Design and Fabrication of a Stator Winding Machine

by

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Abstract

This paper discusses the equipment and techniques used in the creation of a machine that winds wire onto stators for brushless motors. A machine was designed and built to wind brushless motor stators with wire. This project was done as part of a manufacturing engineering class. The focus of the class is automation techniques used in the assembly and manufacture of products.

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Introduction

This year for manufacturing class, our assignment was to design and build a machine capable of winding wire onto the stators of brushless motors. The stators we are using are available as part of a kit from gobrushless.com. Initially the overall goal was to build a machine to completely assemble the motor kits from Go Brushless. However for this quarter winding the stators was a more reasonable goal.

Equipment

For this project a large assortment of pneumatic cylinders and electrically controlled linear actuators were available. A programmable logic controller (plc) manufactured by Koyo was used to provide logic control for the project, model DL06 is the plc used in this project. The linear actuators and controllers used in this project were made by IAI Corporation. Three linear actuators were used in this project. To provide precise rotational positioning, an Animatics Smart Motor model SM2330SQ was used. The linear actuator controllers and the smart motor each communicated with the plc. Various single and double piston air cylinders manufactured by Bimba and SMC were also used to construct this machine.

Creating the Machine

The first step in making the machine to wind stators was to sit down and figure out what really was involved in winding a stator. In order to better understand what was involved in stator winding, each member of the team wound their own stator by hand. Winding stators by hand was helpful, but winding wire mechanically is an entirely different process. After gaining a basic understanding of how the wire must be wound onto the stator, the process of designing and fabricating various machine parts could begin. The main problem now was that winding wire with a machine must be done in a completely different manner than hand winding, since building a complete replica of two human hands was not an option.

One of the first problems that had to be solved was how to hold onto the stator while it was having wire wound onto its teeth. The method used to hold the stator must be secure while allowing the stator to be rotated precisely. To accomplish this task, two aluminum rods were turned to the desired size, and a taper was cut on one end of each rod. The taper was cut so that when the tapered rod ends were pressed together they would firmly hold the stator. One of the rods was then attached to a smart motor that allows the stator to be rotated precisely. The other rod was attached to an air cylinder. Also the rod attached to the air cylinder was cut in half and machined to accept a bearing. This was done to facilitate smooth rotation between the air cylinder which becomes rigid under pressure, and the tapered end of the rod. This allows the stator to be rotated freely by the smart motor. These two parts may be seen in Figures 1 and 2.

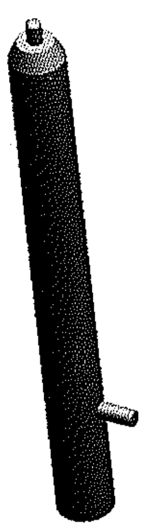


Figure 1. Top of stator holder

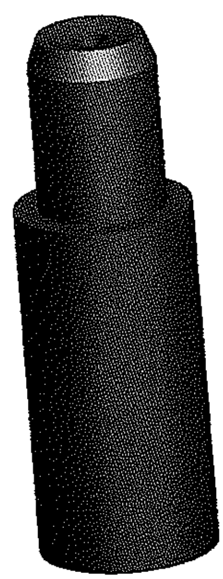


Figure 2. Bottom of stator holder.

With the smart motor providing one axis of movement, the other two axes are provided by two linear actuators connected together. One moves vertically and the other horizontally. To guide the wire onto the stator, a syringe tip from an adhesive dispensing syringe was used. The needle is moved by the linear actuators, and the wire passes from the spool through the needle and onto the stator. The needle is attached to the linear actuators with the needle holder shown in Figure 3.

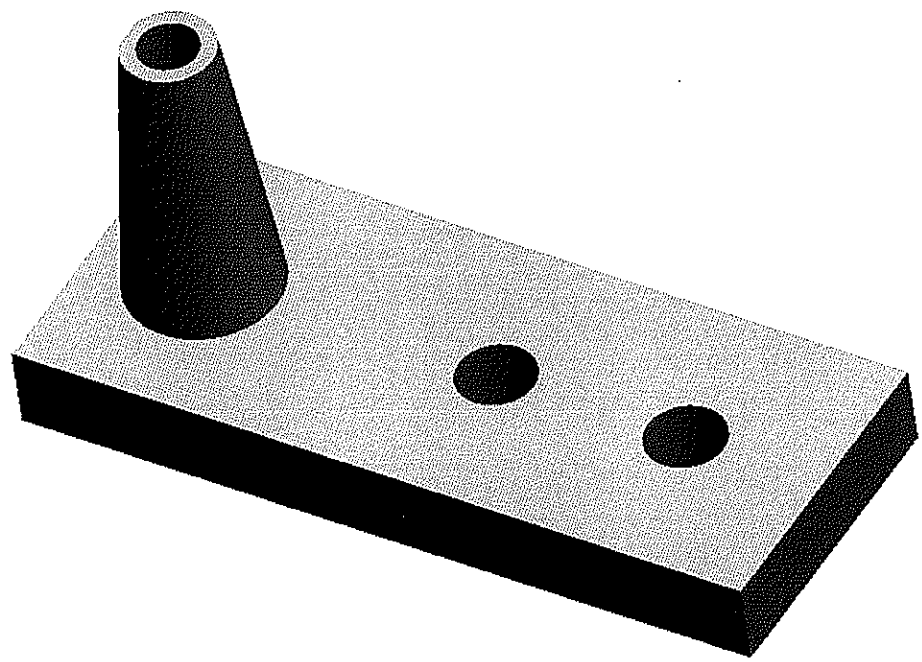


Figure 3. Needle holder.

To accurately determine the angular position of the stator an inductive sensor was used. To locate the stator before the first tooth is wound the smart motor slowly turns the stator until the inductive sensor sees a tooth and then a gap. After the gap is seen the stator is then rotated a specified amount to align the wire feeding needle with a gap in the stator. A close up picture of the inductive sensor and a stator is shown in

Figure 4. Once the stator is positioned initially all the other necessary moves are incremental and are read from a position table in memory.

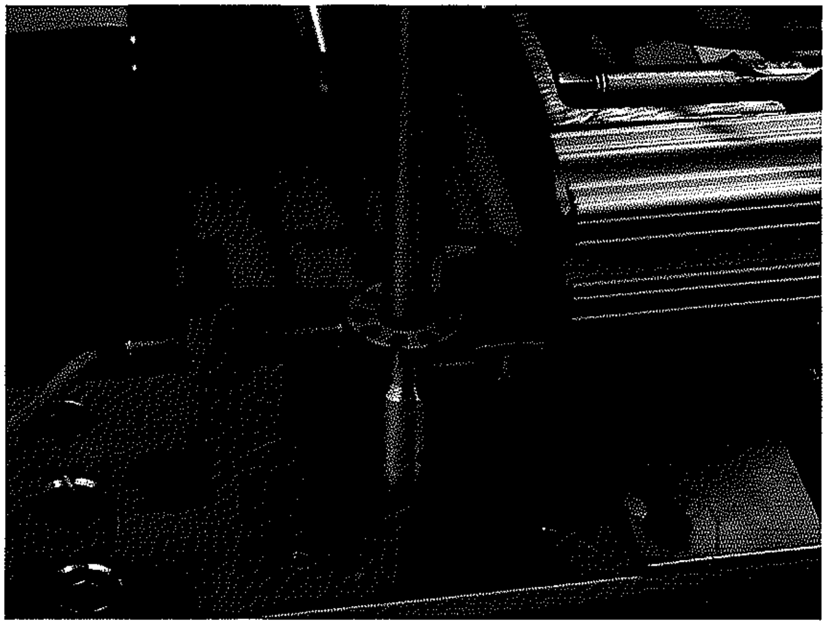


Figure 4. Close up of inductive sensor.

The overall assembly is built using T slot material to hold various parts of the assembly in place. The platform that the machine assembly sits on is also constructed from the same aluminum T slot material. Figure 5 shows a Pro E model of the entire machine, and a picture of the actual machine is shown in Figure 6.

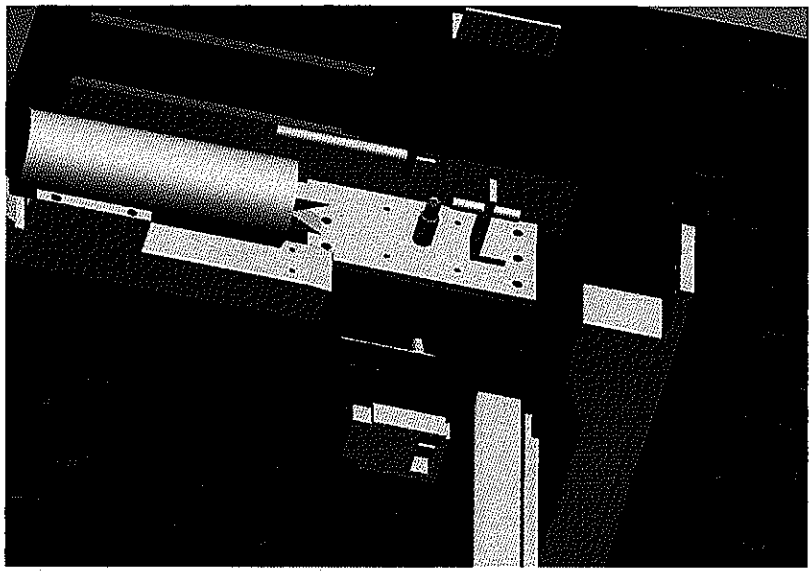


Figure 5. Pro E model of machine.

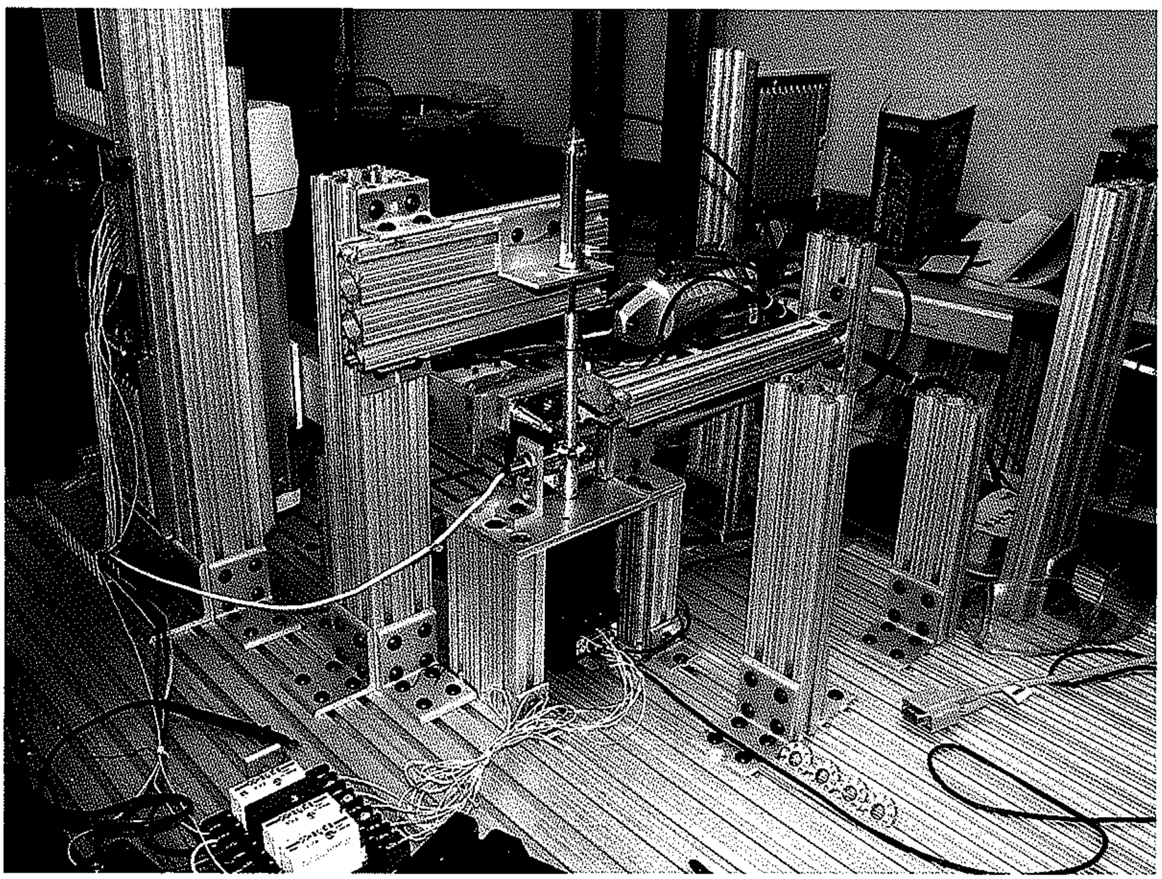


Figure 6. Picture of winding machine.

When the winding process is first started it is necessary to hold the tip of the wire stationary, as the first few turns of wire are wound. To accomplish this, a pneumatic gripper with custom jaws was used. When one phase of the stator has been wound and the wire needs to be cut before the 2nd and 3rd phases can be wound the process is as follows. First the needle is brought upward and a cylinder is extended to keep the wire pointing straight up from the stator. Then the needle is pulled back and the wire cutters are brought in by a linear actuator and the wire is clipped. The next phase can then be wound.

Specifications

This stator winding machine is set up to wind nine tooth stators up to seventeen turns of wire per tooth, though it has only been tested for up to ten turns. The number of stator teeth can be changed but parts of the programs would need to be modified. The only wire that has been tested is the 26 gage wire that comes with the motor kits. The needle must protrude 0.792 inches from the aluminum cone that holds it. This dimension is critical to proper operation of the winding machine, if the needle protrudes too far it will hit the stator or the stator holder and get bent or broken. When the wire is initially threaded into the needle by hand it should extend past the end of the needle between 1 and 3 inches, but not less than 1 inch, the machine will cue the wire to the exact length needed before the winding process is started. The amount of time required to wind one stator is approximately 9:27. This time will of course depend on the number of turns to be wound. The time listed here is for ten turns per stator tooth.

Operating Instructions

Before the power to the machine is turned on several things must be checked. First the linear actuators marked Henry and Bob must be moved back away from the stator to the extent of their range by hand. This is to prevent the linear actuator named Victor from damaging the needle when it moves up. Also before the power is turned on the wire should be threaded into the needle so it has between 1 and 3 inches of wire sticking out. Next, a stator should be loaded into the machine as shown in Figure 4. Once these steps have been done the power switch should be turned on. The linear actuators will now go through a homing sequence. Once all the sliders have stopped moving check all three slider controllers. They should each be displaying p01. If any of the controllers are displaying ready (rdy), then it will be necessary to reload the correct program and the position tables into that controller from the computer using a program named Selwin. If all three sliders are displaying p01, and the wire and stator are in position then press the green button to begin winding. When changing stators, the power must be reset to initiate the stator gap homing function done by the smartmotor.

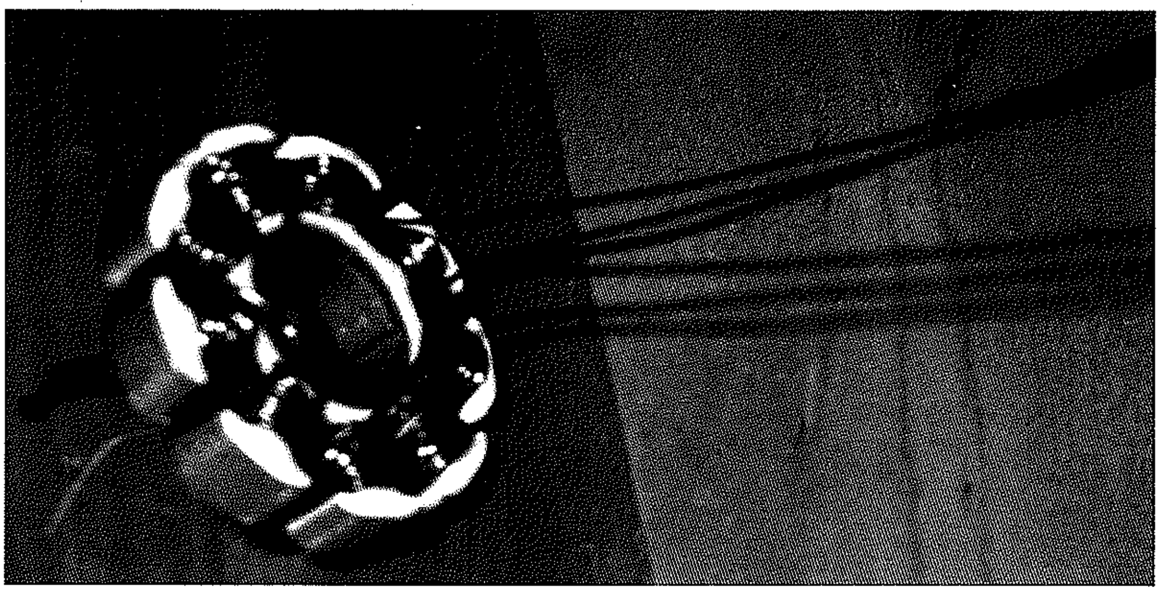
To clear a jam or other malfunction it will be necessary to reset the machine. Resetting the machine requires the following steps. Turn the power off and immediately move the linear actuator Henry back to its home position. Remove whatever is causing the problem and replace the stator back on the stator holder. Now check that the stator is in the correct position, the wire has enough wire sticking out, and Henry is all the way back. Next, turn the power back on. When the homing sequences have finished check the readouts as previously discussed and if they are reading p01, press the green button to begin winding.

To change the number of turns the machine will wind onto the stator change the k value in counter zero in state 31 line 73 in the plc logic. However it is highly recommended that this value not be increased over the initial value. The number of turns may be decreased with out causing issues, but attempting to wind more turns is likely to cause problems.

When a stator has been completely wound, a hard restart must be completed before the next stator is placed into the machine for winding. This restart must be done to reset the homing feature on the smart motor, if the homing feature is not reset the stator will not be placed in the proper position when winding starts. Improper stator positioning is likely to lead to parts breakage. Also care should be taken to keep all body parts clear of the pneumatic wire cutter; if it gets the chance it will bite you.

Results

We were able to successfully wind one stator. The wiring looks fairly clean but some of the insulation on the wire was damaged. As can be seen in the picture of the completed stator the machine does leave plenty of wire fro connecting to a sped controller in an assembled motor. At this point the machine only winds ten turns on each tooth, the ideal number of turns is between seventeen and twenty one turns. Overall the main issue we have had in fine tuning this machine is getting the computer to successfully connect to the smart motor. Without a successful connection the rotation increment cannot be adjusted to achieve good performance.

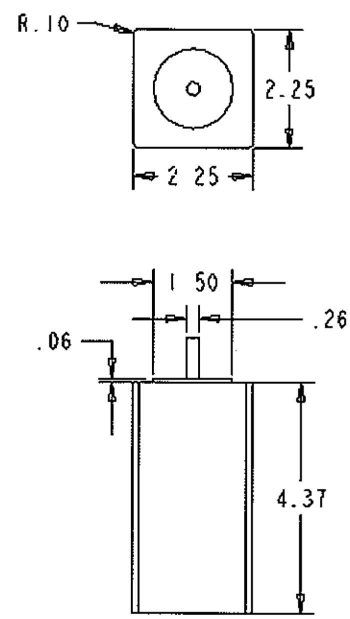


Picture of complete stator

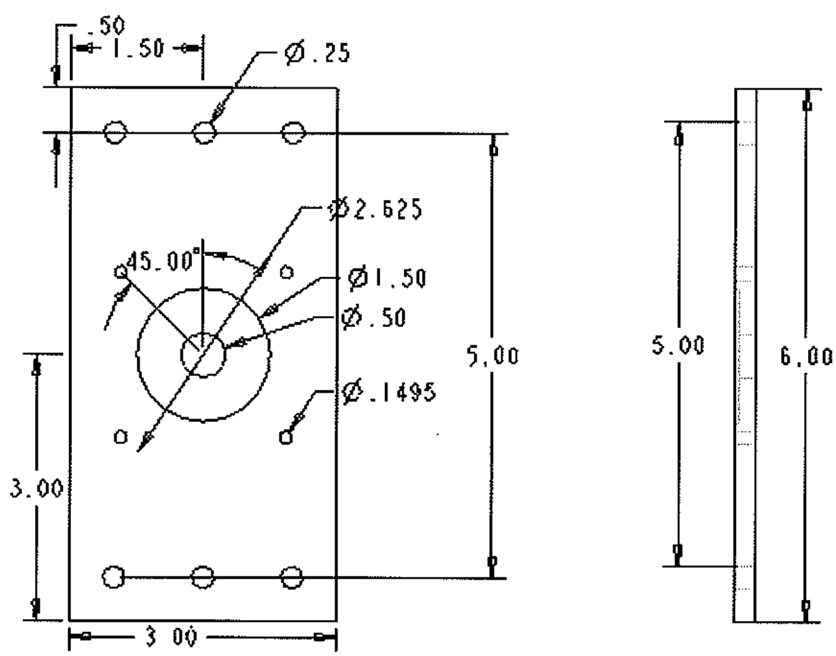
Future work

One feature that would be useful in future machines is a gripper to move in and hold the end of the wire while the cutter moves in and cuts the wire to its initial length. The gripper could then move back and drop the scrap wire into a trash box. Another area that needs to be improved in future machines is a method of automatically loading the stators into the machine, at this point the stators are being loaded into the winder by hand. Also another improvement that could be made is finding a better way to protect the insulation on the wire, since this machine has had some trouble with scraping off the insulation sometimes. Any reduction in this machines temperamental behavior would also be a big improvement, up to this point a mostly functional machine has been arrived at by many hours of progressive tweaking, even with functional logic and programming many of the position tables require frequent tweaking to achieve error free winding. Overall this machine has been a good first attempt at winding stators, as a group we would definitely like to see what future labs design, and how they are able to improve our initial design.

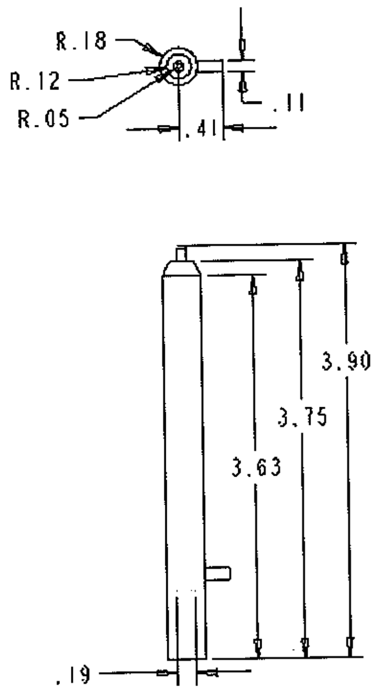
Appendix 1



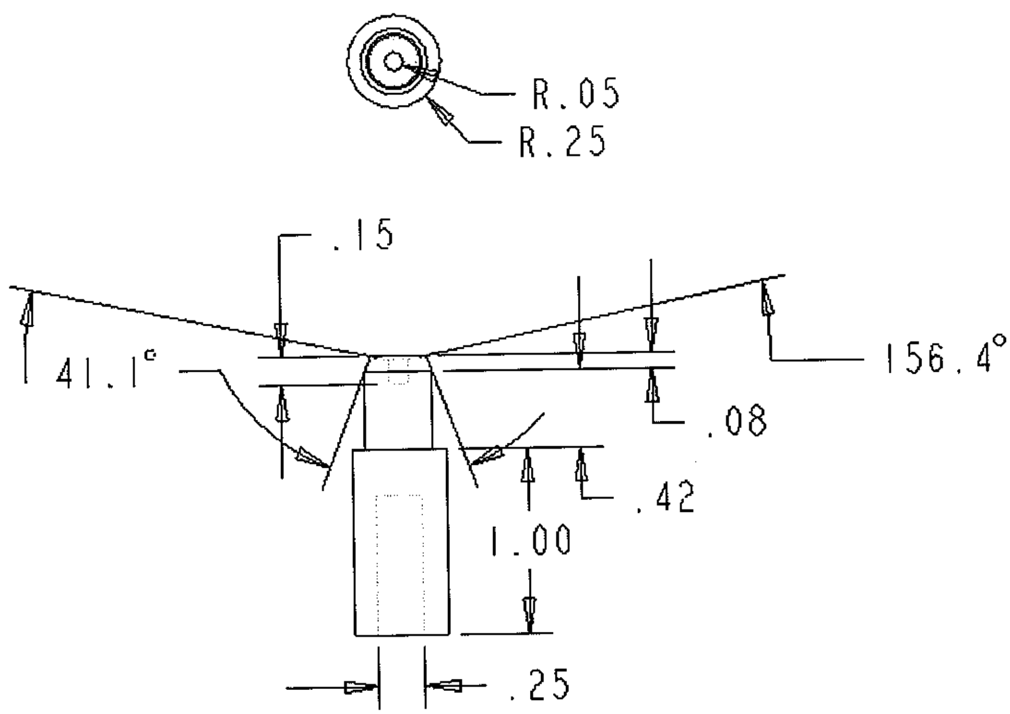
Smart motor.



