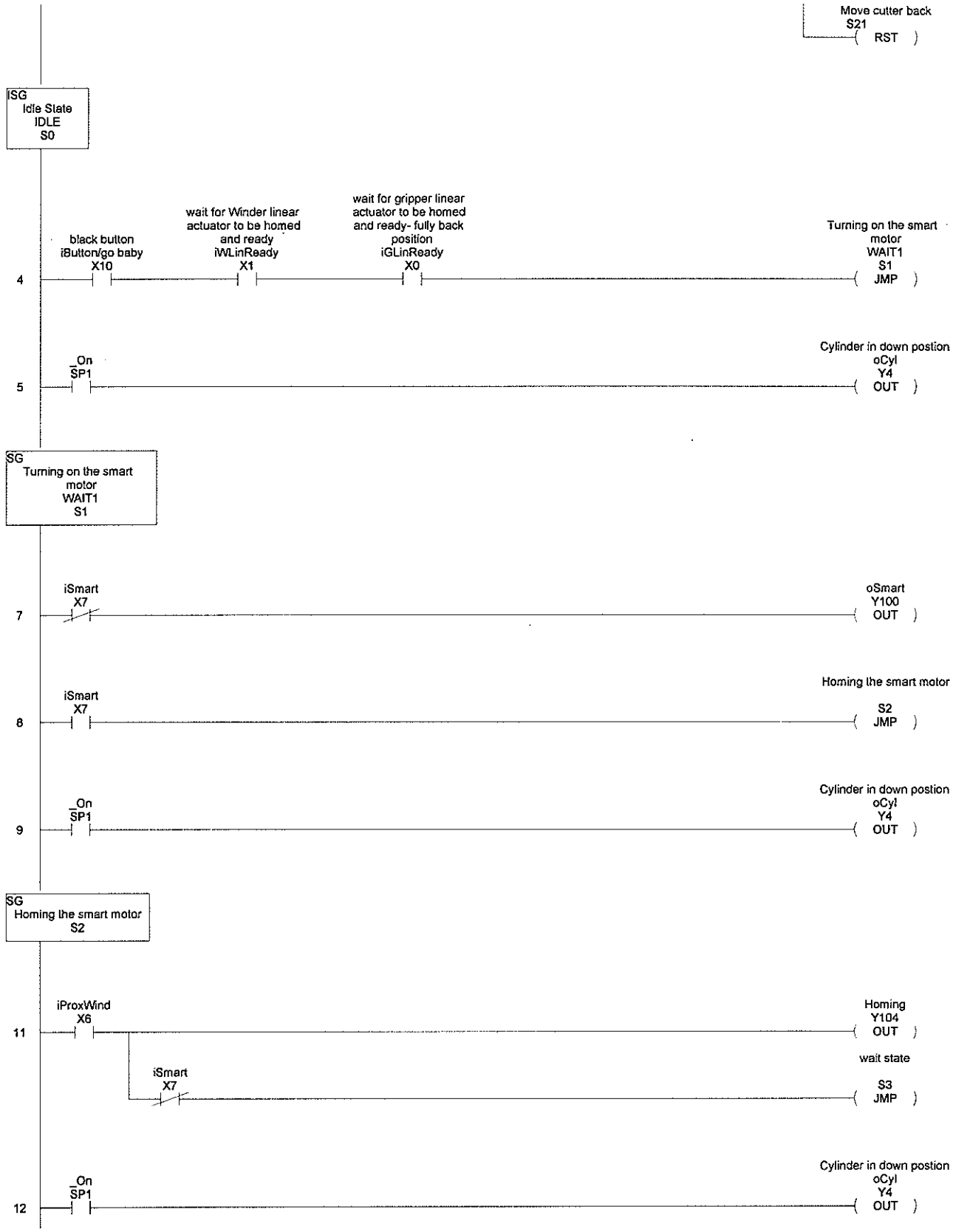
WIRING TABLE

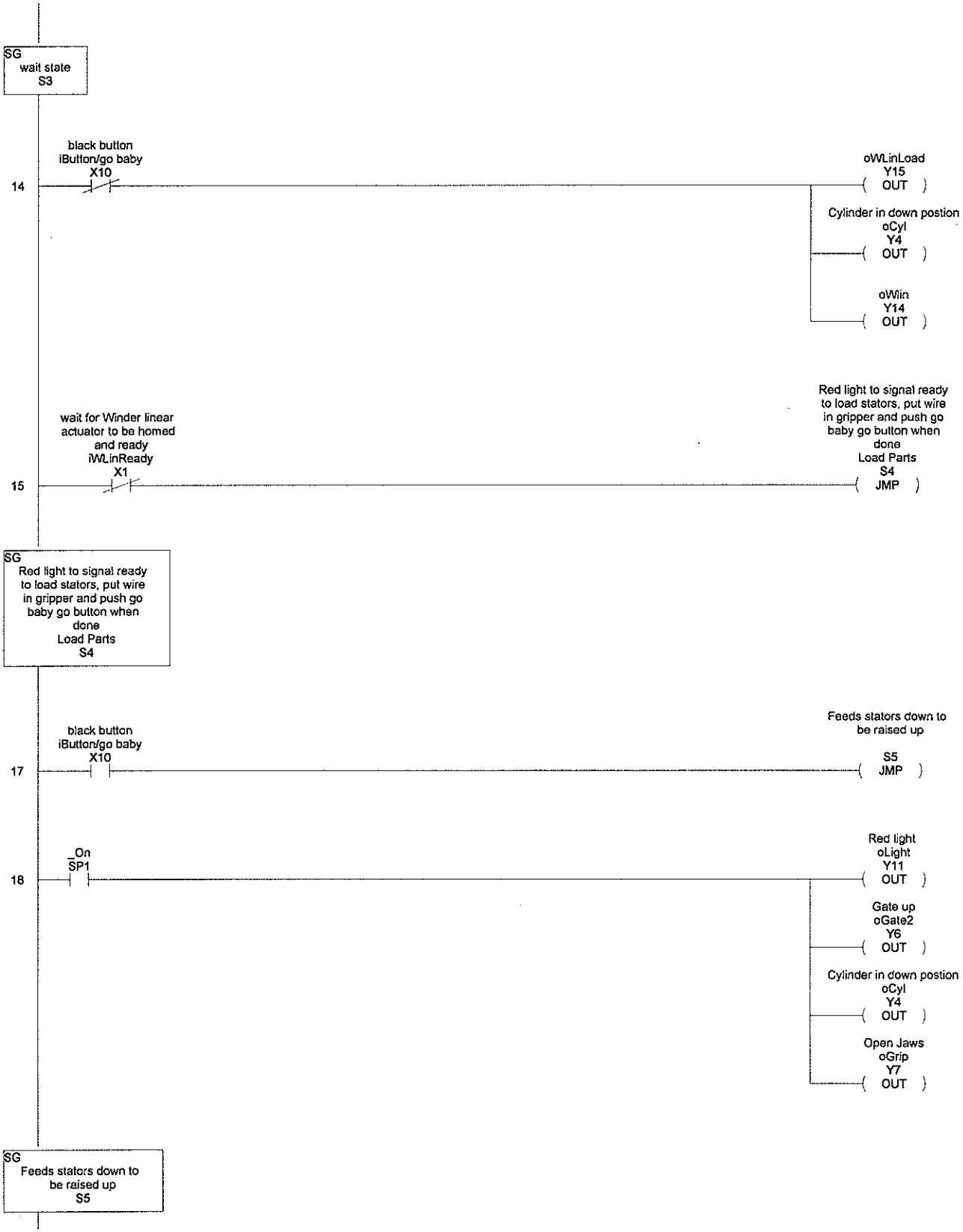
	PLC Input (X)	PLC Output (Y)	Unit's Address	Unit's IO/Action	Inputs(i) & Outputs($_o$)	Wire Color/ Comments	From	To
IAI Slider								
Cutter/Gripper Linear Actuator		Y0	011	IN	$_o$GLinCut	Blue dot	DS Controller	PLC
		Y1	012	IN	$_o$GLinWind	White dot	DS Controller	PLC
		Y2	013	IN		Blue	DS Controller	PLC
		Y3	014	IN		White	DS Controller	PLC
	X0		302	OUT	iGLinReady	white/purple	PLC	DS Controller
Sensor (magnetic)								
Main Cyclinder Position (Magnetic)	X2			DN	iCylDown	Orange	Sensor	PLC
	X3			UP	iCylUp	Yellow	Sensor	PLC
Sensors (proximity & optical)								
Stator Position (Optical)	X4				iOptical	Senses if stator is ready to be lifted to winding position	Sensor	PLC
Stator Rotation Position (Inductive)	X5		C	IN	iProxStator	Senses stator tooth position	Sensor	PLC
Winder Shaft Position (Inductive)	X6				iProxWind	Senses home pos for winder	Sensor	PLC
Pneumatic Cylinders/Valves								
Main Cylinder Position		Y4		DN	$_o$Cyl	Defalt position for cylinder is Down	PLC	Solenoid
Gate 1		Y5		Open	$_o$Gate1		PLC	Solenoid
Gate 2		Y6		Open	$_o$Gate2		PLC	Solenoid
Gripper		Y7		Open	$_o$Grip		PLC	Solenoid
C utter		Y10		Cut	$_o$Cut		PLC	Solenoid
IAI Slider								
Winder Linear Actuator		Y14	011	IN	$_o$Wlin		SEL Controller	PLC
		Y15	012	IN	$_o$WLinLoad		SEL Controller	PLC
		Y16	013	IN	$_o$WLinWind		SEL Controller	PLC
		Y17	014	IN			SEL Controller	PLC
	X1		302	OUT	iWLinReady		PLC	SEL Controller