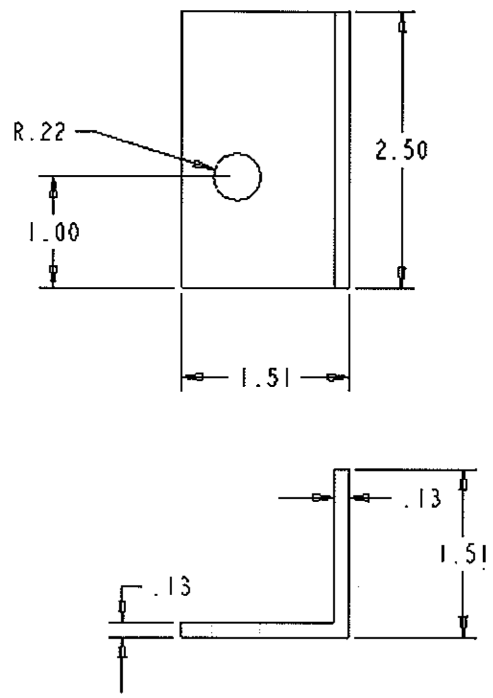
Smart motor mounting plate.



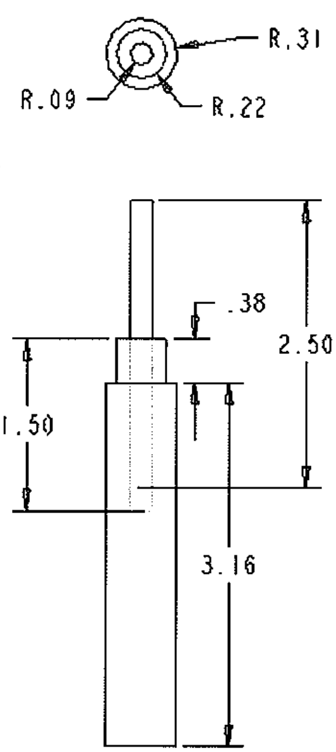
Upper stator holder.



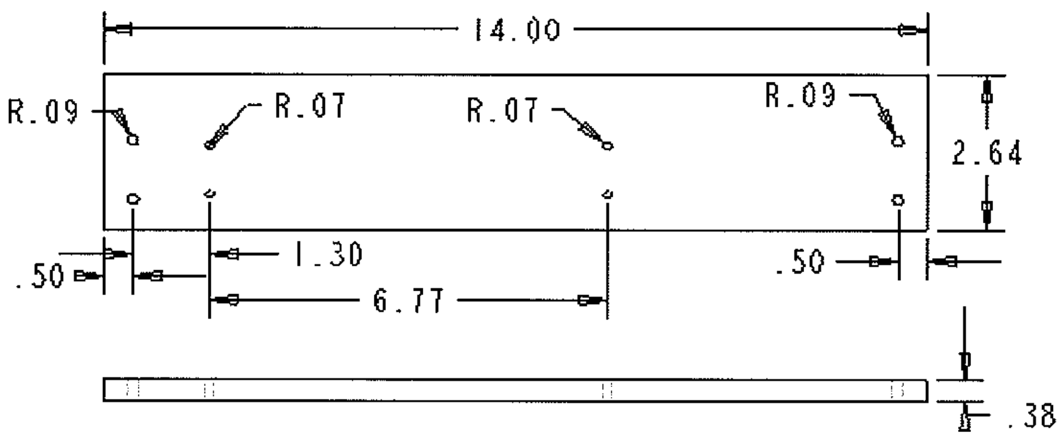
Lower stator holder.



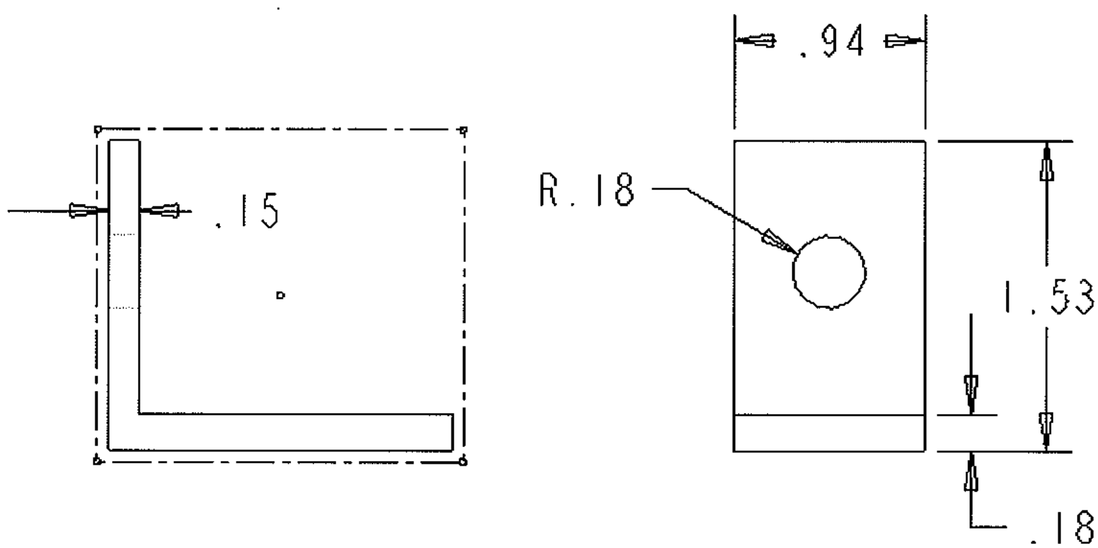
Stator holder cylinder bracket.



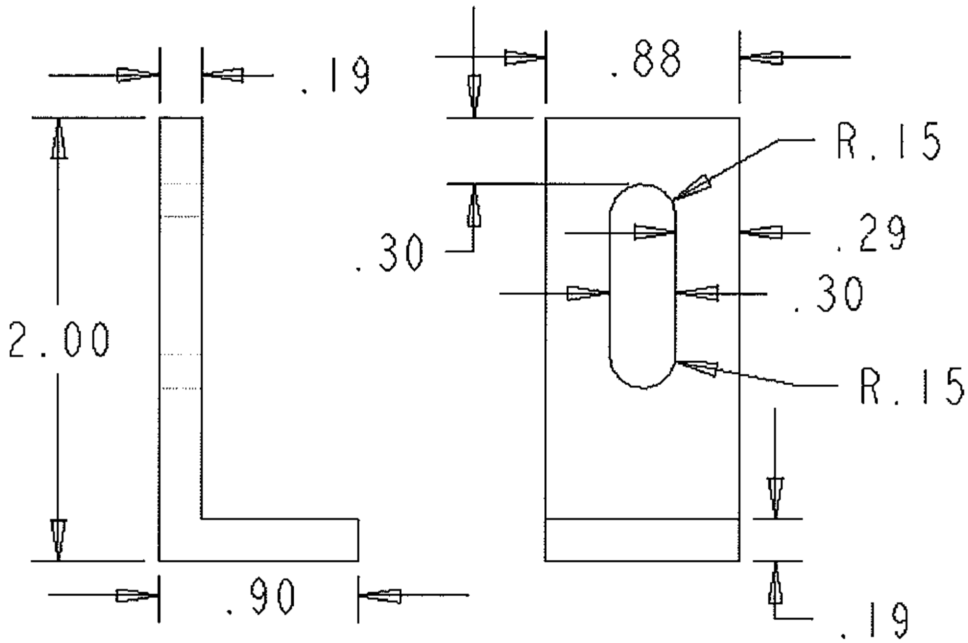
Stator holder cylinder.



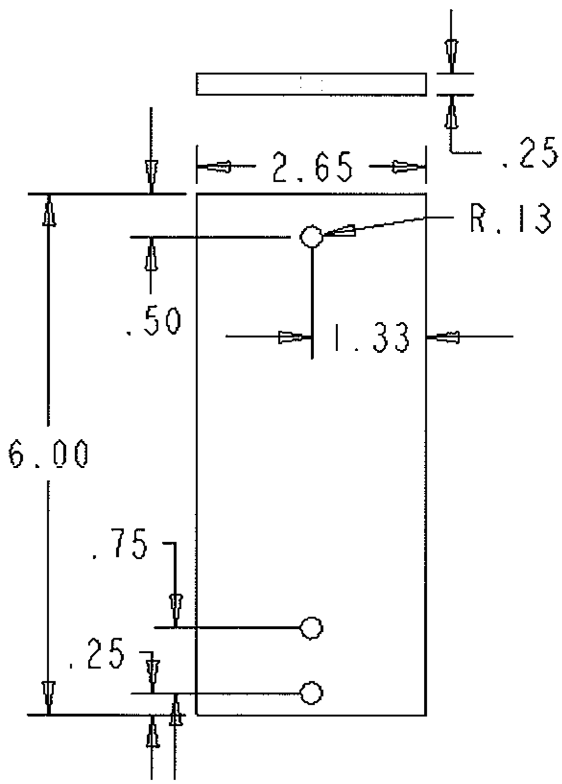
Linear actuator assembly bracket.



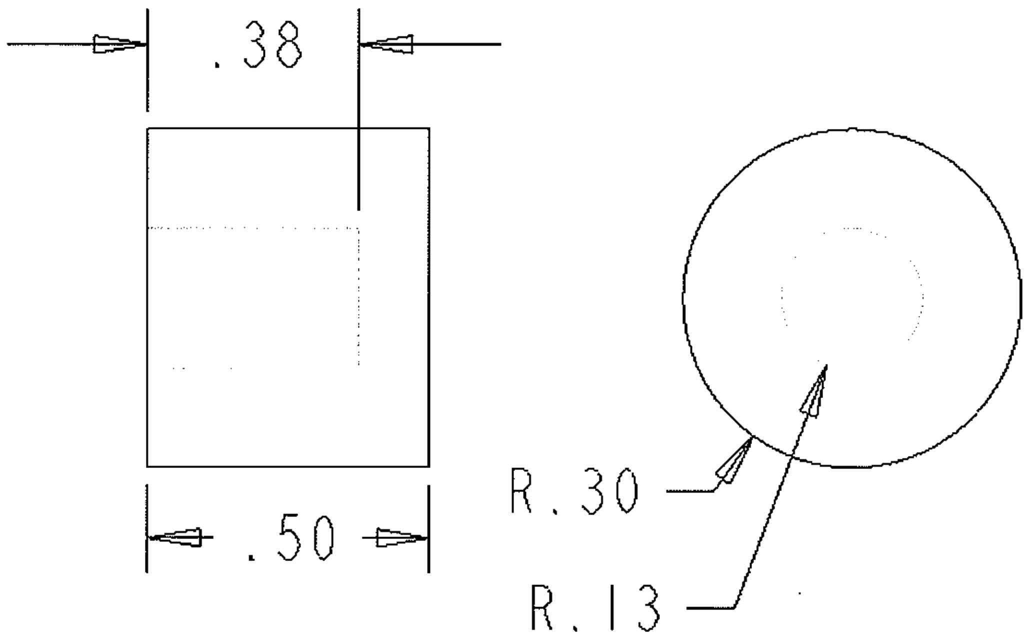
Bracket for air cylinder that acts as a finger.



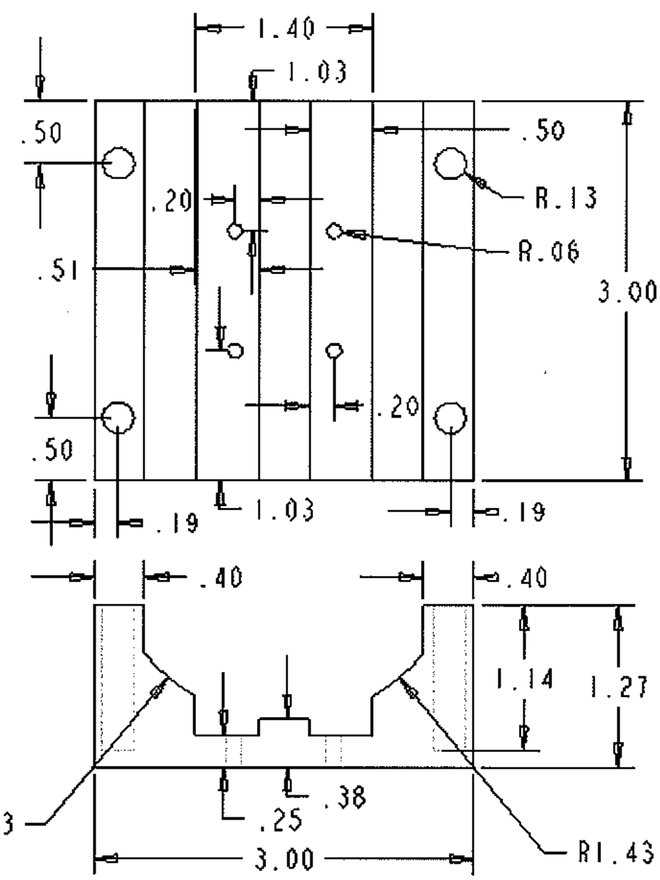
Inductive sensor bracket.



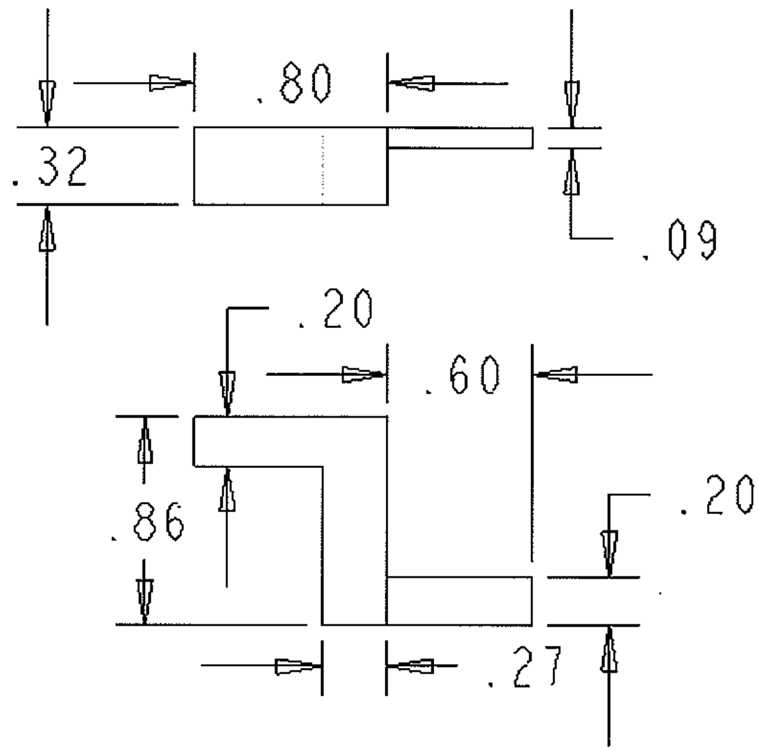
Wire spool bracket.



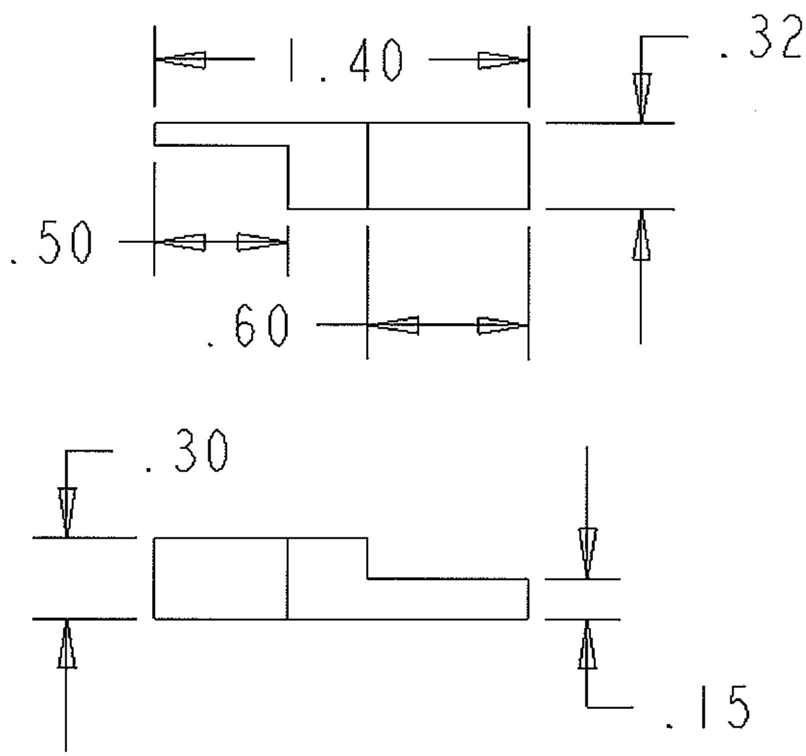
Wire spool spindle.



Wire cutter bracket.



Top gripper jaw



Lower gripper jaw

Linear Actuator	Position	#	Table	
Bob	Home	0	HOME	
	Initial position	10	1	
	Ready to clip	430	2	
Henry	Home (back)	0	HOME	
	Wire tip ready to be pinched	96.25	1	
	Wire ready to be cut	18.78	2	
	Backed up a little	93	3	
	In all the way for the wire wrap	100	4	Change in program too!
Victor	Home (up)	0	HOME	
	Wire pinched	96	1	
	up past peg	70.5	2	
	just below peg	84	3	
	Pull back height for cutting	34	4	
Alec	Initial rotation	45		
	+ 1 peg	265		
	- 1 peg	-265		
	+ 2 pegs	668		

Ns	Step	A/O Cond	Cmnd	Operand 1	Operand 2	Pst	Comment
1	1		BTOF	302			PLC not ready
1	2		SVON	1			Servo on
1	3		ACC	2			Set accel
1	4		VEL	500			Set Velocity
1	5		HOME	1			Go Home
1	6		MOVP	1			Initial position
1	7		BTON	302			Signal PLC ready
1	8	-------	TAG	1			Return for loop
1	9		WTON	011			Wait for PLC Go
1	10		BTOF	302			Signal PLC moving
1	11		MOVP	2			Go to pos 2
1	12		BTON	302			Tell plc ready
1	13		WTOF	011			
1	14		WTON	011			Wait for plc on
1	15		BTOF	302			Signal PLC moving
1	16		MOVP	1			Go to pos 1
1	17		BTON	302			Tell plc ready
1	18		WTOF	011			Wait for plc off
1	19		GOTO	1			Repeat to tag 1

No.	Acc	Vel	Axis(1)
1	x.xx	x	10.000
2	x.xx	x	430.000

Ns	Step	A/O Cond	Cmnd	Operand 1	Operand 2	Pst	Comment
1	1		BTOF	302			Not ready
1	2		SVON	1			Servo on
1	3		HOME	1			go home
1	4		ACC	0.3			
1	5		VEL	50			
1	6		BTON	302			Ready
1	7	-------	TAG	1			Begin loop
1	8		WTON	011			Wait for PLC
1	9		BTOF	302			I'm busy
1	10		IN	014	015		In inc adjs
1	11		TRAN	299	99		copy 99 to 299
2	12		IFEQ	99	0.01		If 1, +0.01
2	13		PGET	1	4		
2	14		TRAN	399	199		copy 199 to 399
2	15		ADD	199	1.5		
2	16		PPUT	1	4		
1	17		EDIF				
2	18		IFEQ	99	0.01		If 2, -0.01
2	19		PGET	1	4		
2	20		ADD	199	-1.5		
2	21		PPUT	1	4		
1	22		EDIF				
2	23		IFEQ	99	3		If 3, reset
2	24		LET	199	100		
2	25		PPUT	1	4		
1	26		EDIF				
1	27		IN	012	013		In pos code
1	28		ADD	99	1		incr for pos table
1	29		MOVP	*99			move
1	30		BTON	302			I'm ready
1	31		WTOF	011			Be sure plc knows
1	32		GOTO	1			Loop around

No.	Acc	Vel	Axis(1)
1	x.xx	x	96.250
2	x.xx	x	18.000
3	x.xx	x	93.000
4	x.xx	x	100.000

Ns	Step	A/O Cond	Cmnd	Operand 1	Operand 2	Pst	Comment
1	1		BTOF	302			I'm not ready
1	2		SVON	1			Servo on
1	3		HOME	1			Go home
1	4		ACC	0.3			
1	5		VEL	15			
1	6		MOVD	34			move to pos4
1	7		BTON	302			I'm ready
1	8	-------	TAG	1			Loop beginning
1	9		WTON	11			Wait for PLC
1	10		BTOF	302			
1	11		IN	12	13		Read binary pos
1	12		ADD	99	1		
1	13		MOVP	*99			move to pos
1	14		BTON	302			
1	15		GOTO	1			

No.	Acc	Vel	Axis(1)
1	x.xx	x	96.000
2	x.xx	x	70.500
3	x.xx	x	84.000
4	x.xx	x	34.000

SMART MOTOR PROGRAM

```
UAI
UBO
UCI
UDI
MP
RP
A=1000
V=10000
P=0
G
TWAIT
WAIT=10
a=UAI
WHILE a==1
WAIT=1
a=UAI
PRINT(#13,"Waiting for PLC")
UB=1
LOOP
UB=0
WAIT=500
c=UCI
WHILE c==1
UB=1
D=1
G
TWAIT
WAIT=200
c=UCI
LOOP
PRINT(#13,"I see the stator peg")
c=UCI
WHILE c==0
UB=1
D=1
G
TWAIT
WAIT=200
c=UCI
LOOP
PRINT(#13,"I see the stator gap")
A=10
V=1000
D=37
G
TWAIT
WAIT=20
PRINT(#13,"Needle centered with gap")
UB=0
O=0
WHILE 1
A=500
V=5000
a=UAI
d=UDI
IF d==1
IF a==0
UB=1
D=-265
G
TWAIT
WAIT=5
PRINT(#13,"Rotated -1 peg")
UB=0
ENDIF
ENDIF
IF d==0
IF a==1
```

```
UB=1
D=265
G
TWAIT
WAIT=5
PRINT(#13,"Rotated +1 peg")
UB=0
ENDIF
ENDIF
IF d==0
IF a==0
UB=1
D=662
G
TWAIT
WAIT=5
PRINT(#13,"Rotated to next wrapping position")
UB=0
ENDIF
ENDIF
PRINT(#13,"Finished, Waiting for PLC")
LOOP
END
```

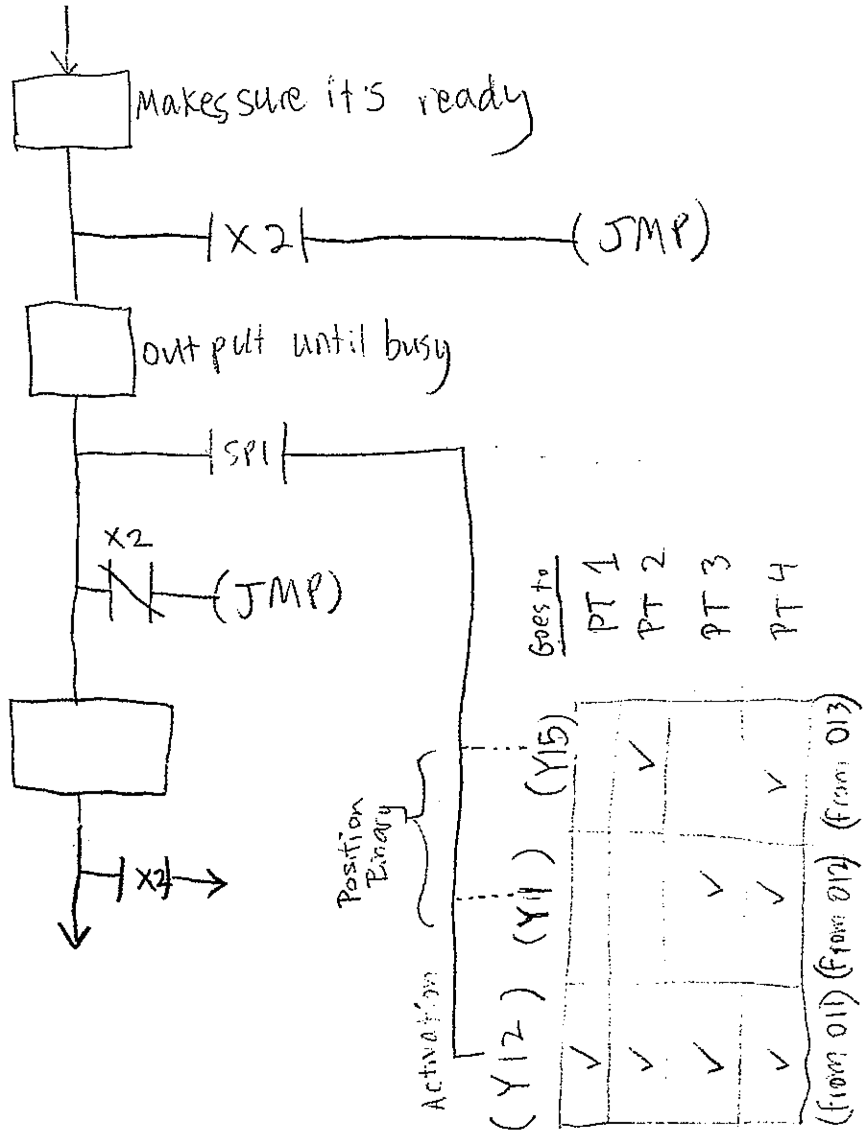
Step	Description	iGreen	iAlec	iInduct	iBob	iHenry	iVictor	oPincher	oClamper	oCutter	oSlammer	oFinger	oAlec	oBob	oHenry	oVictor
0	*Initial*	x	w	x	w	w	w	x	x	x	x	x	H	H	H	H
1	*Stator loaded by hand*	$$									$$					
2	*Rotate until we see stator*			$$									$$			
3	*Rotate until we see gap*			x									x			
4	*Rotate a little more*		$$										#			
5	*Move wire tip fwd*					$$			$$						movp#	
6	*Clamp wire tip*							$$	x							
7	*Back up a little*					$$									mvpi#	
8	*Go vertical*						$$									movp#
9	*Fwds a little*					$$									mvpi#	
10	*Rotate 1 stator peg*		$$										#			
11	*Out a little*					$$									mvpi#	
12	*Down a little lower than 1 peg*						$$									movp#
13	*In a little*					$$									mvpi#	
14	*Rotate back one peg*		$$										#			
15	*Step back one wire-width*					$$									mvpi#	
16	*Repeat 7-15 (9) of times*															
17	*Move up*						$$									movp#

18	*Move in to hub*					$$									mvpi#	
19	*Repeat 16-18 once*															
20	*Rotate to next position (a gap)*		$$										#			
21	*Back up a little*					$$									mvpi#	
22	*Down past peg a little*						$$									movp#
23	*Repeat 16-22*															
24	*Repeat 16-21*															
25	*Go up to above the finger*						$$									movp#
26	*Give the finger*											$$				
27	*Retract past Bob a little*					$$									#	
28	*Send Bob fwd*				$$				$$					#		
29	*Snip*									$$						
30	*Send Bob home*				$$									H		
31	*Lower to home*						$$									H
32	*Open the Gripper*							x								
33	*Rotate*		$$										#			
34	*Repeat 5-33 twice*															
35	*repeat 0*															
36	*Remove stator by hand*															

PLC : VICTOR

VICTOR

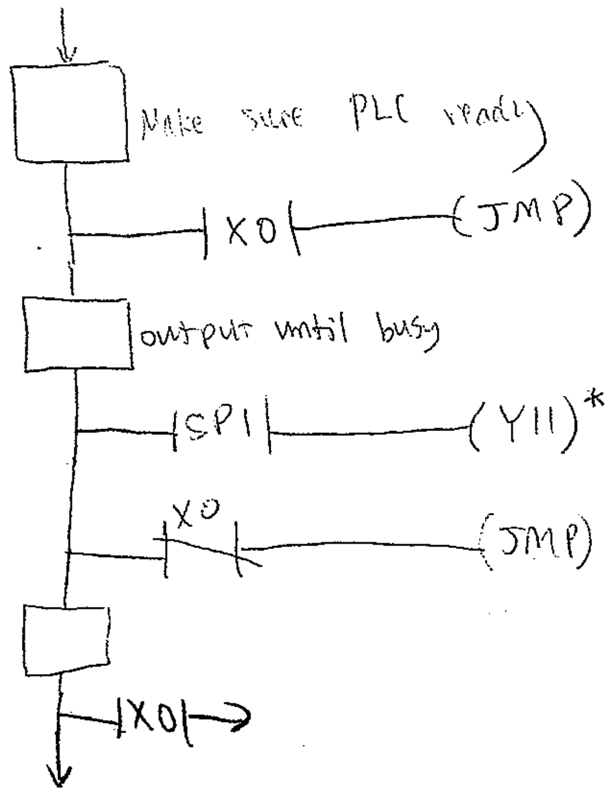
To move Victor: Takes 2 states



PLC : Bob

BOB

To move Bob takes 2 states



* Bob starts at PT 1 (back)
Every time he receives a Y11 command and starts moving, he goes to the "other" position. In this way Y11 is a toggle.

SMI information

ALEC

	Light	means	SMI	PLC
UAI:	on		0	Y17 on
	off		1	Y17 off
UDI:	on		0	Y16 on
	off		1	Y16 off

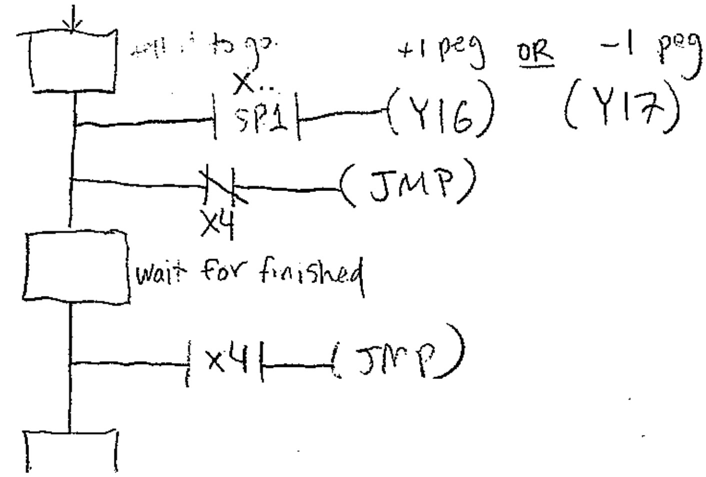
D	A	Y16	Y17	means
0	0	on	on	~~skip 2 stators~~
0	1	on	off	rotate +1 peg
1	0	off	on	rotate −1 peg
1	1	off	off	~~nothing~~

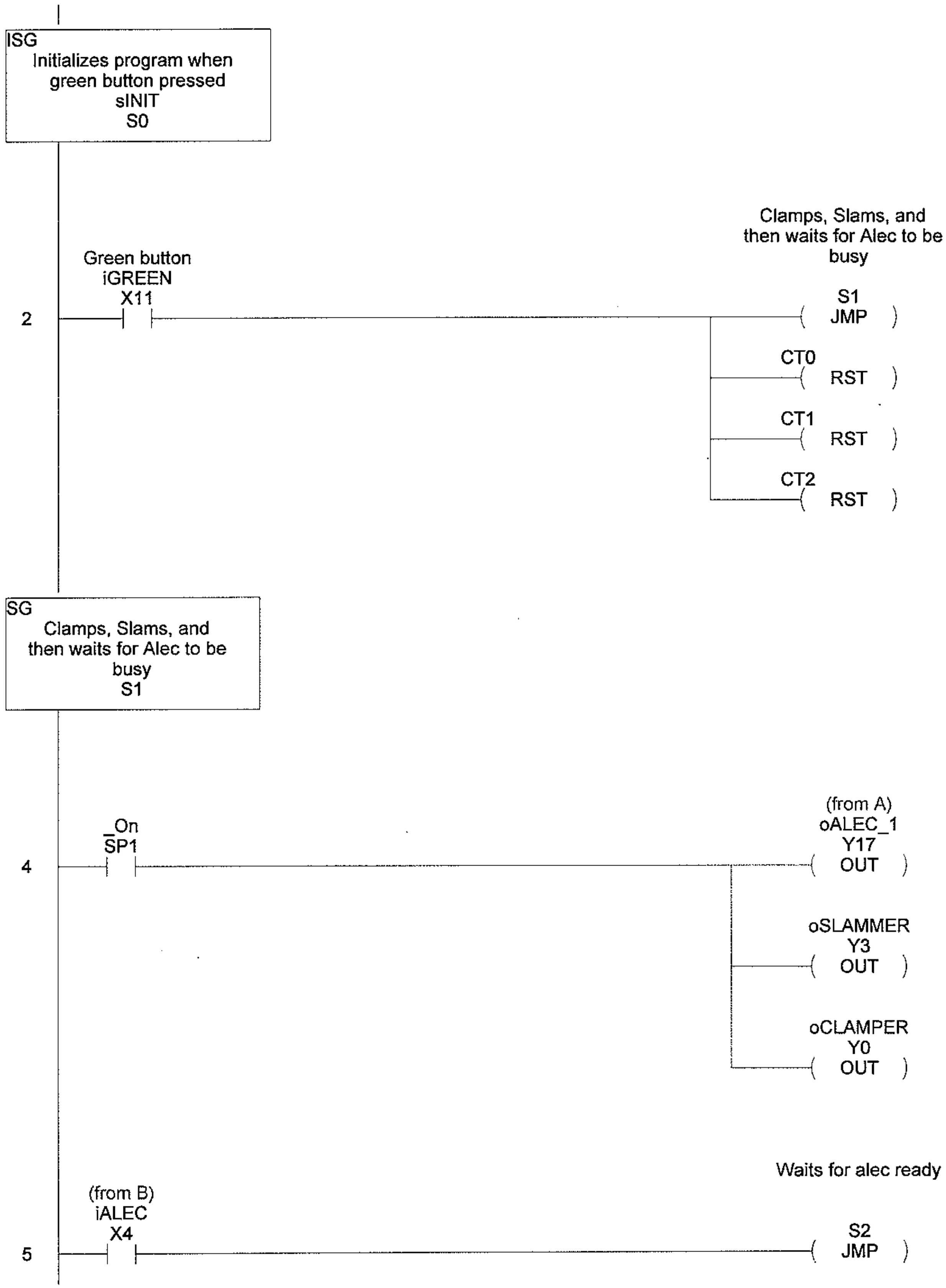
So, Y16 makes it rotate +1 peg, Y17 rotates −1 peg.

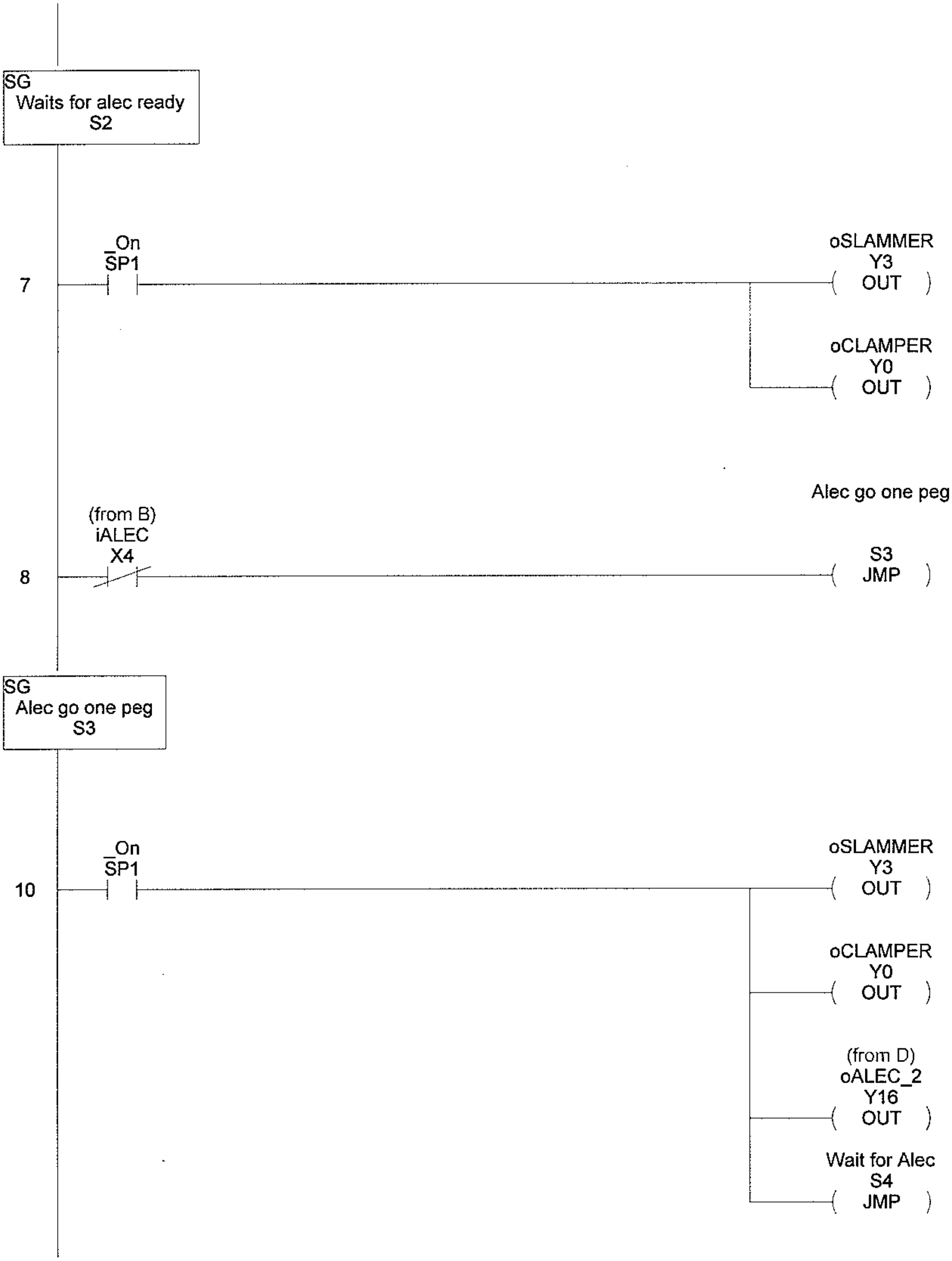
	Light	means	SMI	PLC
UBO:	on	I'm ready	0	—| X4 |—
	off	I'm busy	1	—|/ X4 |—
UCI:	on	I see stator	0	not connected to PLC
	off	I don't see stator	1	not connected to PLC

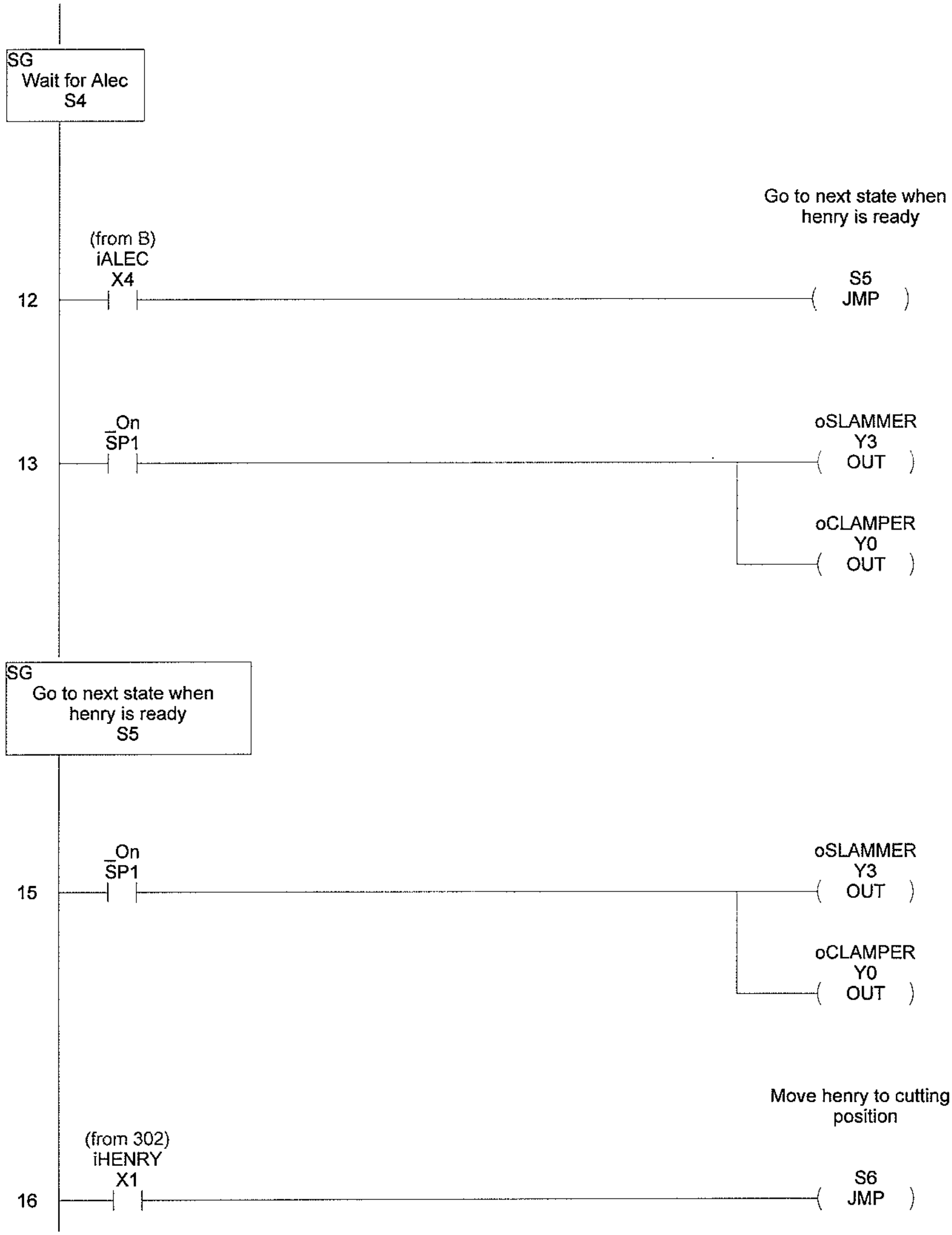
PLC: Alec:

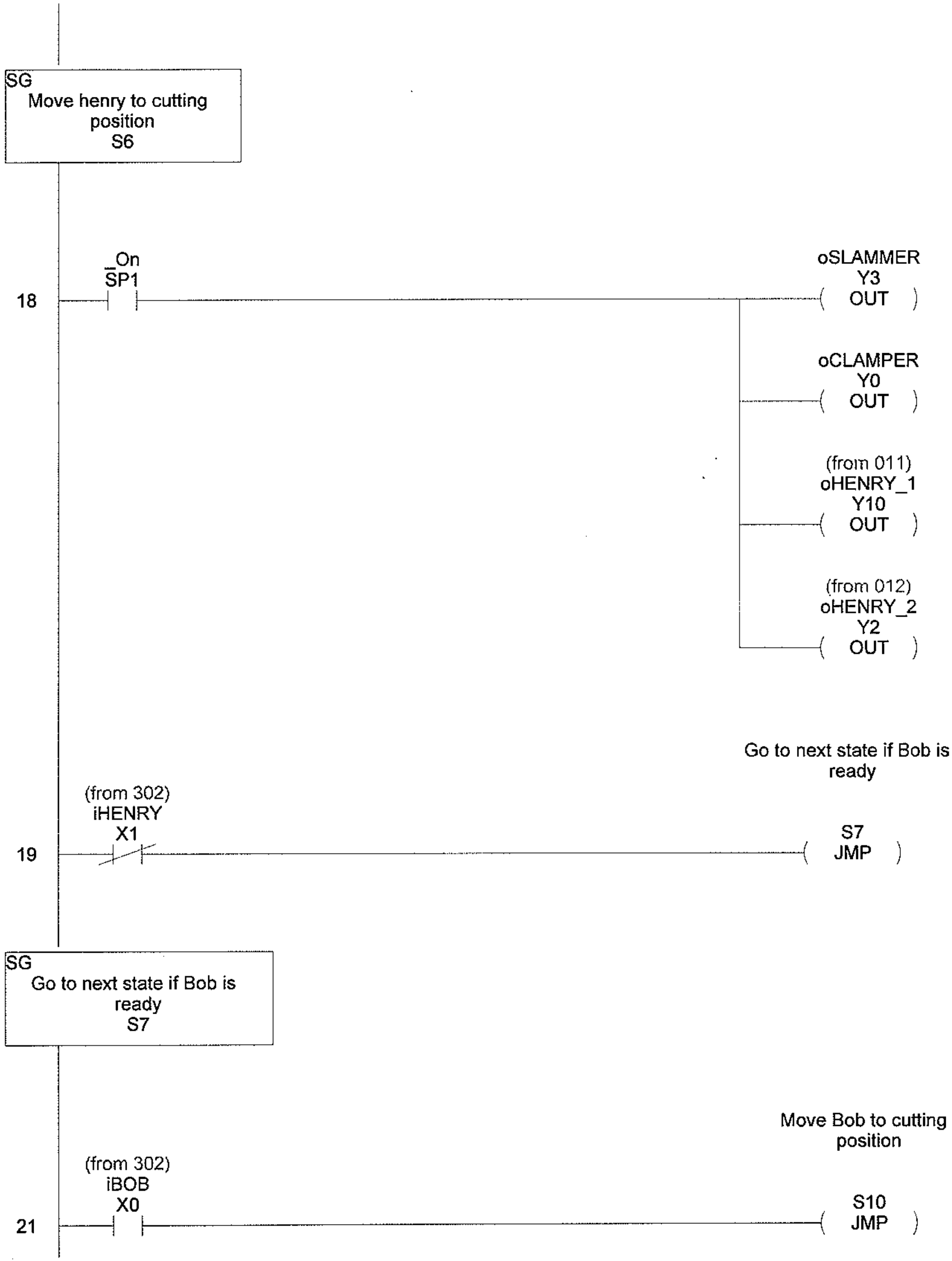
To move Alec takes 2 states:

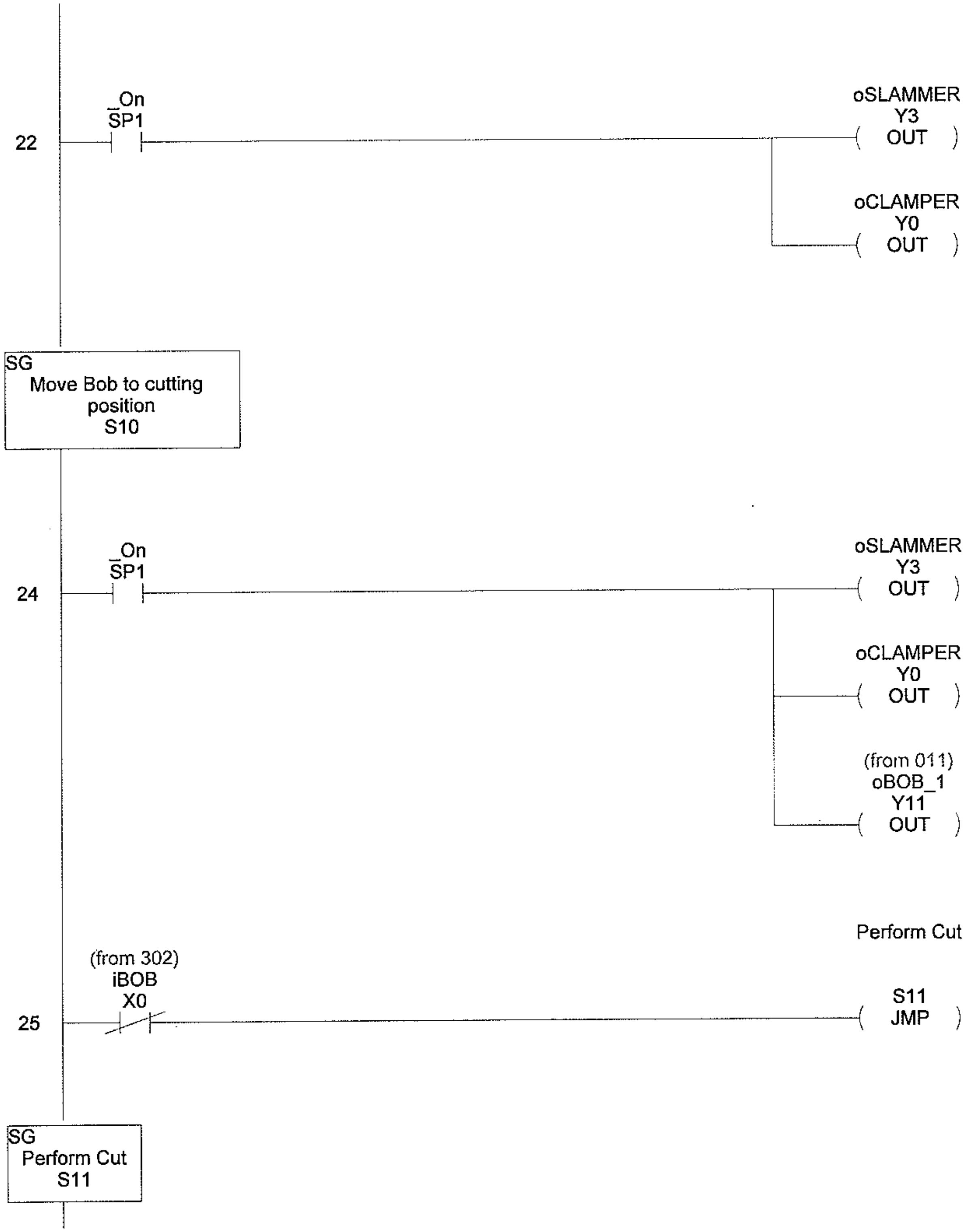


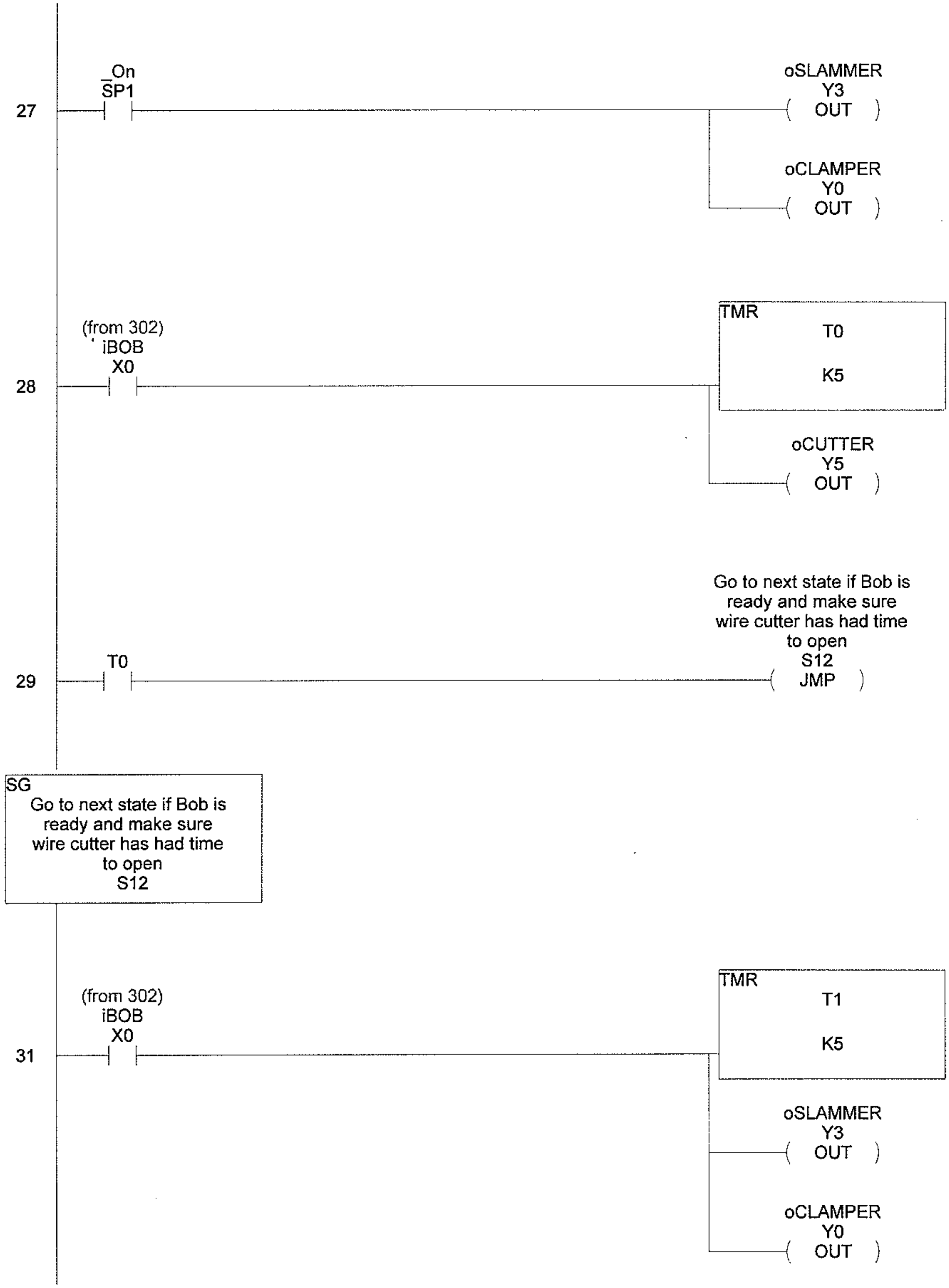

ISG
Initializes program when green button pressed
sINIT
S0
Clamps, Slams, and then waits for Alec to be busy
Green button
iGREEN
X11
2
S1
JMP
CT0
RST
CT1
RST
CT2
RST
SG
Clamps, Slams, and then waits for Alec to be busy
S1
_On
SP1
4
(from A)
oALEC_1
Y17
OUT
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
Waits for alec ready
(from B)
iALEC
X4
5
S2
JMP

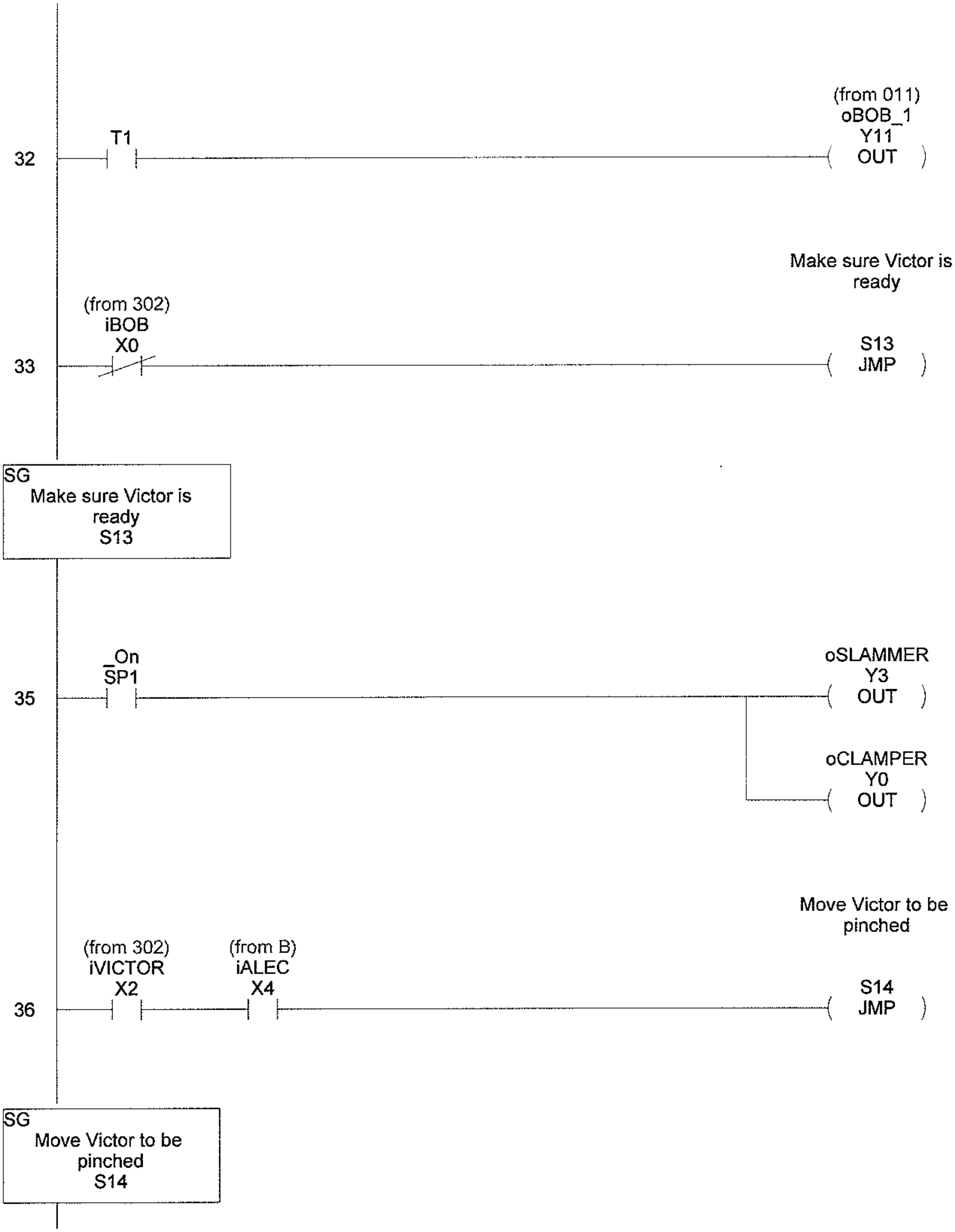

SG
Waits for alec ready
S2
_On
SP1
7
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
Alec go one peg
(from B)
iALEC
X4
8
S3
JMP
SG
Alec go one peg
S3
_On
SP1
10
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
(from D)
oALEC_2
Y16
OUT
Wait for Alec
S4
JMP

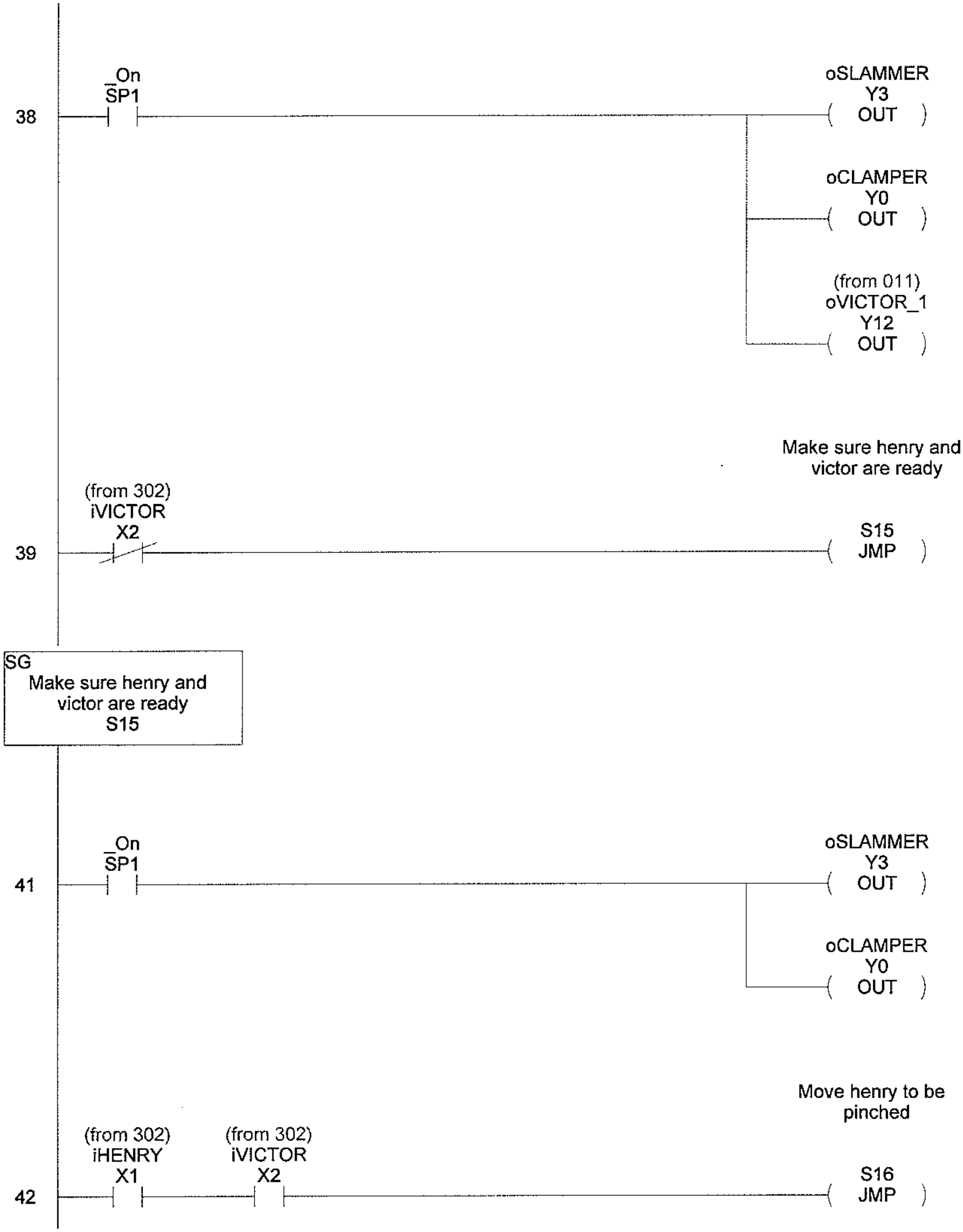

SG
Wait for Alec
S4
Go to next state when
henry is ready
(from B)
iALEC
X4
12
S5
JMP
_On
SP1
13
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
SG
Go to next state when
henry is ready
S5
_On
SP1
15
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
Move henry to cutting
position
(from 302)
iHENRY
X1
16
S6
JMP

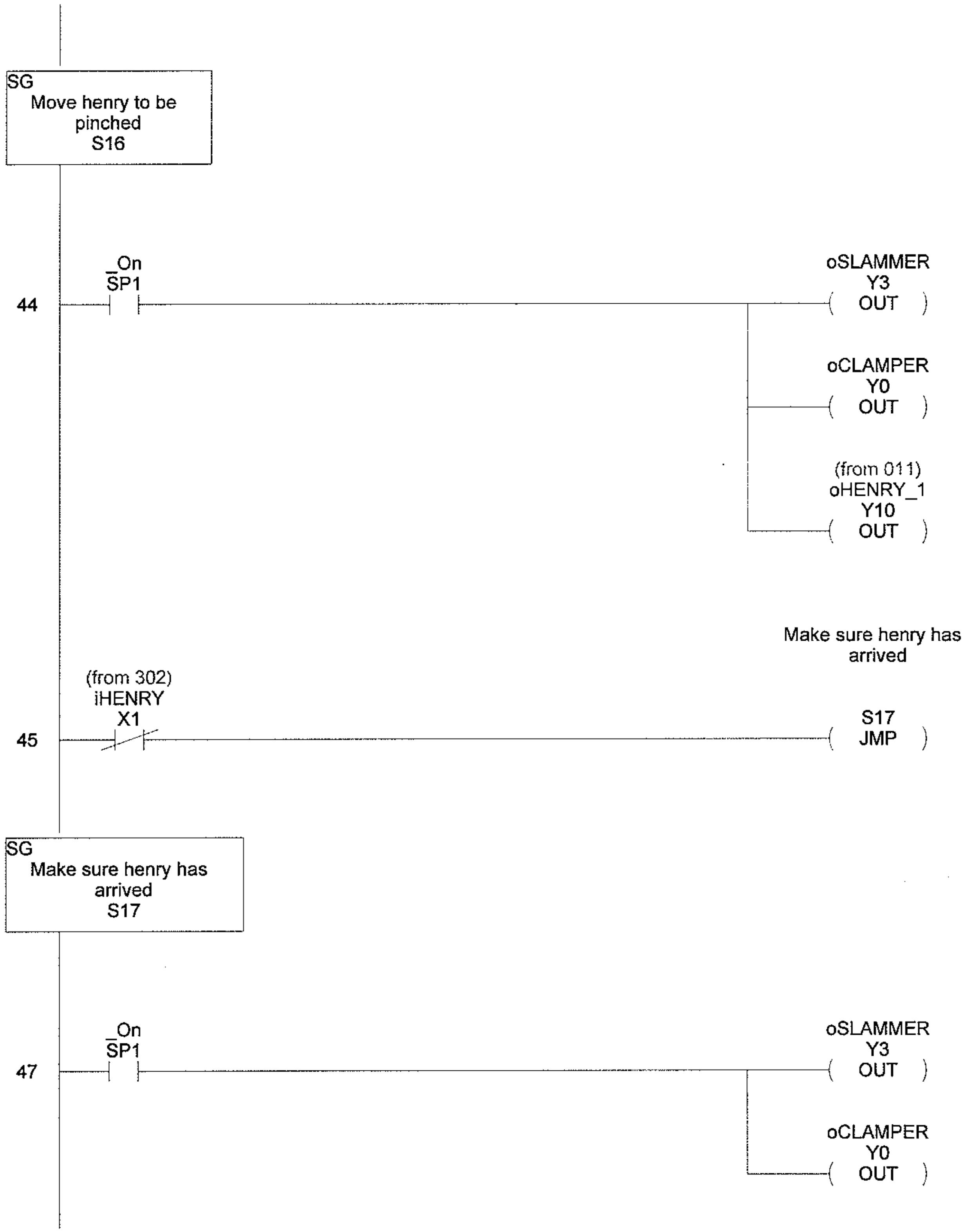

SG
Move henry to cutting position
S6
18
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 012)
oHENRY_2
Y2
OUT
19
(from 302)
iHENRY
X1
Go to next state if Bob is ready
S7
JMP
SG
Go to next state if Bob is ready
S7
21
(from 302)
iBOB
X0
Move Bob to cutting position
S10
JMP

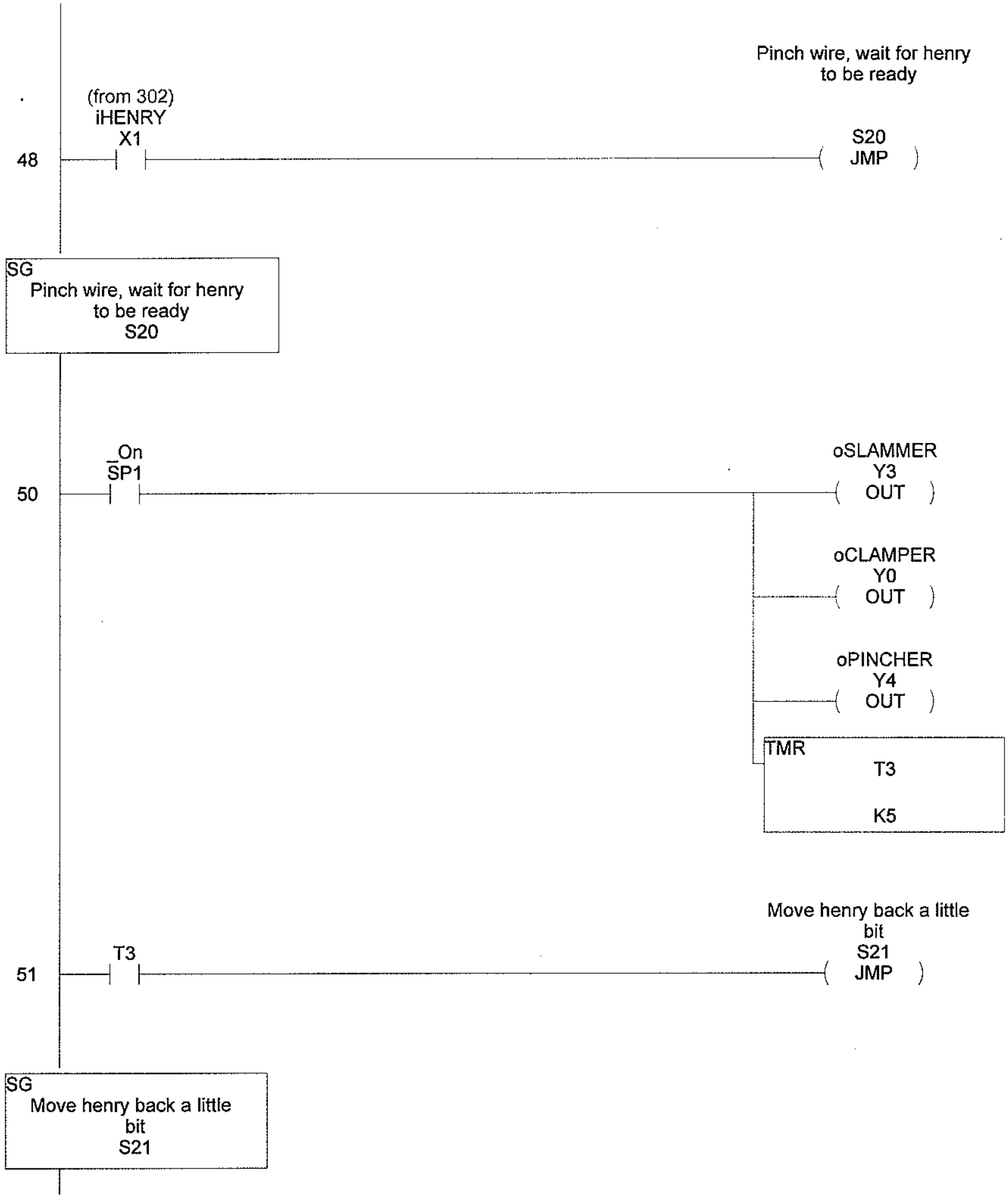

22
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
SG
Move Bob to cutting position
S10
24
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
(from 011)
oBOB_1
Y11
OUT
Perform Cut
25
(from 302)
iBOB
X0
S11
JMP
SG
Perform Cut
S11