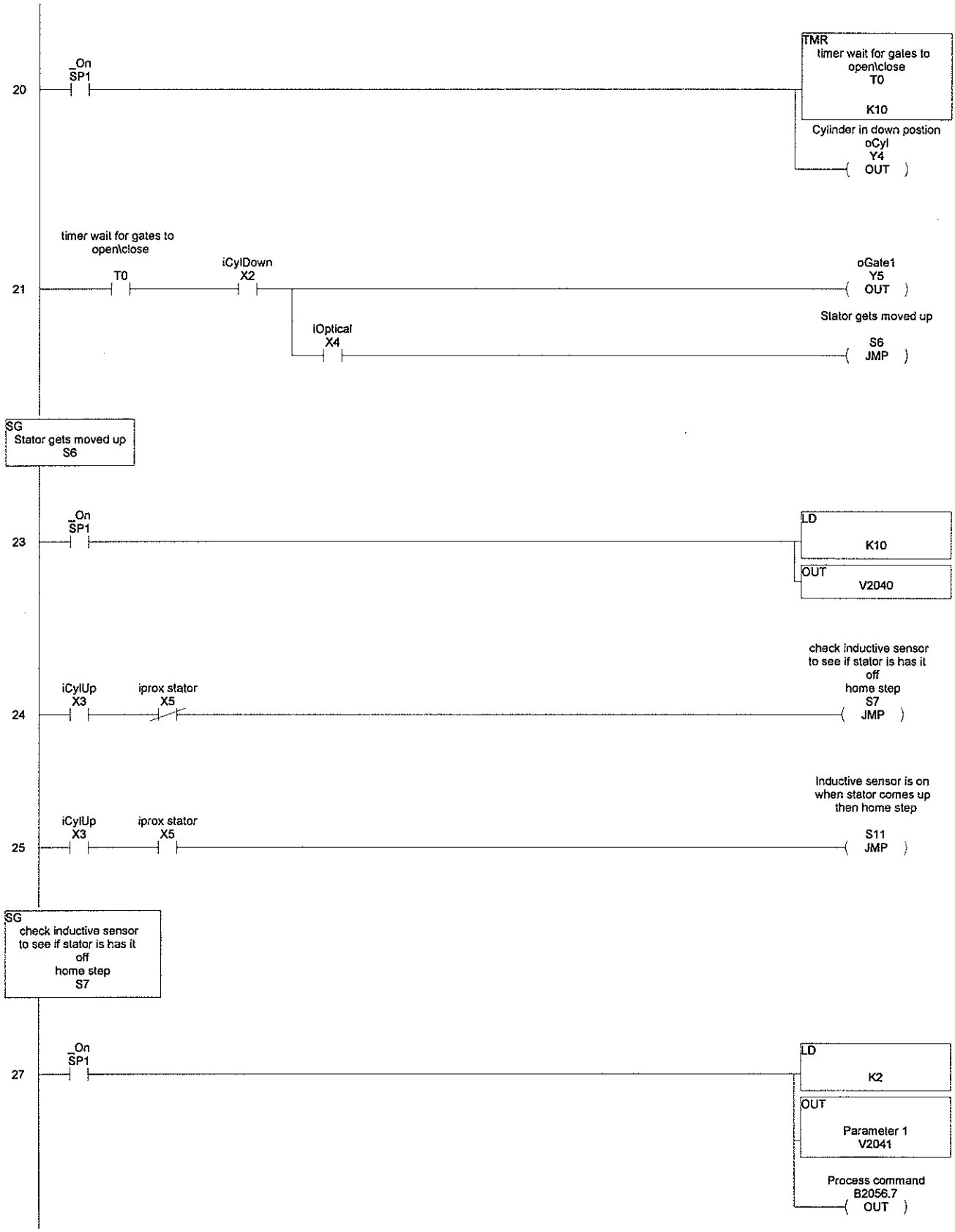
Motors								
Smart Motor	X7		A	OU.	iSmart		PLC	Smart Motor
		Y100	B	IN	oSmart	white/purple	Smart Motor Board	PLC
		Y101	C	IN	oSmartLoad	Yellow	Smart Motor Board	PLC
		Y102	D	IN	oSmartWind	Orange	Smart Motor Board	PLC
		Y103	E	IN	oSmartCut	white/purple	Smart Motor Board	PLC
		Y104	F	IN	Homing	Yellow	Smart Motor Board	PLC
		Y105	G	IN	(not used)	Orange	Smart Motor Board	PLC
Sure Step Motor			C	IN	iProxStator		Sure Step Control Board	PLC
Light		Y11			oLight		Light	PLC
Button (black button)	X10				iButton		Black Button	PLC
Reset (power on) (red button)	X15						Red Button	PLC
Reset Switch	X13						Switch	PLC
Toggle Switch	X120				Toggle		Switch	PLC