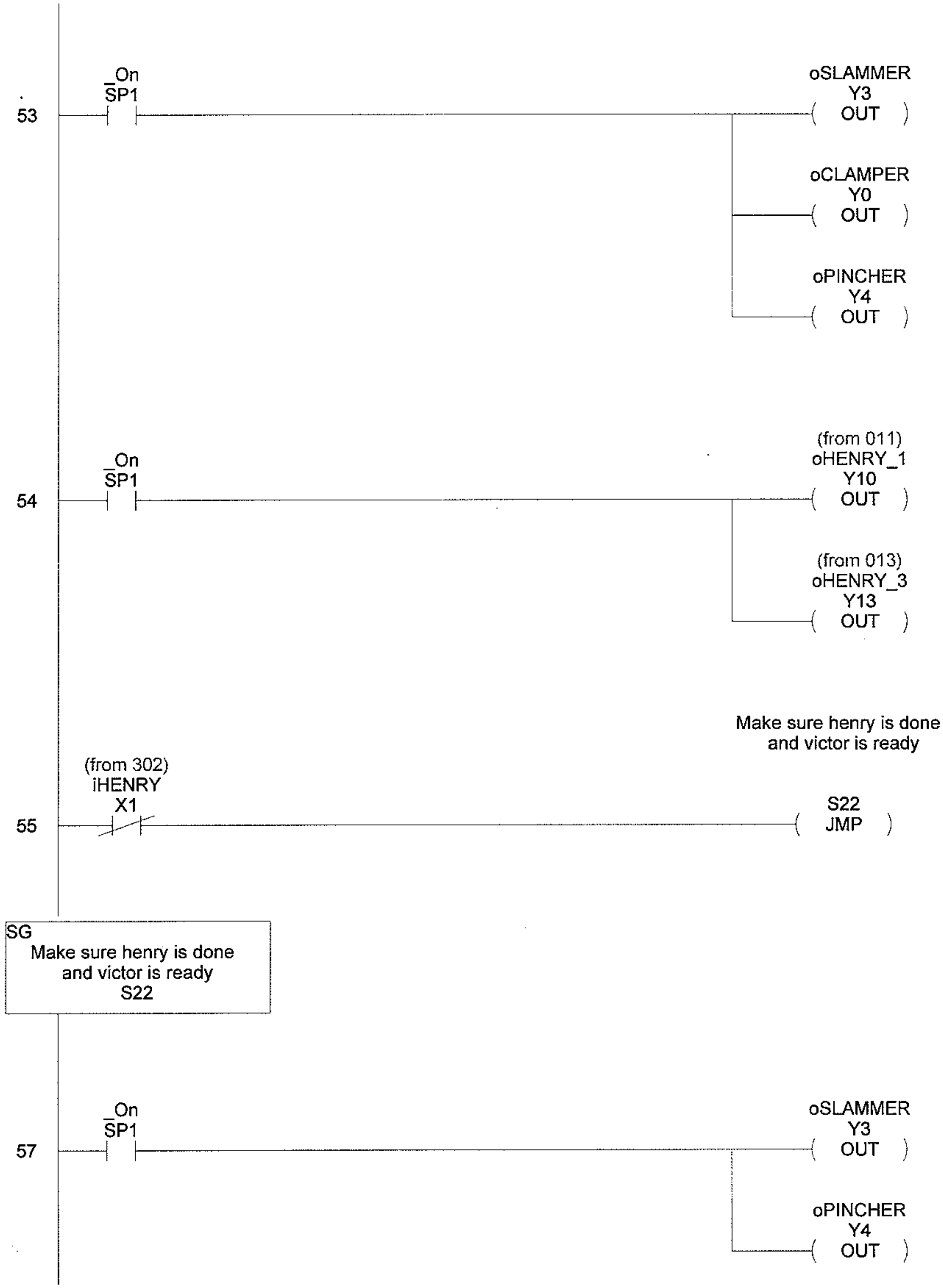

27
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
28
(from 302)
iBOB
X0
TMR
T0
K5
oCUTTER
Y5
OUT
29
T0
Go to next state if Bob is ready and make sure wire cutter has had time to open
S12
JMP
SG
Go to next state if Bob is ready and make sure wire cutter has had time to open
S12
31
(from 302)
iBOB
X0
TMR
T1
K5
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT

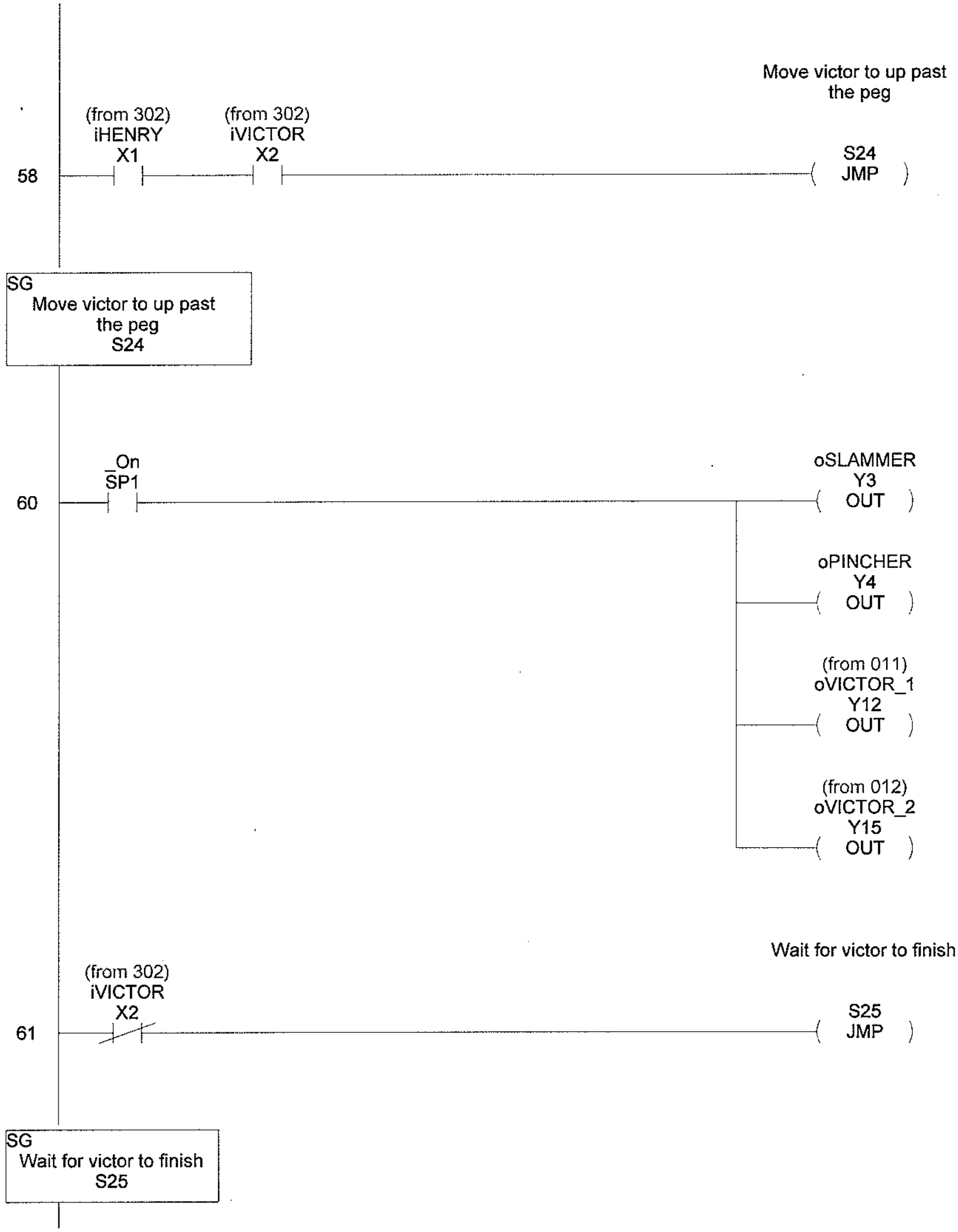

32
T1
(from 011)
oBOB_1
Y11
OUT
Make sure Victor is ready
33
(from 302)
iBOB
X0
S13
JMP
SG
Make sure Victor is ready
S13
35
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
Move Victor to be pinched
36
(from 302)
iVICTOR
X2
(from B)
iALEC
X4
S14
JMP
SG
Move Victor to be pinched
S14

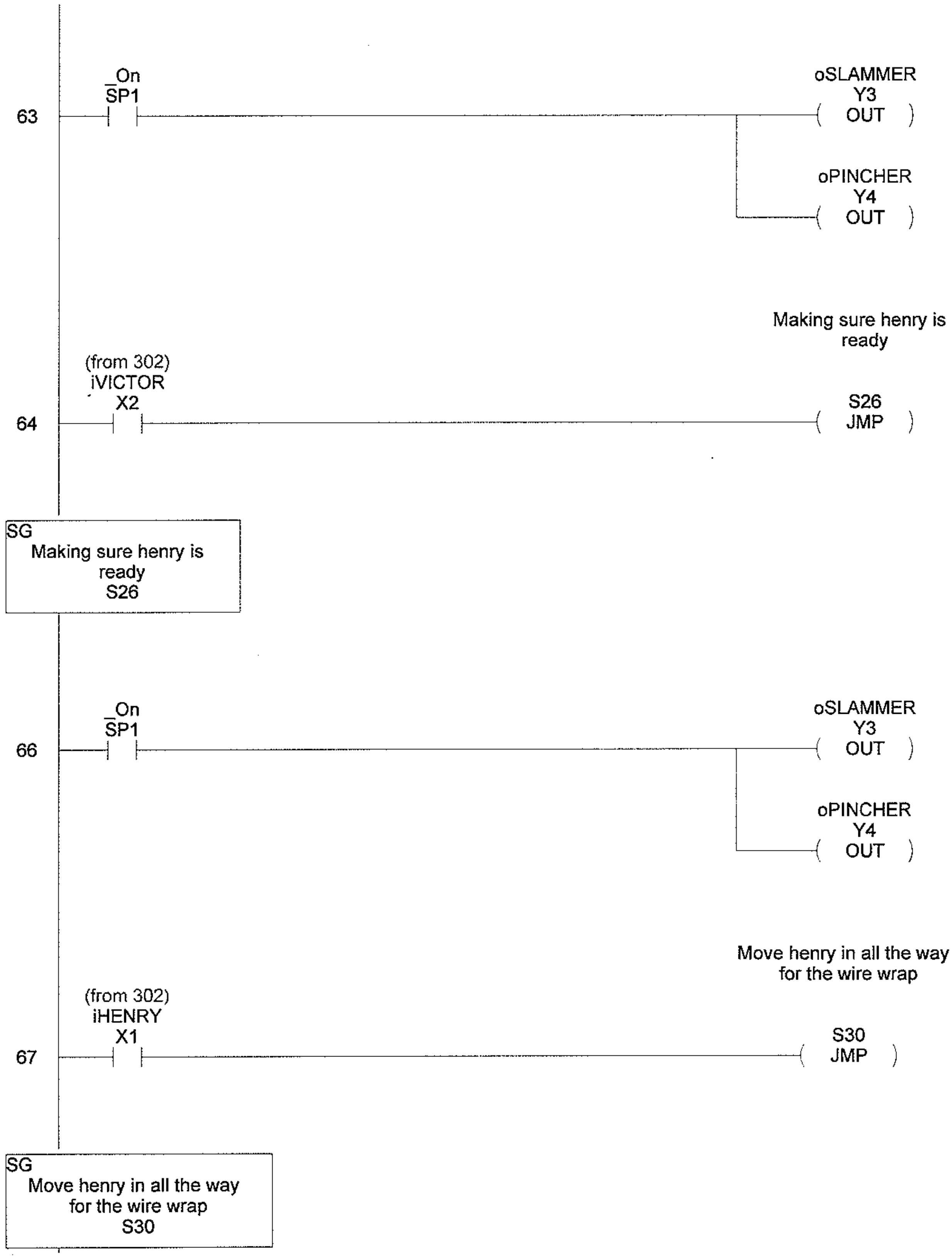

38
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
(from 011)
oVICTOR_1
Y12
OUT
Make sure henry and victor are ready
39
(from 302)
iVICTOR
X2
S15
JMP
SG
Make sure henry and victor are ready
S15
41
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
Move henry to be pinched
42
(from 302)
iHENRY
X1
(from 302)
iVICTOR
X2
S16
JMP

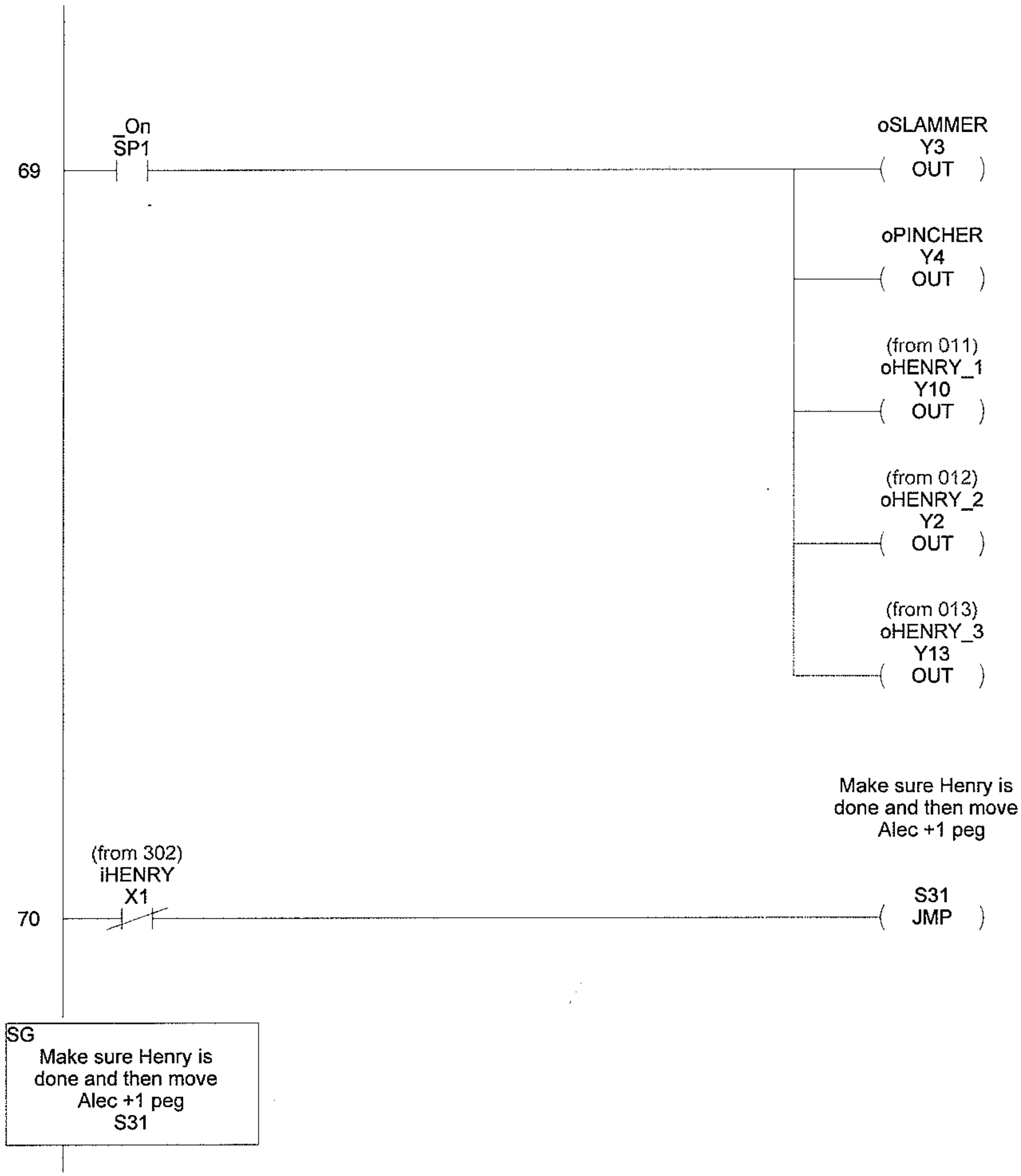

SG
Move henry to be pinched
S16
_On
SP1
44
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
(from 011)
oHENRY_1
Y10
OUT
Make sure henry has arrived
(from 302)
iHENRY
X1
45
S17
JMP
SG
Make sure henry has arrived
S17
_On
SP1
47
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT

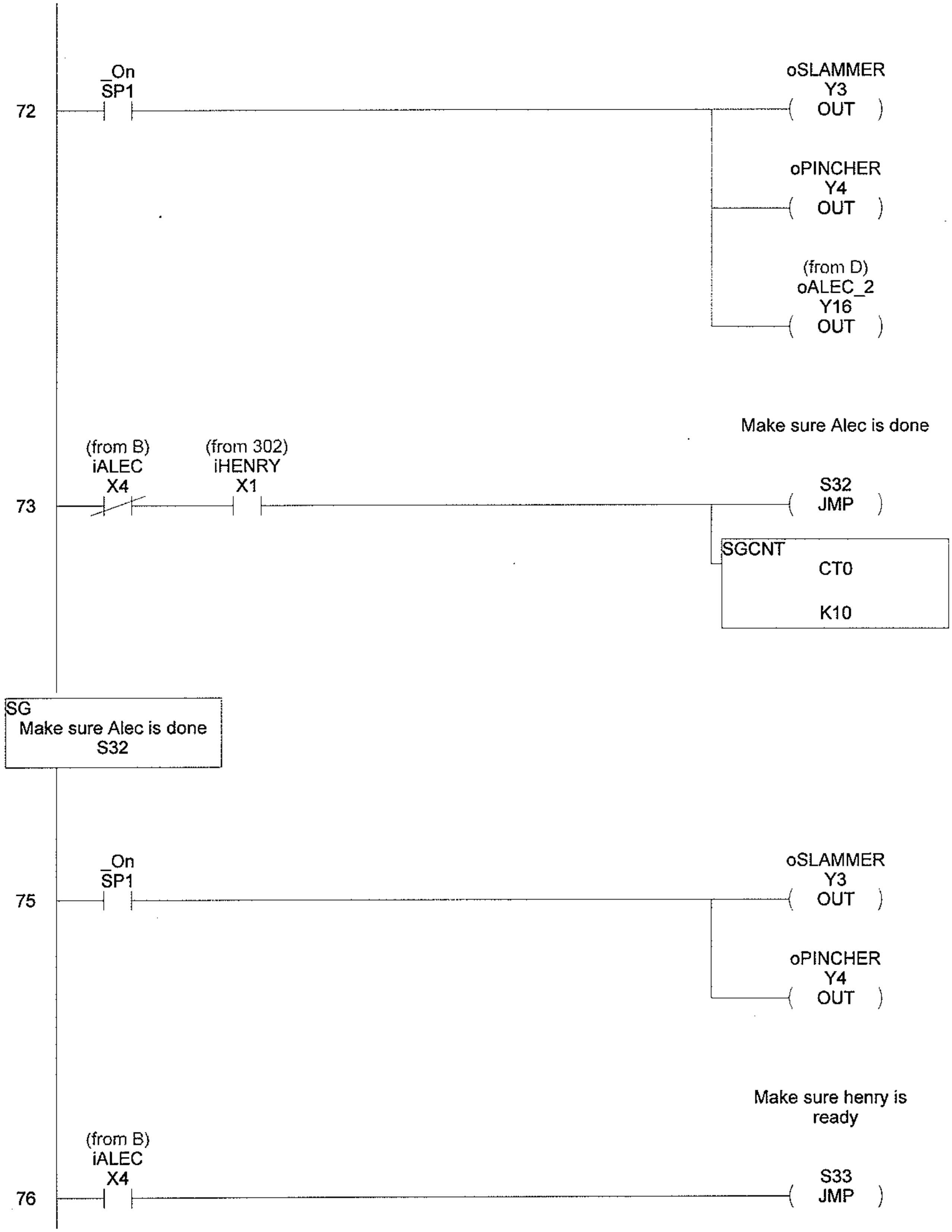

Pinch wire, wait for henry to be ready
(from 302)
iHENRY
X1
48
S20
JMP
SG
Pinch wire, wait for henry to be ready
S20
_On
SP1
50
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
oPINCHER
Y4
OUT
TMR
T3
K5
Move henry back a little bit
T3
51
S21
JMP
SG
Move henry back a little bit
S21

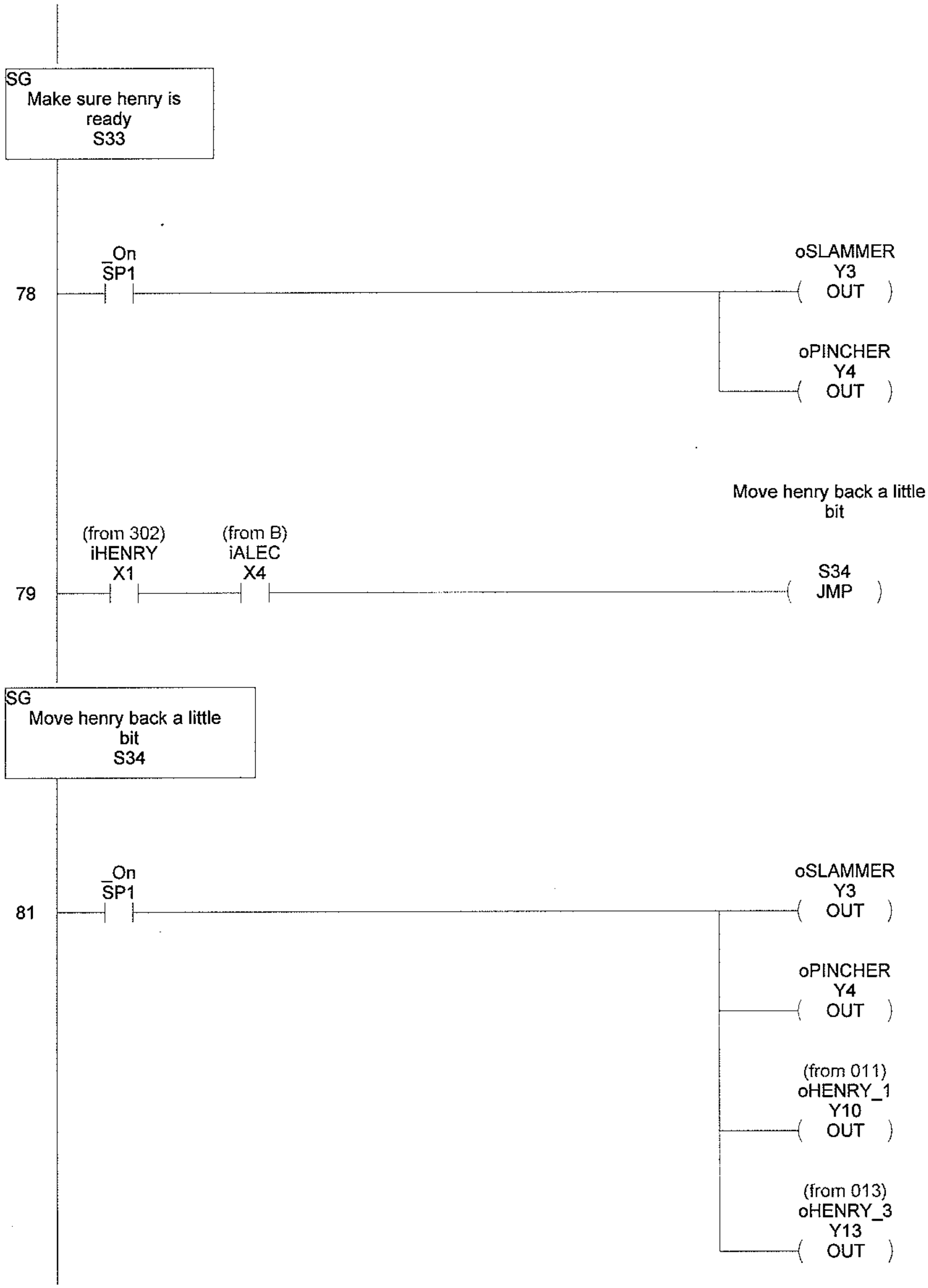

53
_On
SP1
oSLAMMER
Y3
OUT
oCLAMPER
Y0
OUT
oPINCHER
Y4
OUT
54
_On
SP1
(from 011)
oHENRY_1
Y10
OUT
(from 013)
oHENRY_3
Y13
OUT
Make sure henry is done
and victor is ready
55
(from 302)
iHENRY
X1
S22
JMP
SG
Make sure henry is done
and victor is ready
S22
57
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT