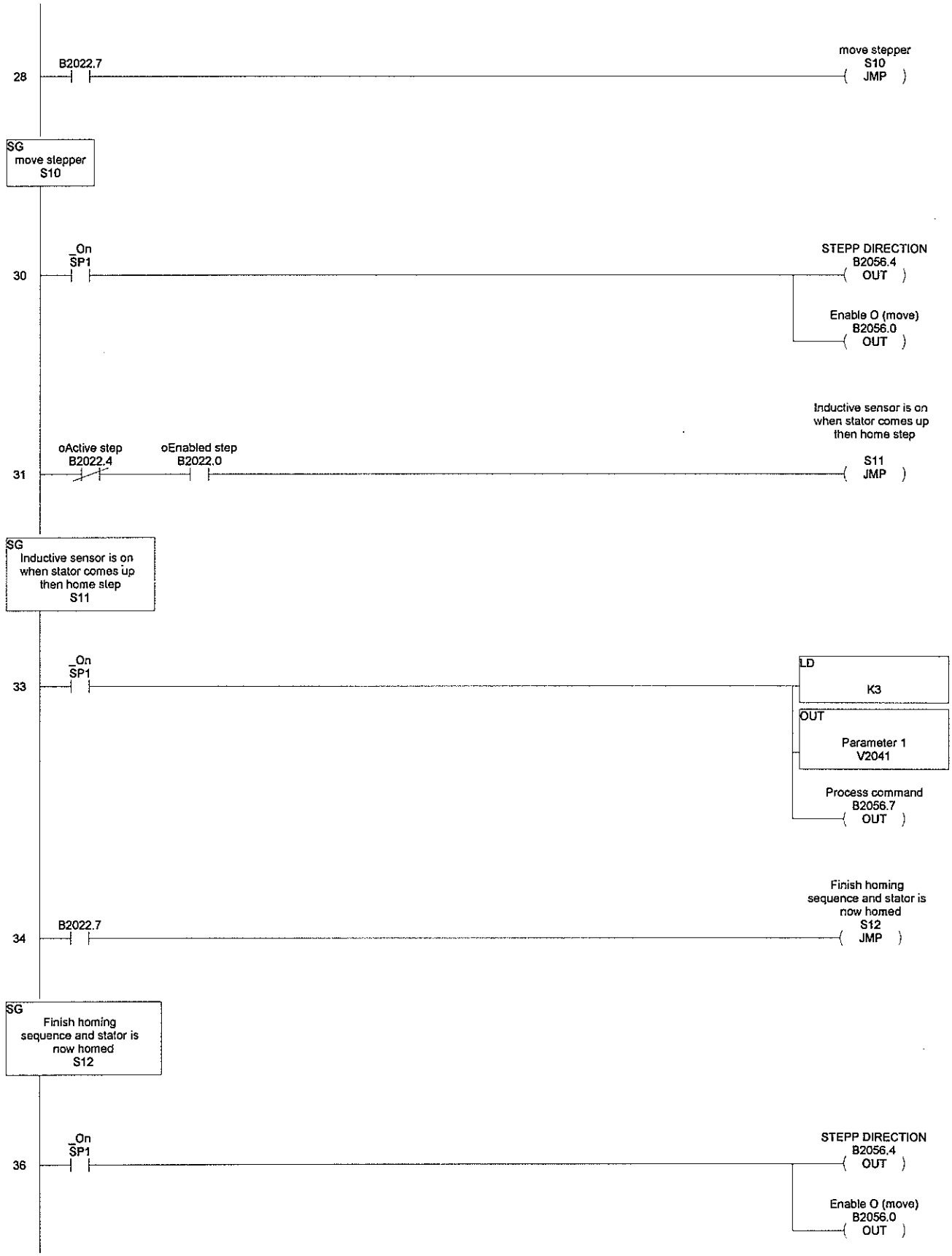

ISG
Resets all stage values
Reset state
S66

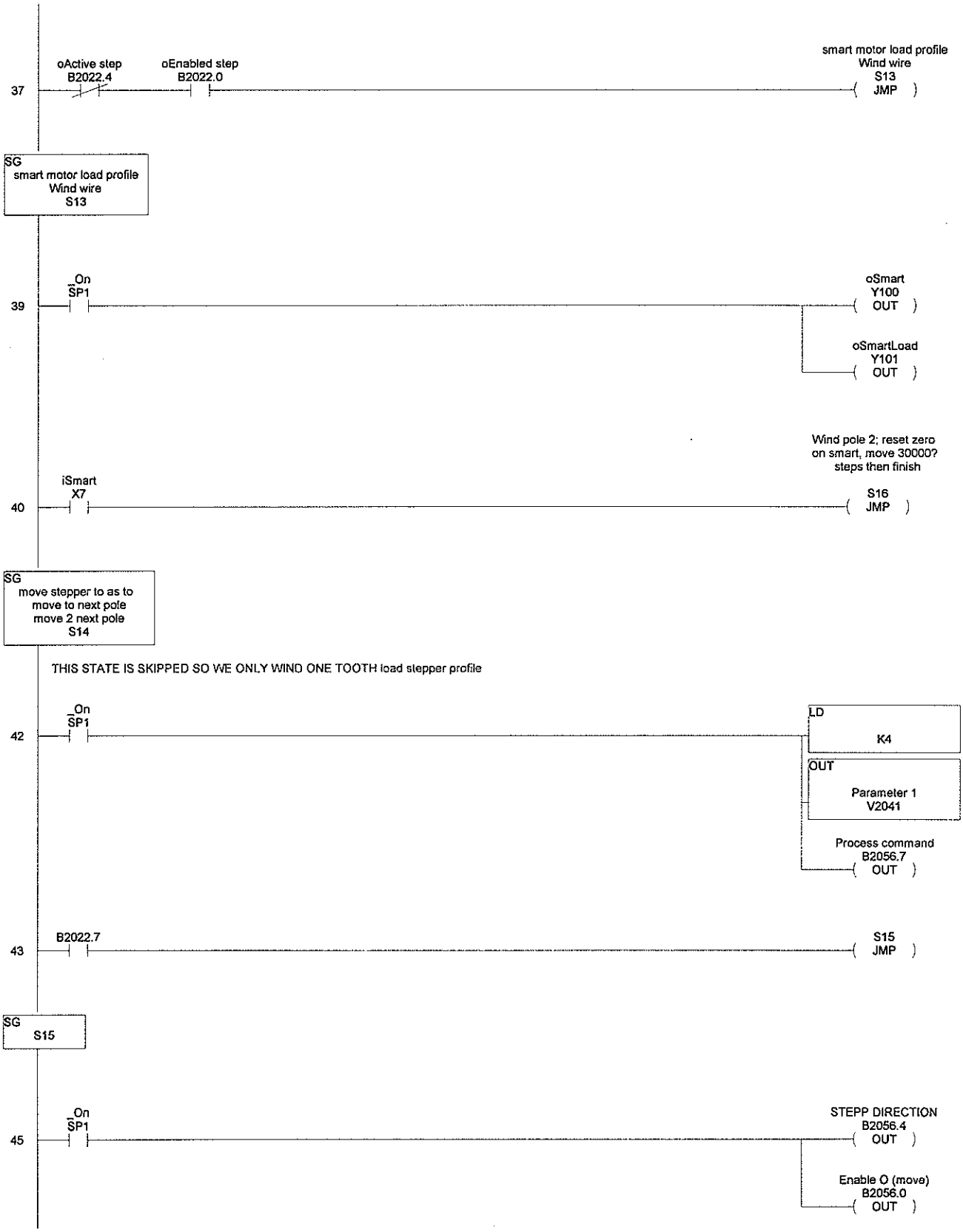

2
Large Estop Switch
RESET (power)
X15
Toggle 7
X127
Red Button
RESET (Switch)
X13
Turning on the smart motor
WAIT1
S1
RST
Homing the smart motor
S2
RST
wait state
S3
RST
Red light to signal ready to load stators, put wire in gripper and push go baby go button when done
Load Parts
S4
RST
Idle State
IDLE
S0
SET
Feeds stators down to be raised up
S5
RST
Stator gets moved up
S6
RST
check inductive sensor to see if stator is has it off
home step
S7
RST
move stepper
S10
RST
Inductive sensor is on when stator comes up then home step
S11
RST
Finish homing sequence and stator is now homed
S12
RST
smart motor load profile
Wind wire
S13
RST
move stepper to as to move to next pole
move 2 next pole
S14
RST
S15
RST
Wind pole 2; reset zero on smart, move 30000? steps then finish
S16
RST
Move to Cut
S17
RST
Cut wire, release stator
S20
RST

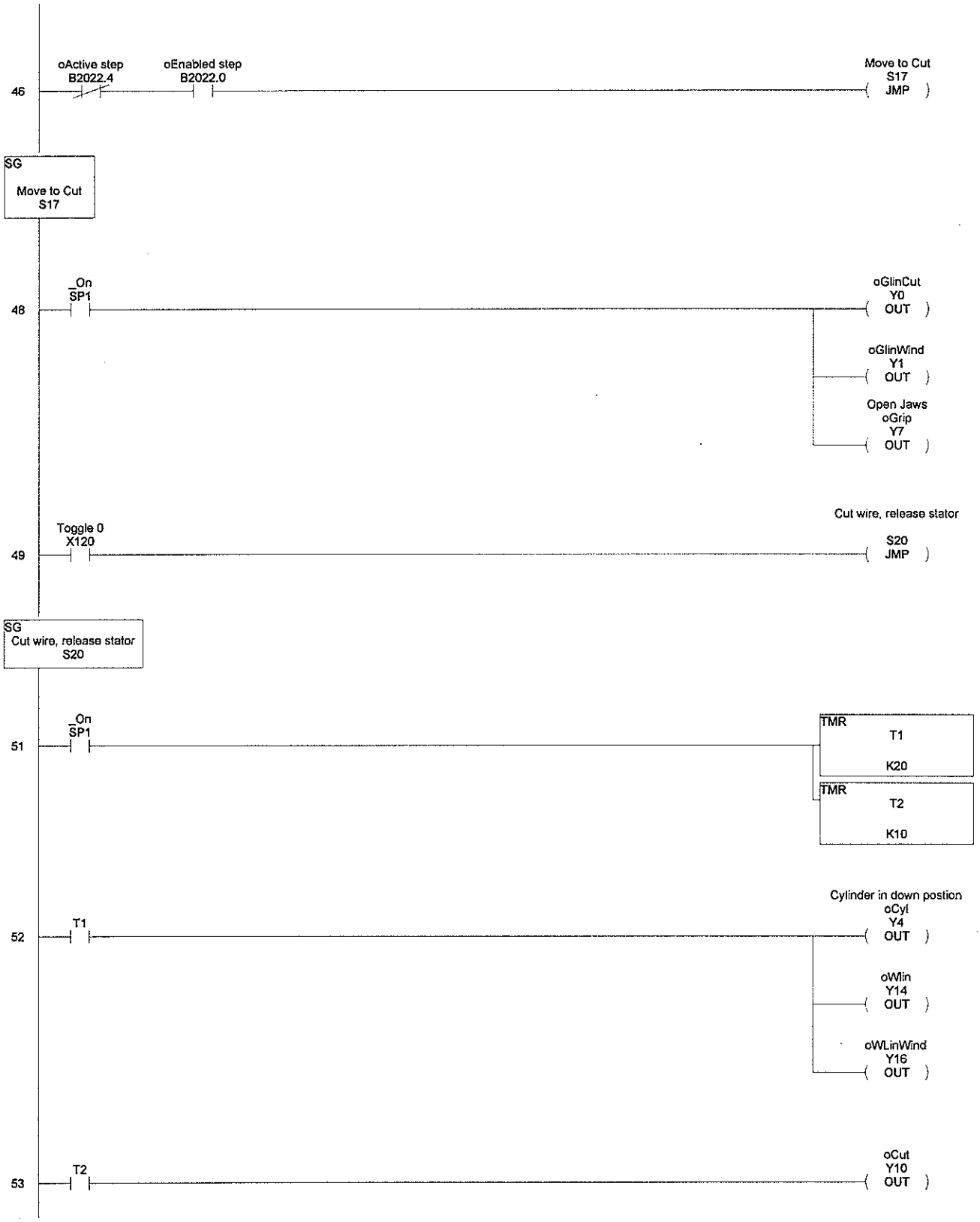

Move cutter back
S21
RST
ISG
Idle State
IDLE
S0
black button
iButton/go baby
X10
wait for Winder linear actuator to be homed and ready
iWLinReady
X1
wait for gripper linear actuator to be homed and ready- fully back position
iGLinReady
X0
Turning on the smart motor
WAIT1
S1
JMP
4
_On
SP1
Cylinder in down postion
oCyl
Y4
OUT
5
SG
Turning on the smart motor
WAIT1
S1
iSmart
X7
oSmart
Y100
OUT
7
iSmart
X7
Homing the smart motor
S2
JMP
8
_On
SP1
Cylinder in down postion
oCyl
Y4
OUT
9
SG
Homing the smart motor
S2
iProxWind
X6
Homing
Y104
OUT
11
iSmart
X7
wait state
S3
JMP
_On
SP1
Cylinder in down postion
oCyl
Y4
OUT
12