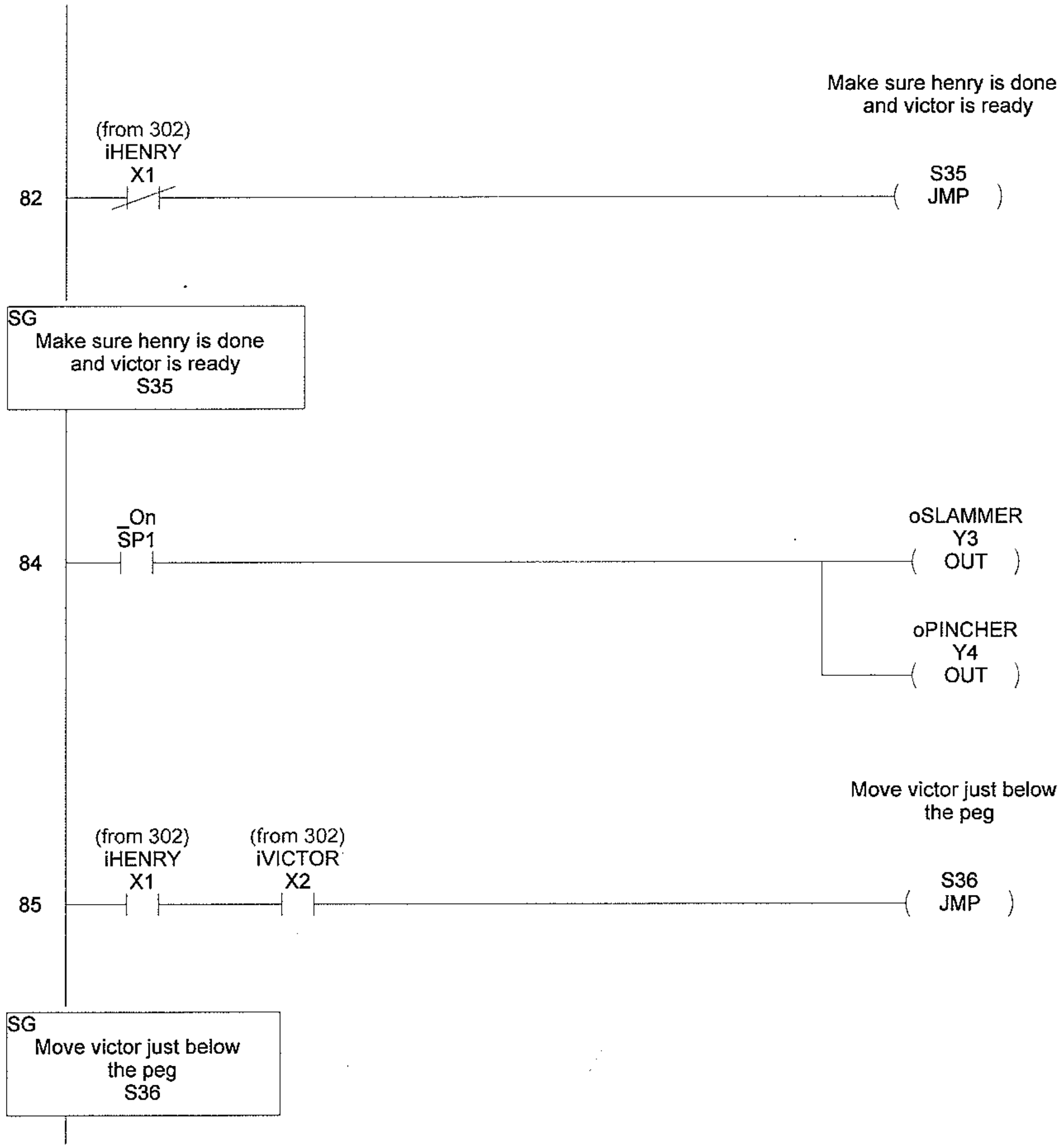

Move victor to up past the peg
(from 302)
iHENRY
X1
(from 302)
iVICTOR
X2
58
S24
JMP
SG
Move victor to up past the peg
S24
_On
SP1
60
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oVICTOR_1
Y12
OUT
(from 012)
oVICTOR_2
Y15
OUT
Wait for victor to finish
(from 302)
iVICTOR
X2
61
S25
JMP
SG
Wait for victor to finish
S25

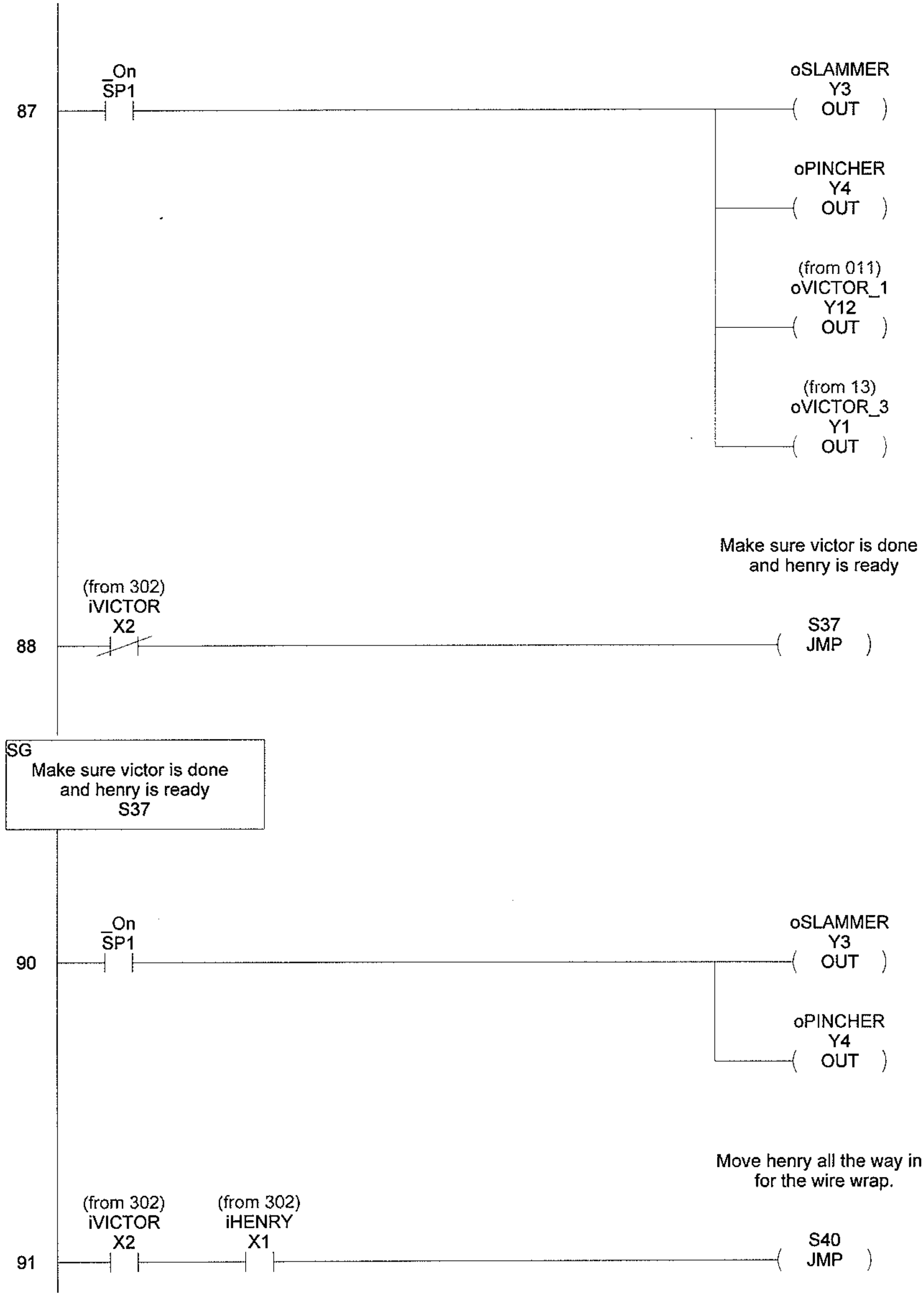

_On
SP1
63
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Making sure henry is ready
(from 302)
iVICTOR
X2
64
S26
JMP
SG
Making sure henry is ready
S26
_On
SP1
66
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Move henry in all the way for the wire wrap
(from 302)
iHENRY
X1
67
S30
JMP
SG
Move henry in all the way for the wire wrap
S30

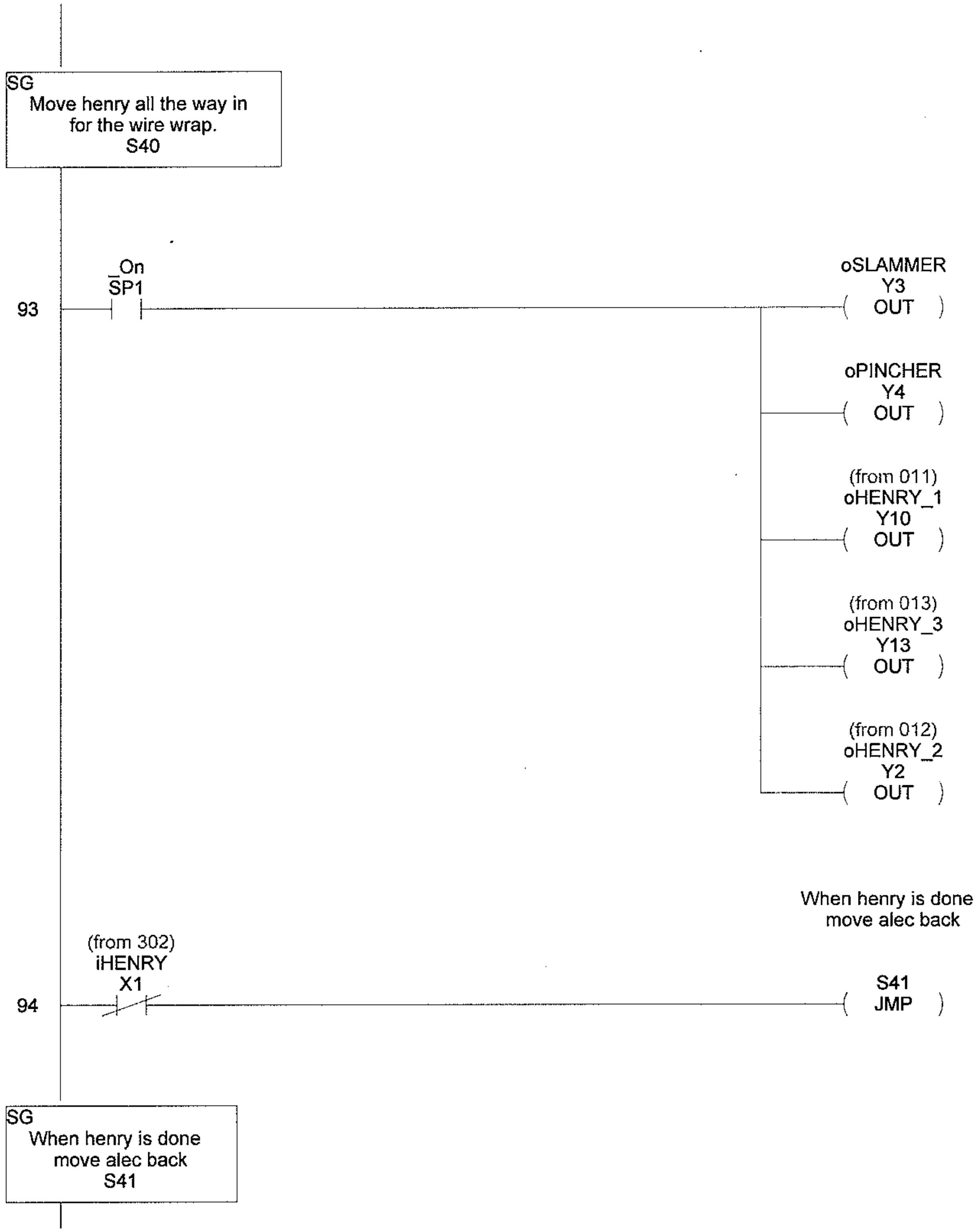

69
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 012)
oHENRY_2
Y2
OUT
(from 013)
oHENRY_3
Y13
OUT
Make sure Henry is done and then move Alec +1 peg
70
(from 302)
iHENRY
X1
S31
JMP
SG
Make sure Henry is done and then move Alec +1 peg
S31

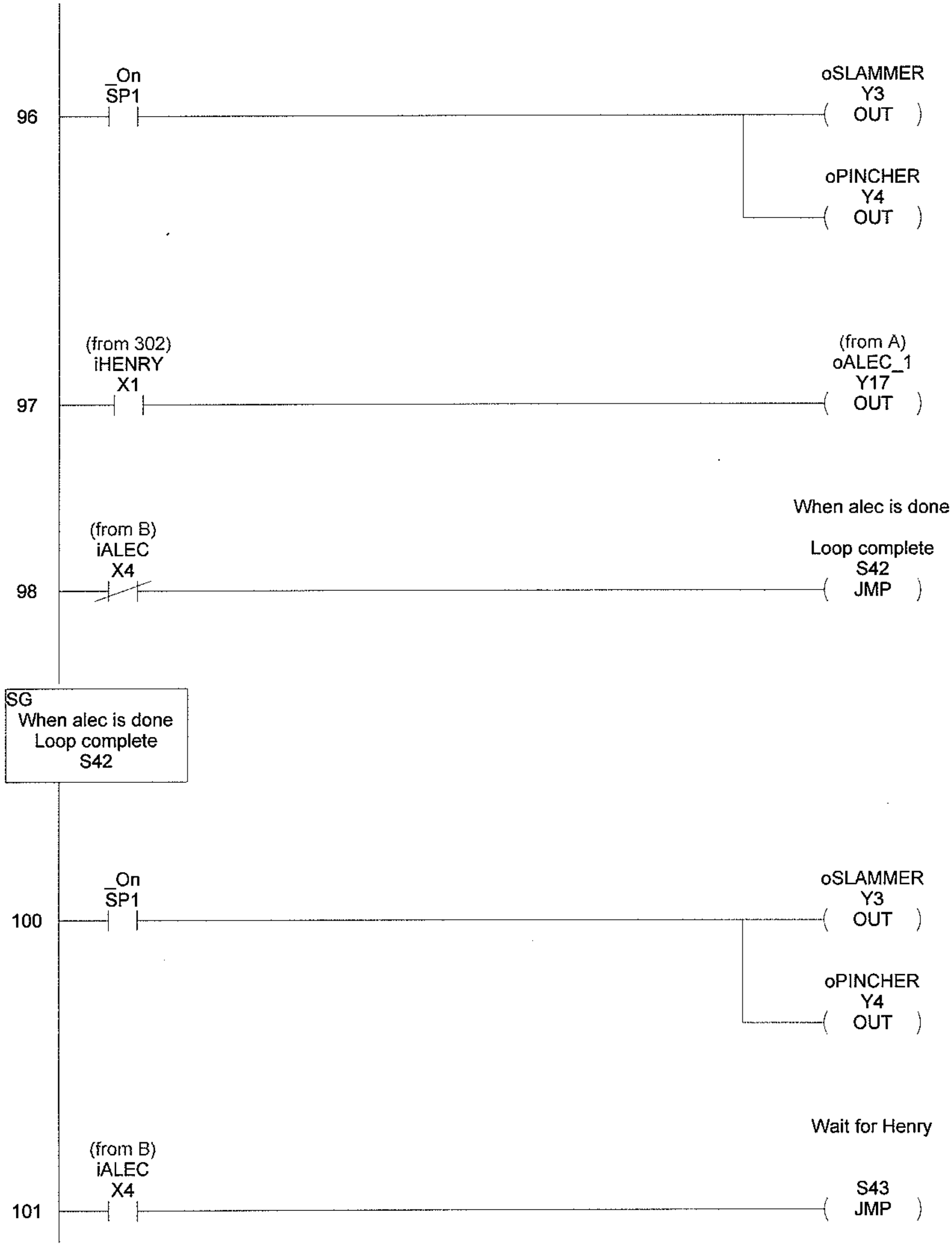

72
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from D)
oALEC_2
Y16
OUT
Make sure Alec is done
73
(from B)
iALEC
X4
(from 302)
iHENRY
X1
S32
JMP
SGCNT
CT0
K10
SG
Make sure Alec is done
S32
75
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Make sure henry is ready
76
(from B)
iALEC
X4
S33
JMP

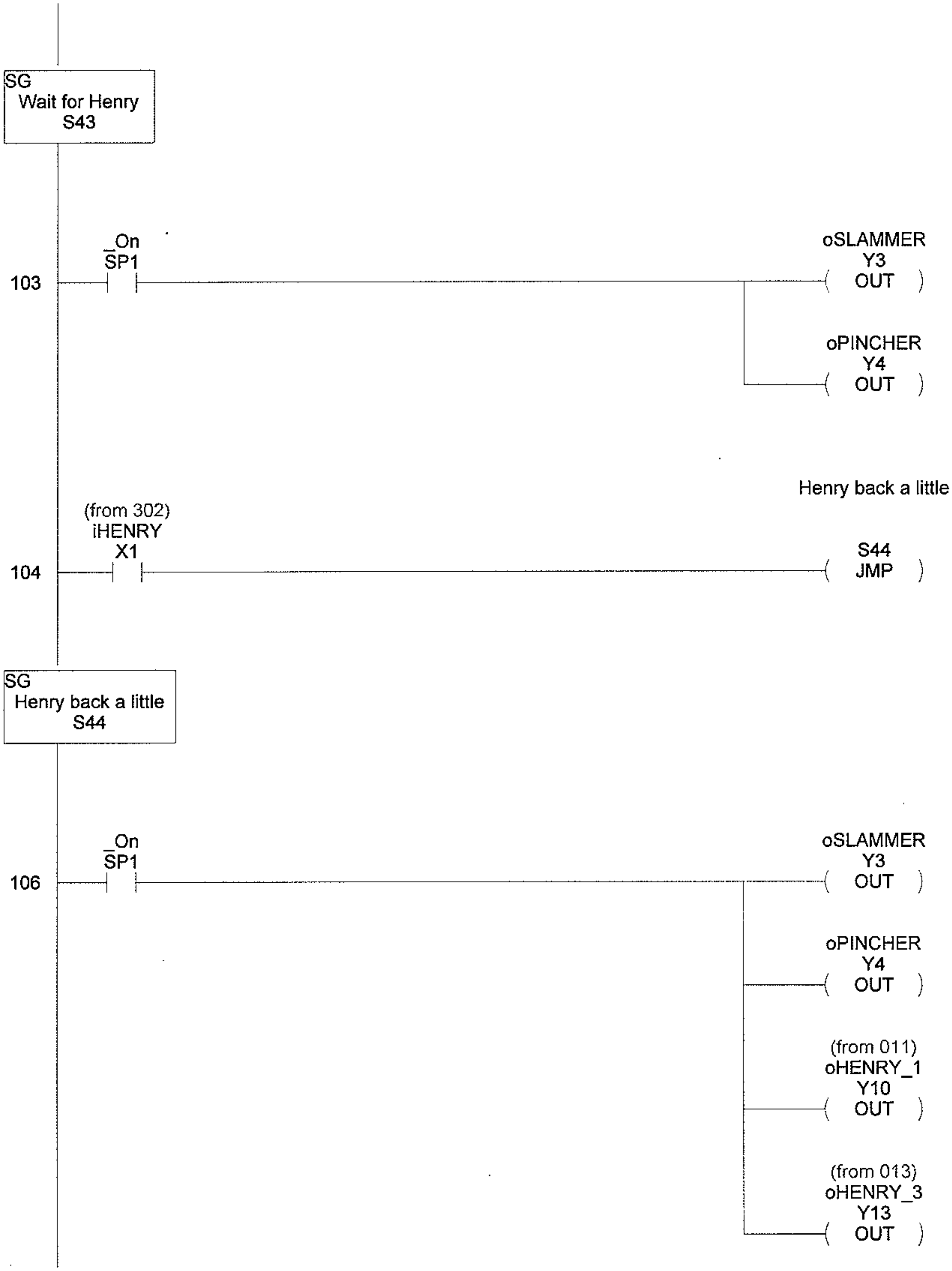

SG
Make sure henry is ready
S33
78
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Move henry back a little bit
79
(from 302)
iHENRY
X1
(from B)
iALEC
X4
S34
JMP
SG
Move henry back a little bit
S34
81
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 013)
oHENRY_3
Y13
OUT

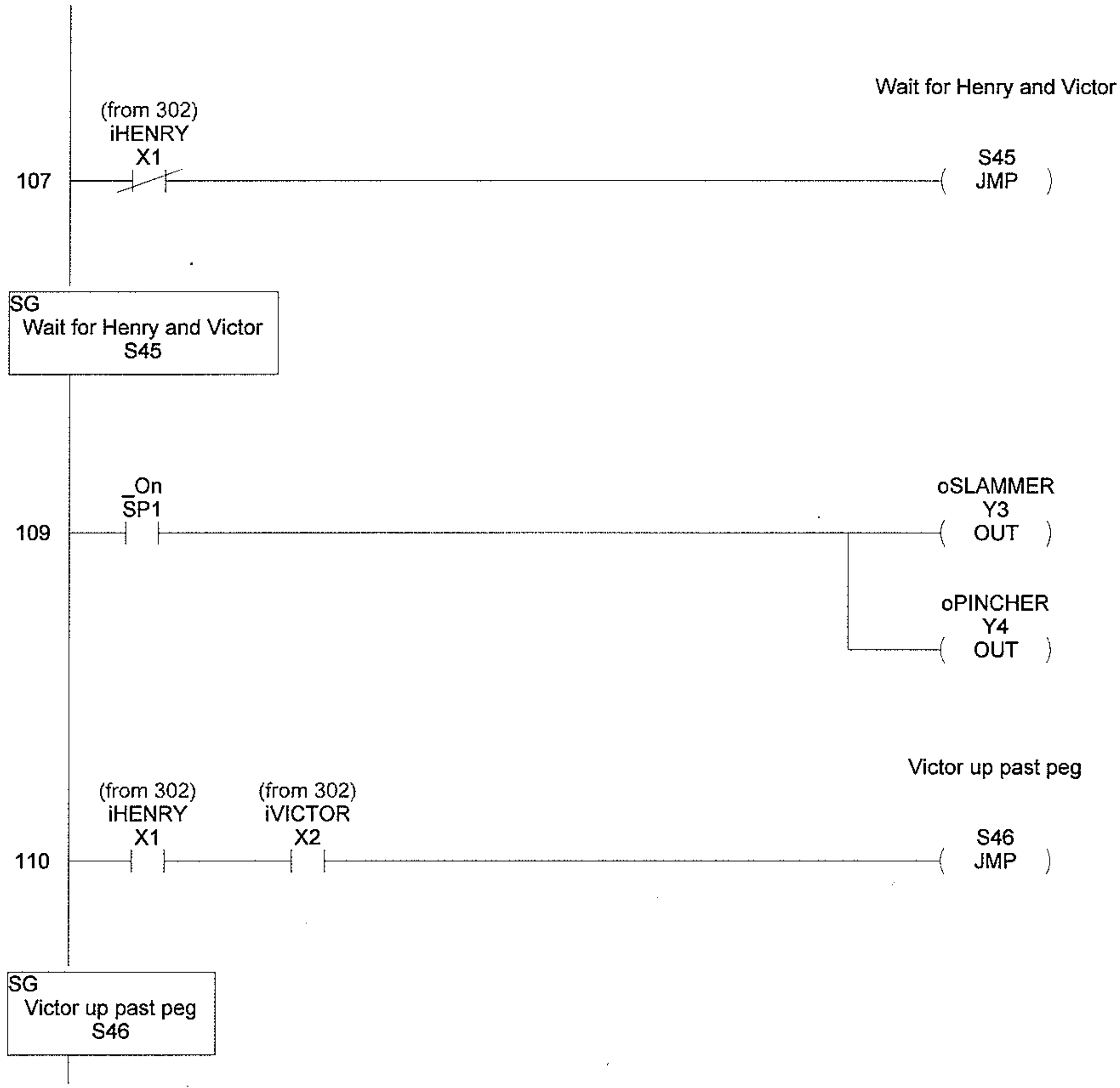

Make sure henry is done
and victor is ready
(from 302)
iHENRY
X1
82
S35
JMP
SG
Make sure henry is done
and victor is ready
S35
_On
SP1
84
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Move victor just below
the peg
(from 302)
iHENRY
X1
(from 302)
iVICTOR
X2
85
S36
JMP
SG
Move victor just below
the peg
S36