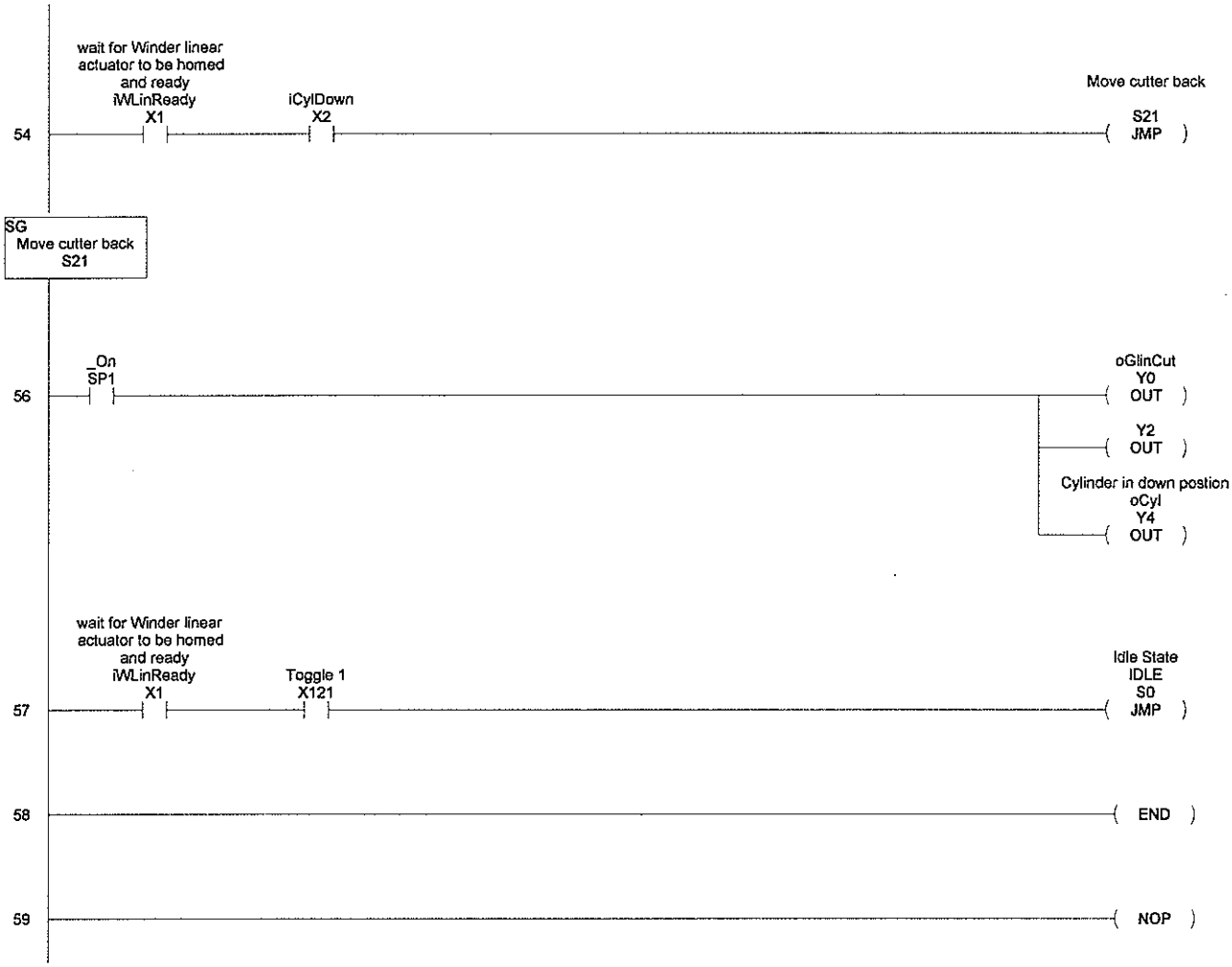

SG
wait state
S3
black button
iButton/go baby
X10
14
oWLinLoad
Y15
OUT
Cylinder in down postion
oCyl
Y4
OUT
oWin
Y14
OUT
wait for Winder linear
actuator to be homed
and ready
iWLinReady
X1
15
Red light to signal ready
to load stators, put wire
in gripper and push go
baby go button when
done
Load Parts
S4
JMP
SG
Red light to signal ready
to load stators, put wire
in gripper and push go
baby go button when
done
Load Parts
S4
black button
iButton/go baby
X10
17
Feeds stators down to
be raised up
S5
JMP
_On
SP1
18
Red light
oLight
Y11
OUT
Gate up
oGate2
Y6
OUT
Cylinder in down postion
oCyl
Y4
OUT
Open Jaws
oGrip
Y7
OUT
SG
Feeds stators down to
be raised up
S5


20
_On
SP1
TMR
timer wait for gates to open\close
T0
K10
Cylinder in down postion
oCyl
Y4
OUT
timer wait for gates to open\close
T0
21
iCylDown
X2
oGate1
Y5
OUT
Stator gets moved up
iOptical
X4
S6
JMP
SG
Stator gets moved up
S6
23
_On
SP1
LD
K10
OUT
V2040
check inductive sensor to see if stator is has it off home step
S7
24
iCylUp
X3
iprox stator
X5
JMP
Inductive sensor is on when stator comes up then home step
25
iCylUp
X3
iprox stator
X5
S11
JMP
SG
check inductive sensor to see if stator is has it off home step
S7
27
_On
SP1
LD
K2
OUT
Parameter 1
V2041
Process command
B2056.7
OUT


28
B2022.7
move stepper
S10
JMP
SG
move stepper
S10
30
On
SP1
STEPP DIRECTION
B2056.4
OUT
Enable O (move)
B2056.0
OUT
Inductive sensor is on
when stator comes up
then home step
31
oActive step
B2022.4
oEnabled step
B2022.0
S11
JMP
SG
Inductive sensor is on
when stator comes up
then home step
S11
33
On
SP1
LD
K3
OUT
Parameter 1
V2041
Process command
B2056.7
OUT
Finish homing
sequence and stator is
now homed
34
B2022.7
S12
JMP
SG
Finish homing
sequence and stator is
now homed
S12
36
On
SP1
STEPP DIRECTION
B2056.4
OUT
Enable O (move)
B2056.0
OUT