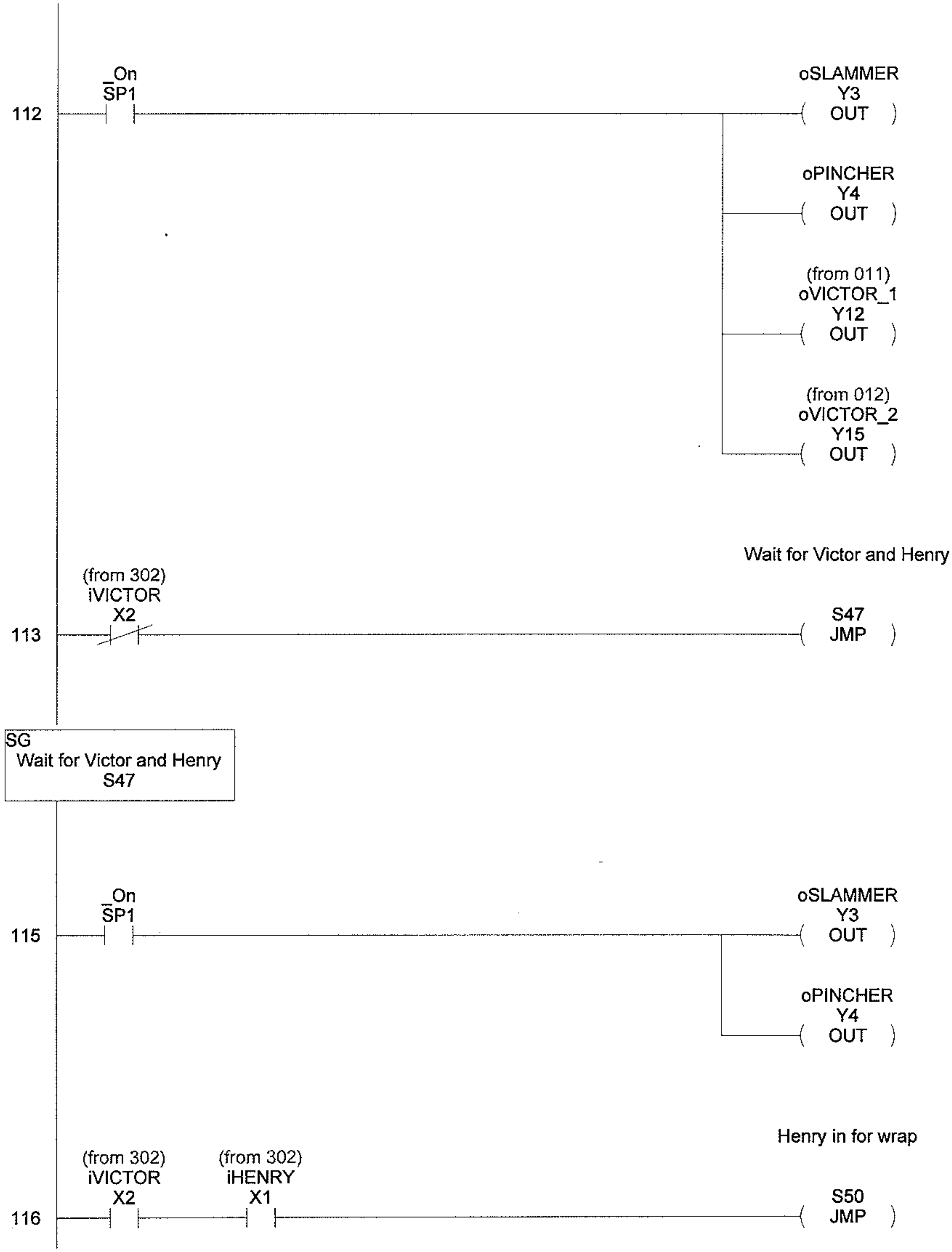

87
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oVICTOR_1
Y12
OUT
(from 13)
oVICTOR_3
Y1
OUT
Make sure victor is done and henry is ready
88
(from 302)
iVICTOR
X2
S37
JMP
SG
Make sure victor is done and henry is ready
S37
90
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Move henry all the way in for the wire wrap.
91
(from 302)
iVICTOR
X2
(from 302)
iHENRY
X1
S40
JMP

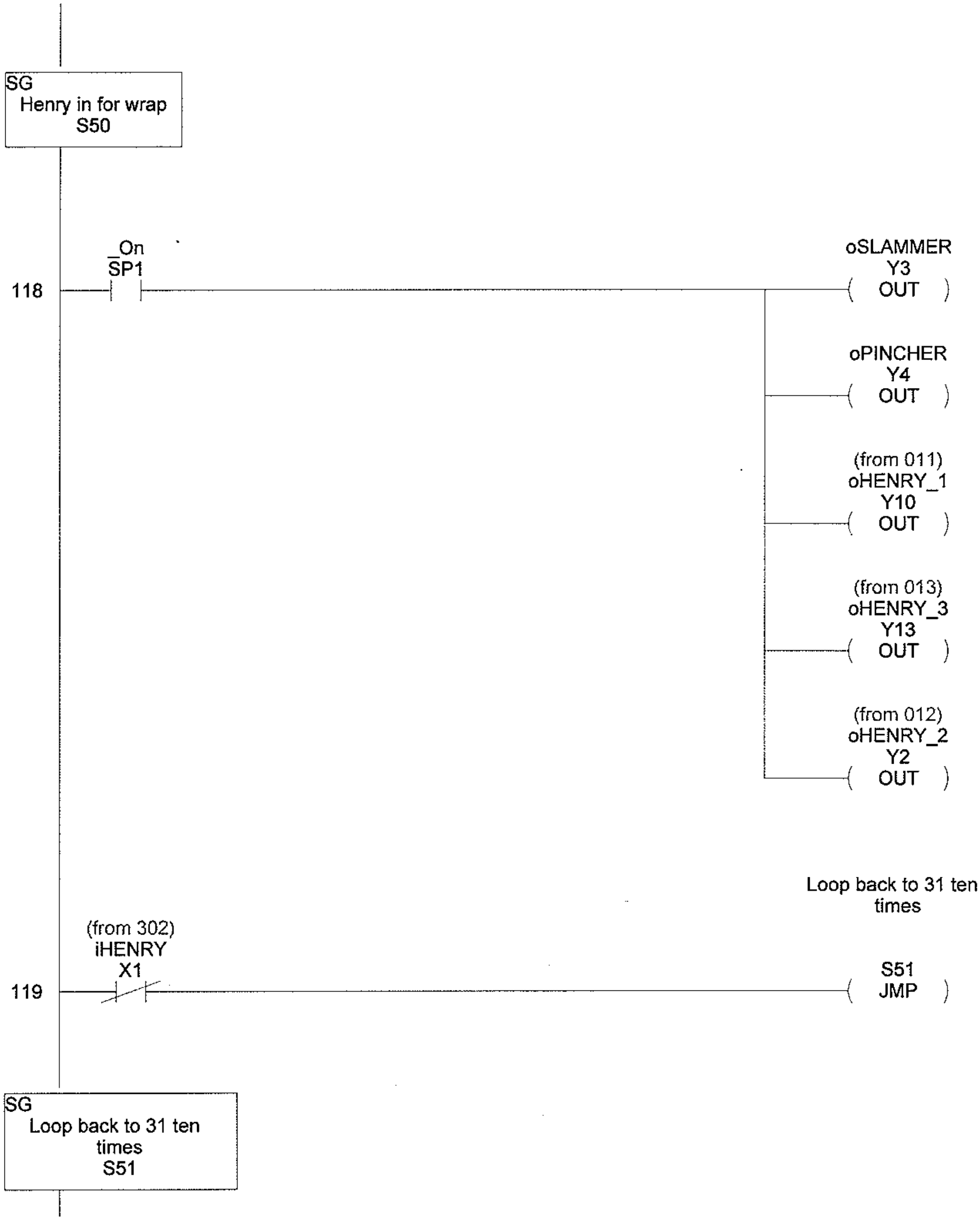

SG
Move henry all the way in
for the wire wrap.
S40
93
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 013)
oHENRY_3
Y13
OUT
(from 012)
oHENRY_2
Y2
OUT
When henry is done
move alec back
94
(from 302)
iHENRY
X1
S41
JMP
SG
When henry is done
move alec back
S41

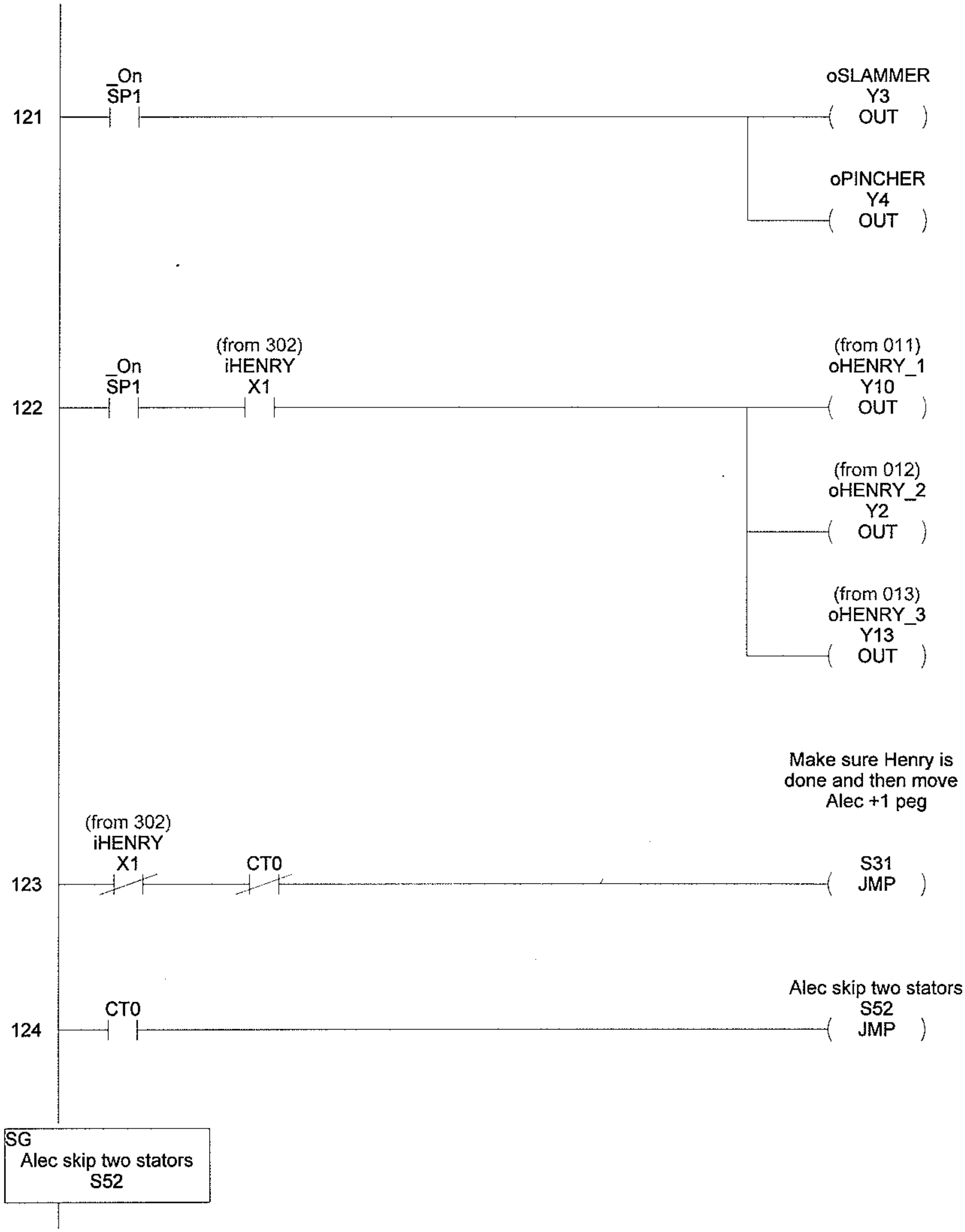

96
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
97
(from 302)
iHENRY
X1
(from A)
oALEC_1
Y17
OUT
98
(from B)
iALEC
X4
When alec is done
Loop complete
S42
JMP
SG
When alec is done
Loop complete
S42
100
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
101
(from B)
iALEC
X4
Wait for Henry
S43
JMP

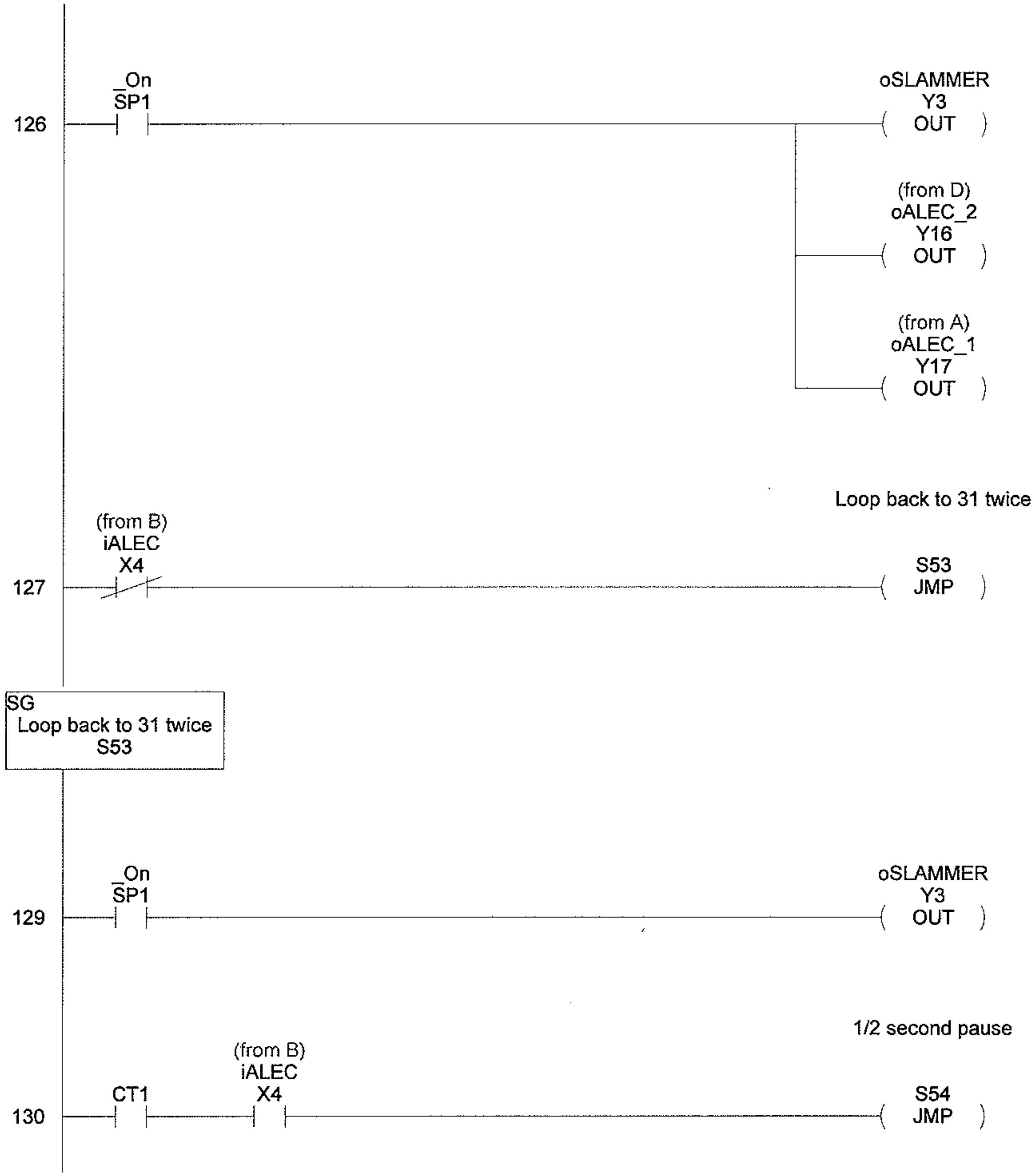

SG
Wait for Henry
S43
103
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
104
(from 302)
iHENRY
X1
Henry back a little
S44
JMP
SG
Henry back a little
S44
106
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 013)
oHENRY_3
Y13
OUT

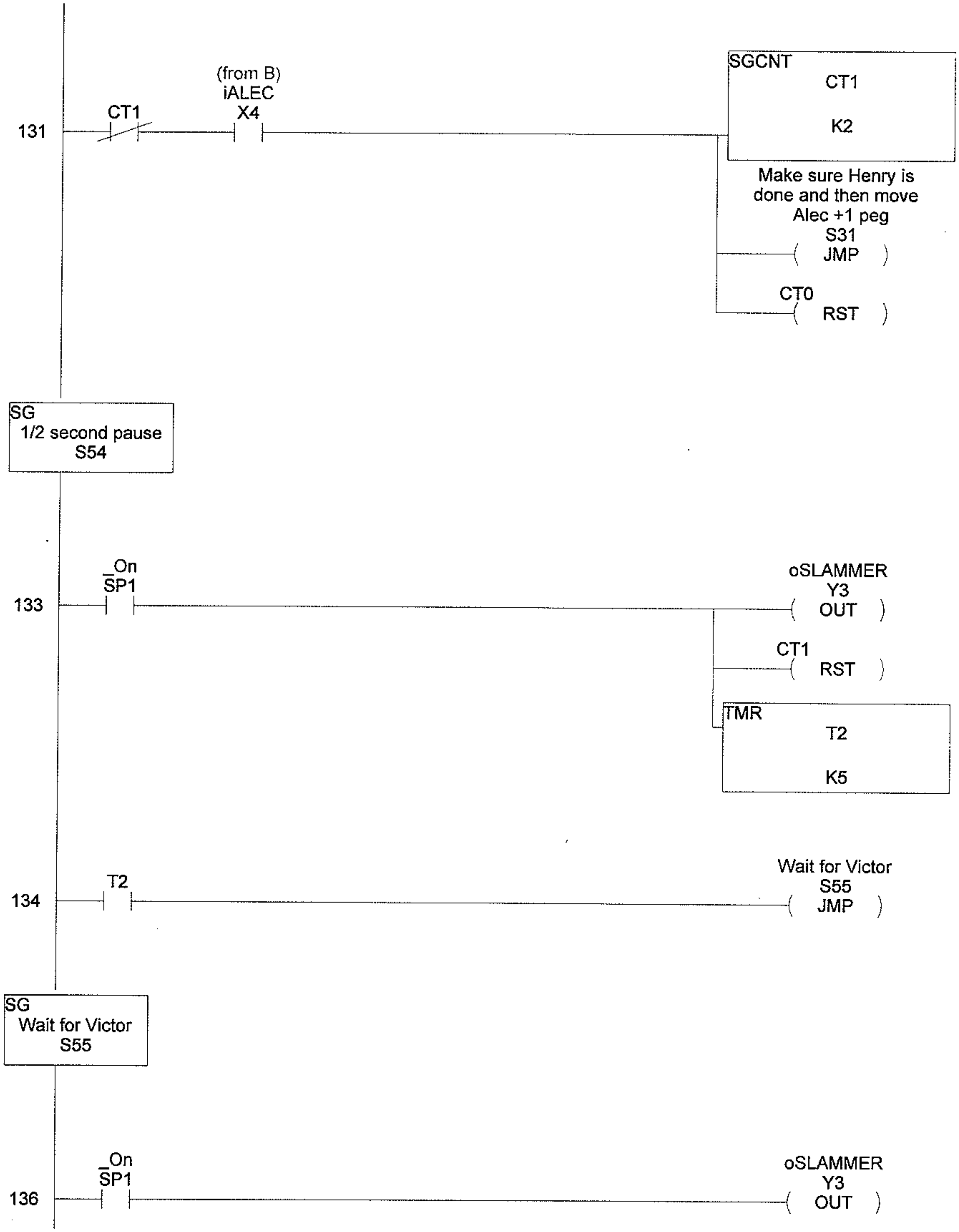

Wait for Henry and Victor
(from 302)
iHENRY
X1
107
S45
JMP
SG
Wait for Henry and Victor
S45
_On
SP1
109
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Victor up past peg
(from 302)
iHENRY
X1
(from 302)
iVICTOR
X2
110
S46
JMP
SG
Victor up past peg
S46

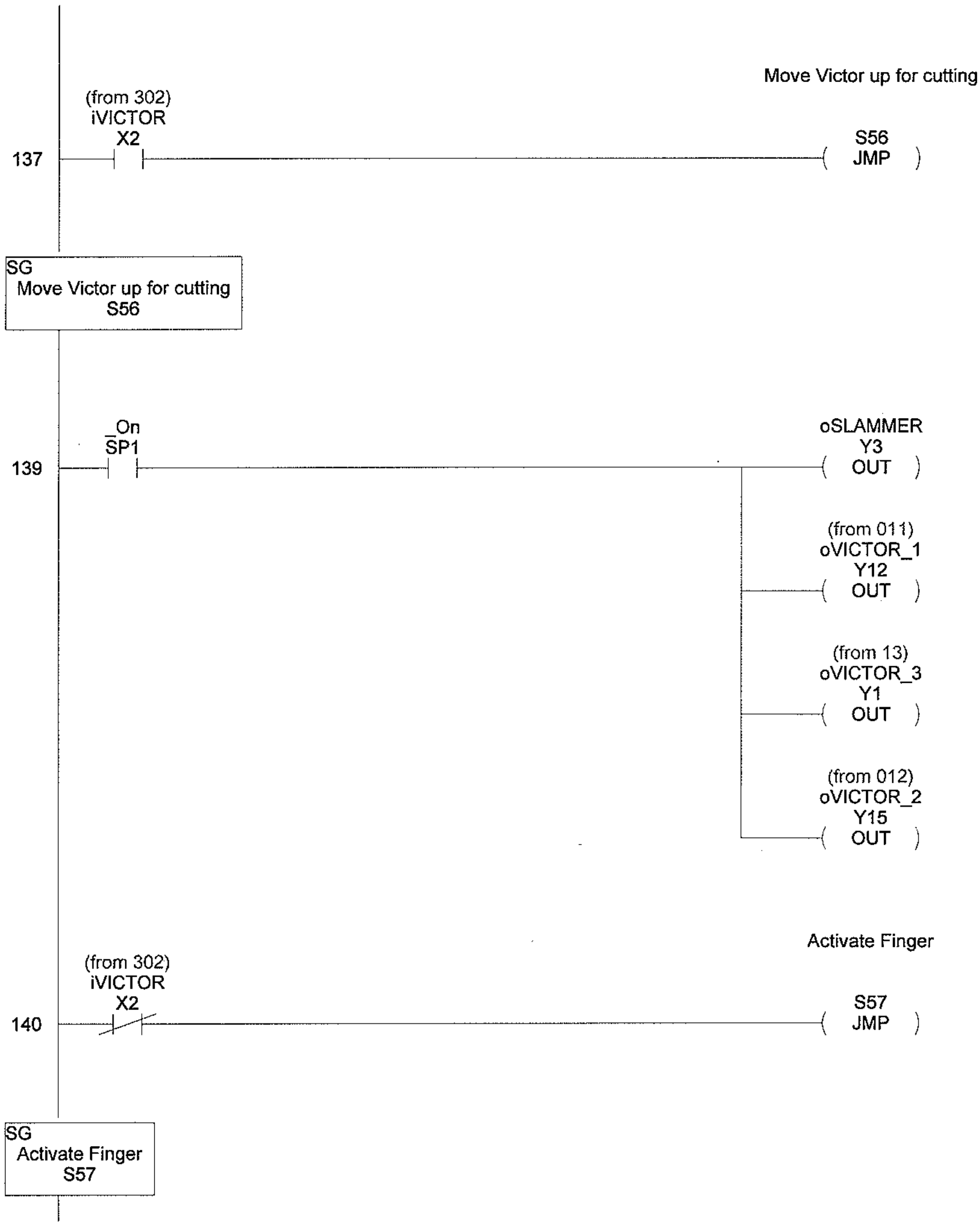

112
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oVICTOR_1
Y12
OUT
(from 012)
oVICTOR_2
Y15
OUT
Wait for Victor and Henry
113
(from 302)
iVICTOR
X2
S47
JMP
SG
Wait for Victor and Henry
S47
115
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
Henry in for wrap
116
(from 302)
iVICTOR
X2
(from 302)
iHENRY
X1
S50
JMP