37
oActive step
B2022.4
oEnabled step
B2022.0
smart motor load profile
Wind wire
S13
JMP
SG
smart motor load profile
Wind wire
S13
39
_On
SP1
oSmart
Y100
OUT
oSmartLoad
Y101
OUT
Wind pole 2; reset zero
on smart, move 30000?
steps then finish
40
iSmart
X7
S16
JMP
SG
move stepper to as to
move to next pole
move 2 next pole
S14
THIS STATE IS SKIPPED SO WE ONLY WIND ONE TOOTH load stepper profile
42
_On
SP1
LD
K4
OUT
Parameter 1
V2041
Process command
B2056.7
OUT
43
B2022.7
S15
JMP
SG
S15
45
_On
SP1
STEPP DIRECTION
B2056.4
OUT
Enable O (move)
B2056.0
OUT


oActive step
B2022.4
oEnabled step
B2022.0
Move to Cut
S17
JMP
46
SG
Move to Cut
S17
_On
SP1
48
oGlinCut
Y0
OUT
oGlinWind
Y1
OUT
Open Jaws
oGrip
Y7
OUT
Cut wire, release stator
S20
JMP
Toggle 0
X120
49
SG
Cut wire, release stator
S20
_On
SP1
51
TMR
T1
K20
TMR
T2
K10
Cylinder in down postion
oCyl
Y4
OUT
T1
52
oWin
Y14
OUT
oWLinWind
Y16
OUT
oCut
Y10
OUT
T2
53


wait for Winder linear actuator to be homed and ready
iWLinReady
X1
iCylDown
X2
Move cutter back
S21
JMP
54
SG
Move cutter back
S21
_On
SP1
56
oGlinCut
Y0
OUT
Y2
OUT
Cylinder in down postion
oCyl
Y4
OUT
wait for Winder linear actuator to be homed and ready
iWLinReady
X1
Toggle 1
X121
Idle State
IDLE
S0
JMP
57
58
END
59
NOP

Winder linear actuator

F:\WINDER\GLIN.PRG 06/11/08 18:08 06/11/08 19:32 P 1

Ns	Step	A/O	Cond	Cmnd	Operand 1	Operand 2	Pst	Comment
1	1			BTOF	302			Tell PLC not rdy
1	2			SVON	1			Servo on
1	3			ACC	1			Set Acceleration
1	4			VEL	100			Set Velocity
1	5			HOME	1			Go Home
1	6			BTON	302			Signal PLC ready
1	7	-------		TAG	1			Return for loop
1	8			WTON	011			Wait for PLC Go
1	9			IN	012	014		Read move # bits
1	10			BTOF	302			Signal PLC moving
2	11			IFEQ	99	1		Is 012 true?
2	12			MOVP	1			80 mm
2	13			BTOF	302			Extra handshaking
1	14			EDIF				
2	15			IFEQ	99	2		Is 013 true?
2	16			MOVP	2			10mm
2	17			BTOF	302			Extra handshaking
1	18			EDIF				
1	19			BTON	302			Tell PLC ready
1	20			WTOF	011			Be sure PLC saw it
1	21			GOTO	1			Repeat to Tag 1

Gripper Linear Actuator

C:\SELWIN\HWINSLD.PRG 06/11/08 18:16 06/11/08 19:31 P 1

Ns	Step	A/O	Cond	Cmnd	Operand 1	Operand 2	Pst	Comment
1	1			BTOF	302			Tell PLC not rdy
1	2			SVON	1			Servo on
1	3			ACC	1			Set Acceleration
1	4			VEL	100			Set Velocity
1	5			HOME	1			Go Home
1	6			BTON	302			Signal PLC ready
1	7	-------		TAG	1			Return for loop
1	8			WTON	011			Wait for PLC Go
1	9			IN	012	014		Read move # bits
1	10			BTOF	302			Signal PLC moving
2	11			IFEQ	99	1		Is 012 true?
2	12			MOVP	1			40mm
2	13			BTOF	302			extra handshaking
1	14			EDIF				
1	15			BTON	302			Tell PLC ready
1	16			WTOF	011			Be sure PLC saw it
1	17			GOTO	1			Repeat to Tag 1

```
UAO
UFI
O=0
UA=0
 WHILE UBI==0
 LOOP
UA=1
KP = 300
A=100
V=6000
P=10000
G
WHILE Bt
      IF UFI==1
      S
      O=0
      ENDIF
LOOP
UA=0

C1

PRINT(#13,"GOING INTO THE LOOP")

WHILE UBI==0
LOOP

PRINT(#13,"OUT OF THE LOOP")

IF UBI==1
V = 4833
A = 100
P = @P+4290     ' do one rotation slowly

 WAIT
V = 96636      ' this tell it to go faster
P = @P+42880    ' this is what says how many turns
G
TWAIT
ENDIF

UA = 1
GOTO 1

END
```