SG
Henry in for wrap
S50
118
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 013)
oHENRY_3
Y13
OUT
(from 012)
oHENRY_2
Y2
OUT
119
(from 302)
iHENRY
X1
Loop back to 31 ten
times
S51
JMP
SG
Loop back to 31 ten
times
S51

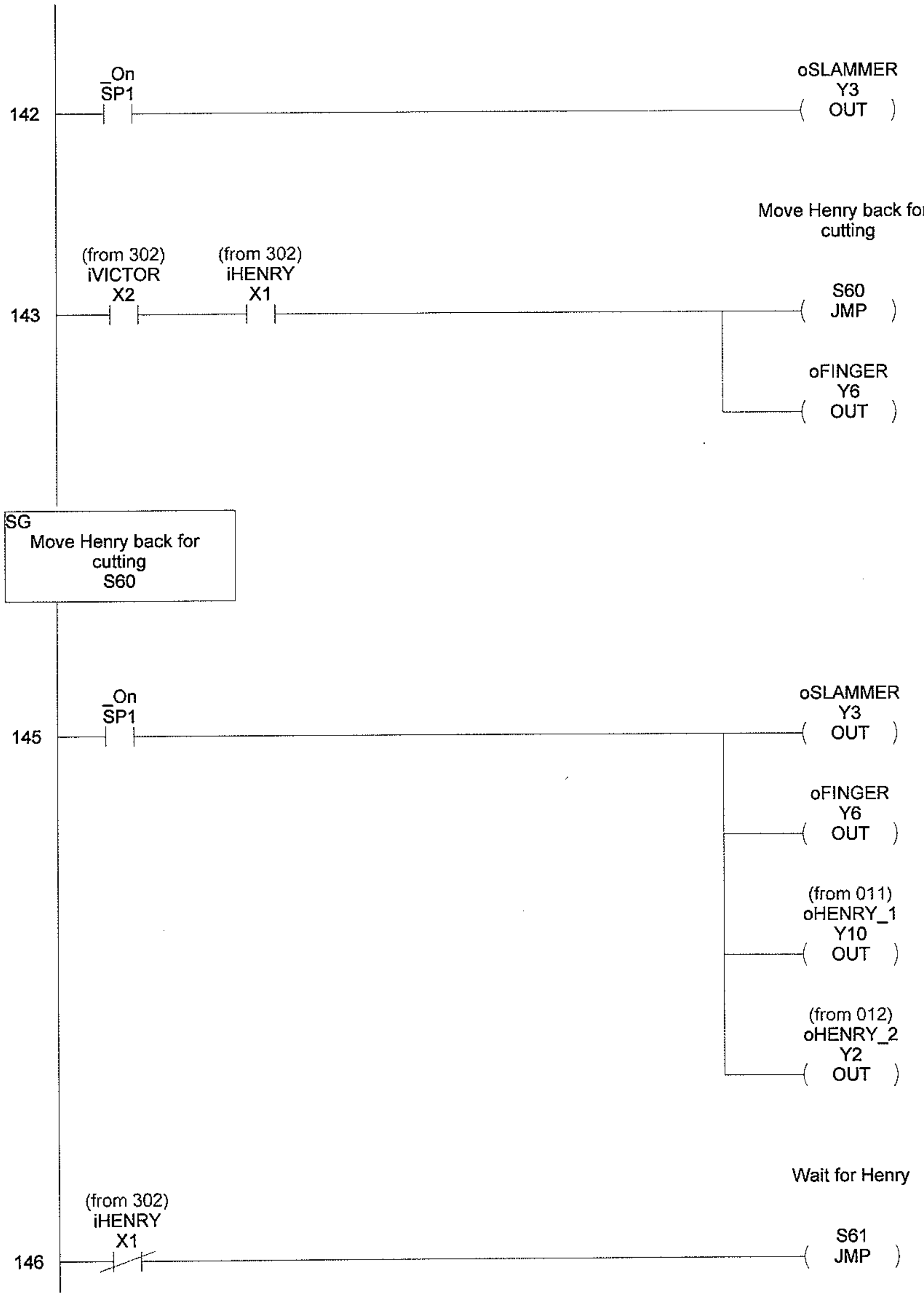

121
_On
SP1
oSLAMMER
Y3
OUT
oPINCHER
Y4
OUT
122
_On
SP1
(from 302)
iHENRY
X1
(from 011)
oHENRY_1
Y10
OUT
(from 012)
oHENRY_2
Y2
OUT
(from 013)
oHENRY_3
Y13
OUT
Make sure Henry is done and then move Alec +1 peg
123
(from 302)
iHENRY
X1
CT0
S31
JMP
124
CT0
Alec skip two stators
S52
JMP
SG
Alec skip two stators
S52

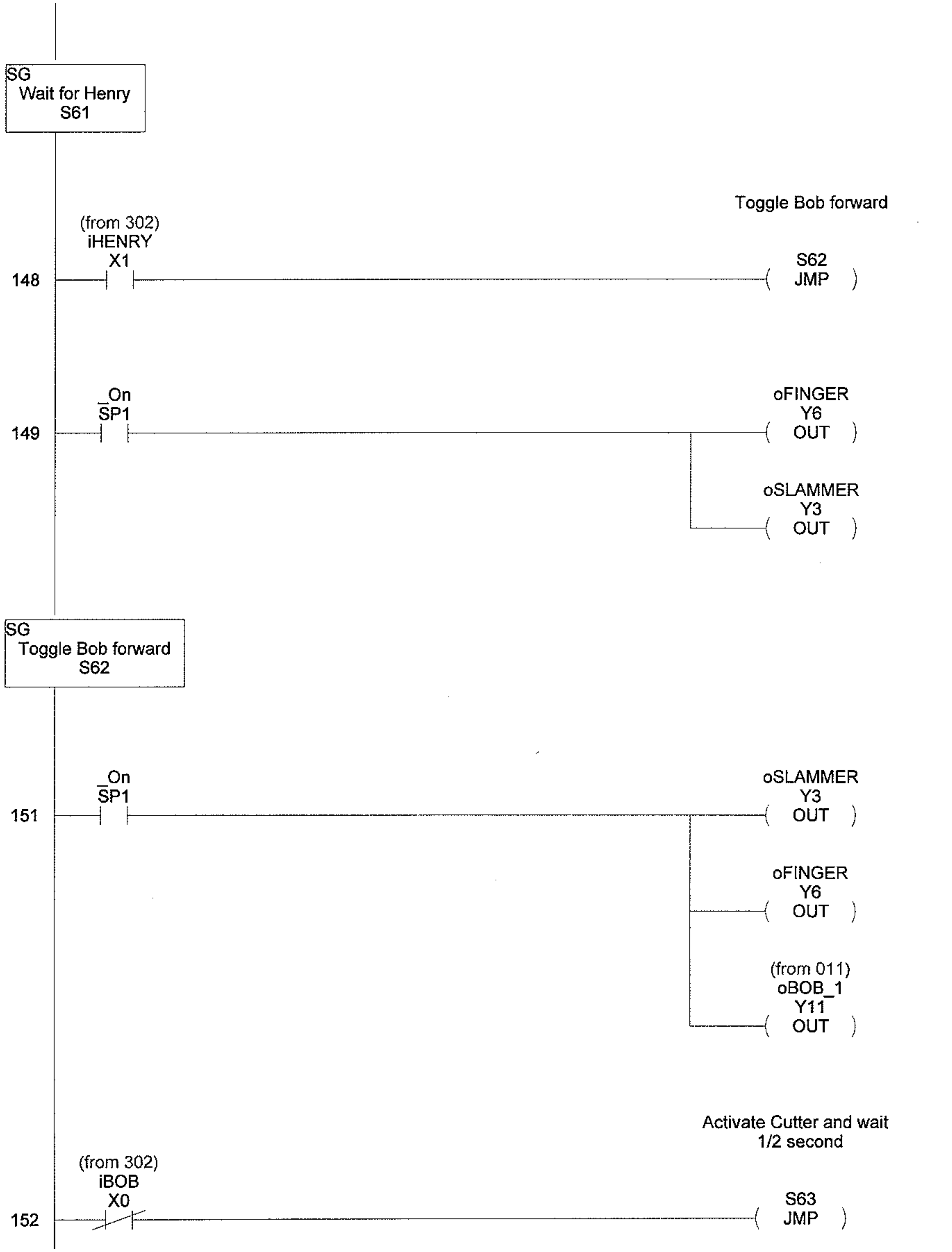

126
_On
SP1
oSLAMMER
Y3
OUT
(from D)
oALEC_2
Y16
OUT
(from A)
oALEC_1
Y17
OUT
Loop back to 31 twice
127
(from B)
iALEC
X4
S53
JMP
SG
Loop back to 31 twice
S53
129
_On
SP1
oSLAMMER
Y3
OUT
1/2 second pause
130
CT1
(from B)
iALEC
X4
S54
JMP

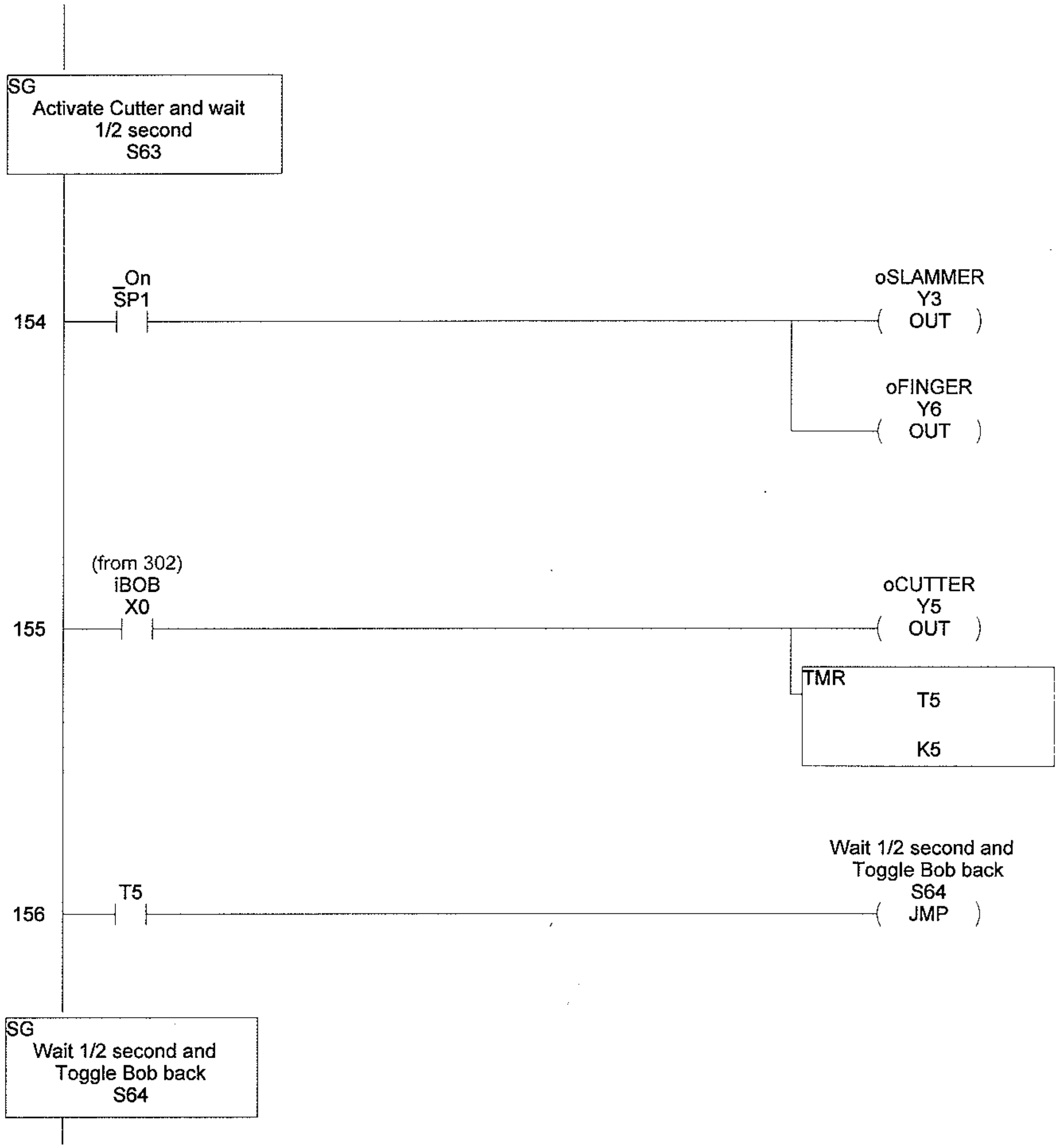

131
CT1
(from B)
iALEC
X4
SGCNT
CT1
K2
Make sure Henry is done and then move Alec +1 peg
S31
JMP
CT0
RST
SG
1/2 second pause
S54
133
_On
SP1
oSLAMMER
Y3
OUT
CT1
RST
TMR
T2
K5
134
T2
Wait for Victor
S55
JMP
SG
Wait for Victor
S55
136
_On
SP1
oSLAMMER
Y3
OUT

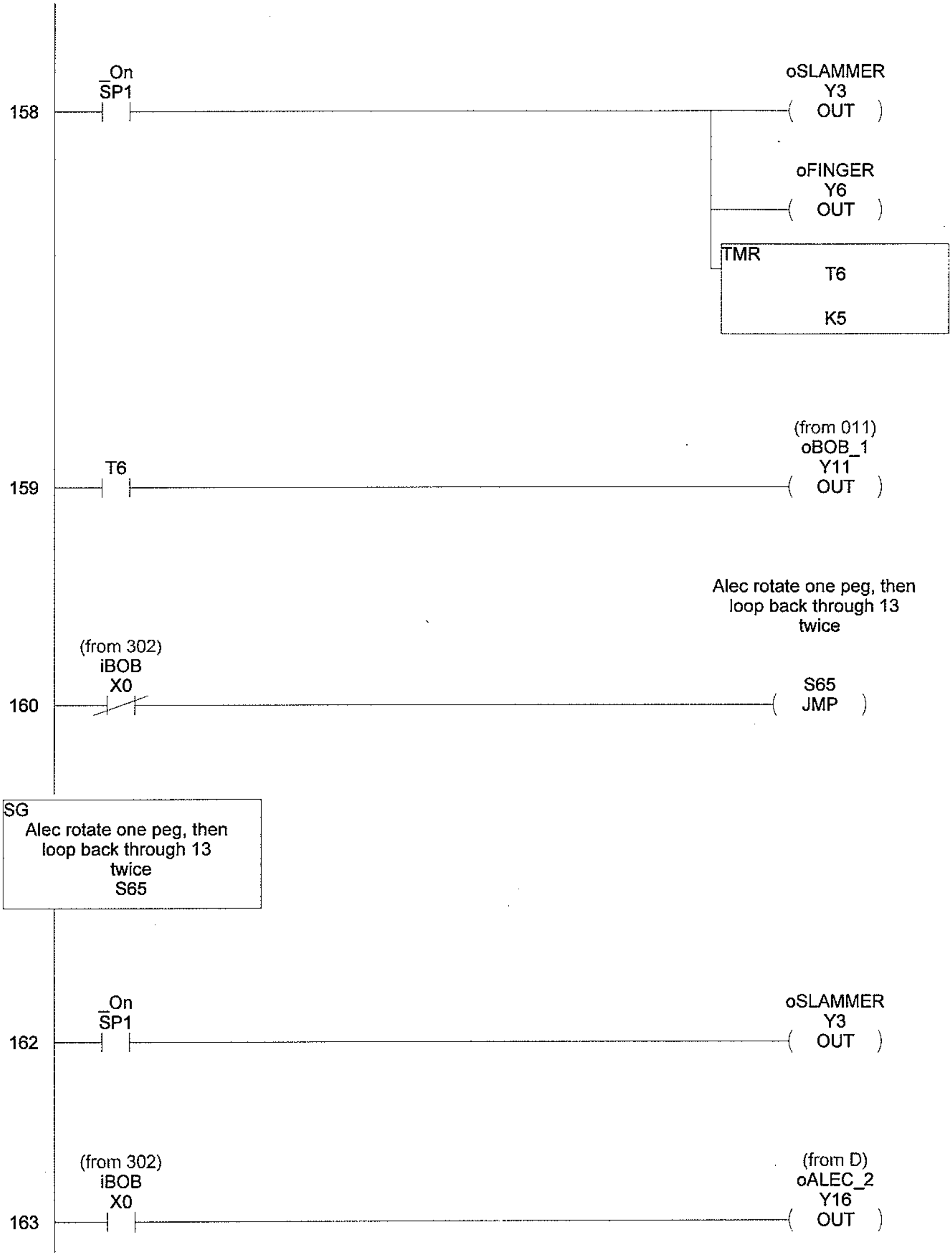


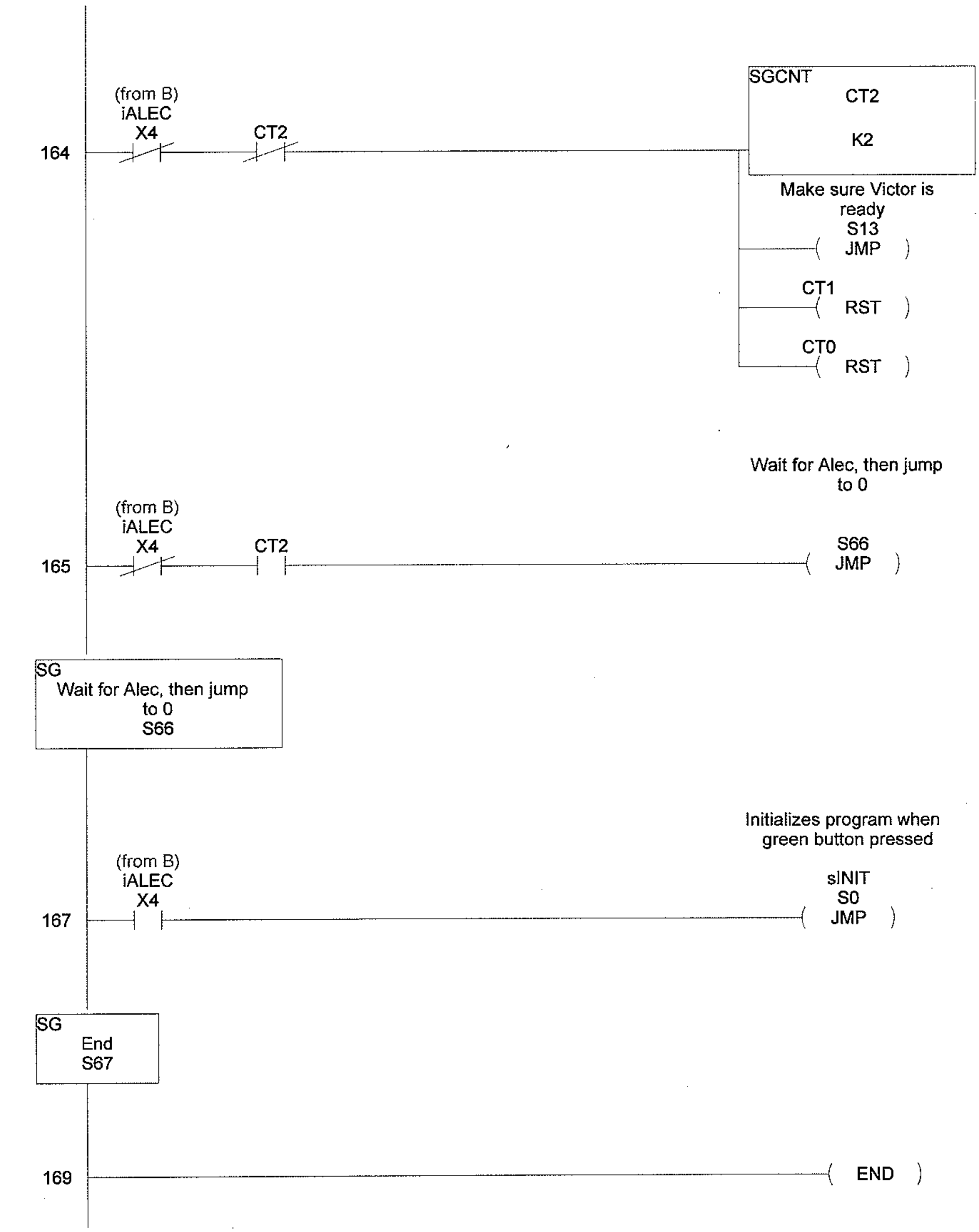
Move Victor up for cutting
(from 302)
iVICTOR
X2
137
S56
JMP
SG
Move Victor up for cutting
S56
_On
SP1
139
oSLAMMER
Y3
OUT
(from 011)
oVICTOR_1
Y12
OUT
(from 13)
oVICTOR_3
Y1
OUT
(from 012)
oVICTOR_2
Y15
OUT
Activate Finger
(from 302)
iVICTOR
X2
140
S57
JMP
SG
Activate Finger
S57


142
_On
SP1
oSLAMMER
Y3
OUT
Move Henry back for cutting
143
(from 302)
iVICTOR
X2
(from 302)
iHENRY
X1
S60
JMP
oFINGER
Y6
OUT
SG
Move Henry back for cutting
S60
145
_On
SP1
oSLAMMER
Y3
OUT
oFINGER
Y6
OUT
(from 011)
oHENRY_1
Y10
OUT
(from 012)
oHENRY_2
Y2
OUT
Wait for Henry
146
(from 302)
iHENRY
X1
S61
JMP


SG
Wait for Henry
S61
Toggle Bob forward
(from 302)
iHENRY
X1
148
S62
JMP
_On
SP1
149
oFINGER
Y6
OUT
oSLAMMER
Y3
OUT
SG
Toggle Bob forward
S62
_On
SP1
151
oSLAMMER
Y3
OUT
oFINGER
Y6
OUT
(from 011)
oBOB_1
Y11
OUT
Activate Cutter and wait
1/2 second
(from 302)
iBOB
X0
152
S63
JMP


SG
Activate Cutter and wait
1/2 second
S63
_On
SP1
154
oSLAMMER
Y3
OUT
oFINGER
Y6
OUT
(from 302)
iBOB
X0
155
oCUTTER
Y5
OUT
TMR
T5
K5
T5
156
Wait 1/2 second and
Toggle Bob back
S64
JMP
SG
Wait 1/2 second and
Toggle Bob back
S64


158
_On
SP1
oSLAMMER
Y3
OUT
oFINGER
Y6
OUT
TMR
T6
K5
159
T6
(from 011)
oBOB_1
Y11
OUT
Alec rotate one peg, then
loop back through 13
twice
160
(from 302)
iBOB
X0
S65
JMP
SG
Alec rotate one peg, then
loop back through 13
twice
S65
162
_On
SP1
oSLAMMER
Y3
OUT
163
(from 302)
iBOB
X0
(from D)
oALEC_2
Y16
OUT


164
(from B)
iALEC
X4
CT2
SGCNT
CT2
K2
Make sure Victor is ready
S13
JMP
CT1
RST
CT0
RST
165
(from B)
iALEC
X4
CT2
Wait for Alec, then jump to 0
S66
JMP
SG
Wait for Alec, then jump to 0
S66
167
(from B)
iALEC
X4
Initializes program when green button pressed
sINIT
S0
JMP
SG
End
S67
169
END