Simulating a G.W. Bliss Punch Press Combination Clutch and Motor Control, Version 1.0

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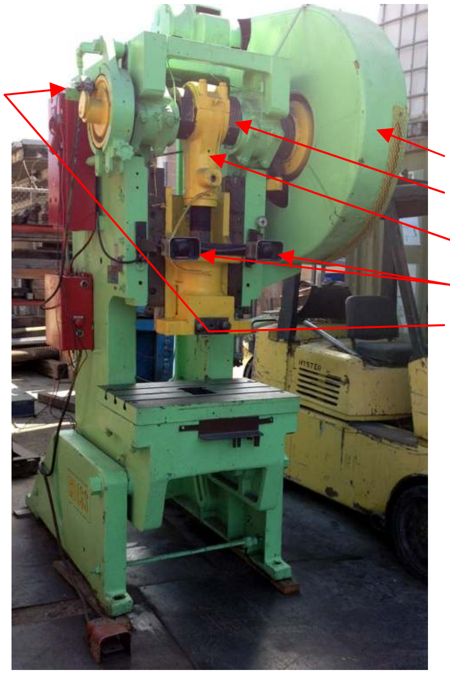
Scope

This article explains the operation of the D46H-002 Combination Clutch and Motor Control found on a G.W. Bliss Punch Press. The schematic was last updated 3/31/1981(see appendix). An Excel based simulator has been developed that predicts relay logic outputs based on the schematic and helped in the debugging of the controller. I'm no expert on this machine so welcome others to help me correct any errors in the article.



This is not the punch press we fixed but does show all key elements.

Flywheel
Crank shaft
Ram
RUN buttons
Rotary Limit Switch

Not shown:

- the clutch that connects the flywheel to the crank shaft when compressed air is applied
- the brake that stops the motion of the ram when not driven by the flywheel

Overview of A Punch Cycle from an Energy Standpoint

Energy within the punch press is stored in the flywheel. The faster it turns, the more energy stored.

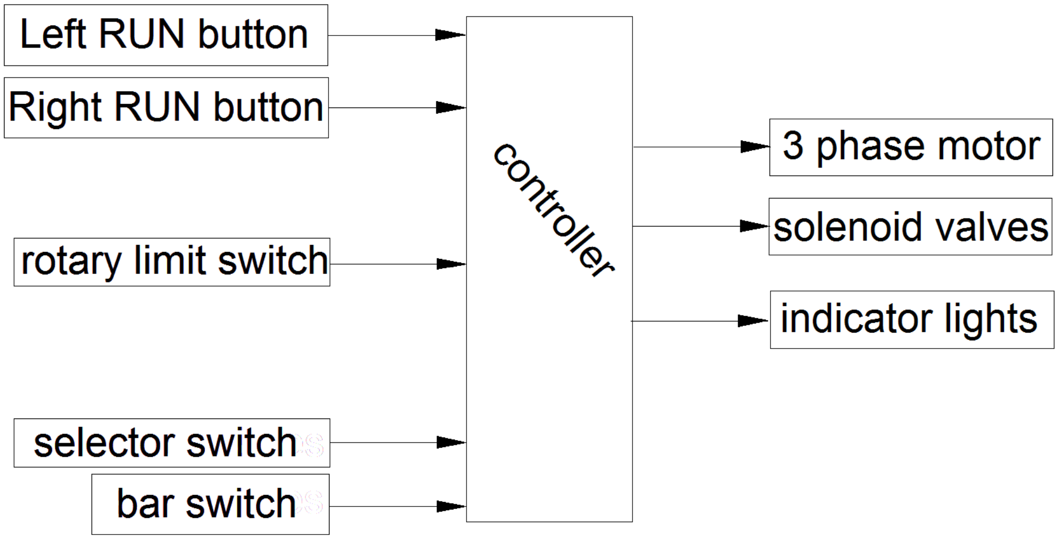
Before the cycle begins, the flywheel is spinning at a constant RPM so has a known amount of energy.

When the clutch engages, this energy is coupled to the drive shaft and ram's mass. This causes a sudden drop in RPM as the shaft starts to rotate and the ram begins to fall. Since the ram is falling, the RPM is then constant or slightly rises.

Then the ram hits the part and the RPM quickly drops. How much it drops is a function of the amount of energy needed to punch out the part.

The rising of the ram takes energy so the RPM must then slowly decrease. Once back to near the top, the clutch disengages and the ram brake engages. Once the clutch has disengaged, the flywheel builds back up to full speed. Total cycle time is around 3 seconds.

Basic Function



The selector switch sets the behavior of the press. In our case, it is set to continuous. The bar switch was always in the inactive state. The motor is continuously running and powers the flywheel. When the solenoid valves are activated, a clutch connects the flywheel to the drive shaft and removes the ram brake. As the drive shaft turns, it moves the ram down and then back up. The shaft position is reported back to the controller via the Rotary Limit Switch (RLS). When the Left RUN and Right RUN buttons are pressed within a preset time interval, the controller starts the sequence. At 0° the ram is fully retracted. At 180° it is down as far as it will go and the part has been struck. At some point between near 360° the solenoid valves is deactivated. The clutch then releases and the ram brake activates.When the ram reaches 360° the cycle is complete.

Note that if the Rotary Limit Switch is giving incorrect information to the controller, the output of the controller is likely wrong too.

Fault Behavior

The press would start out in a normal state. When it cycled with no material under the ram, it would rarely trip out. With soft metal, it tripped out occassionally although this got worse over the last year. With hard metal, it was tripping out in the middle of each cycle. When the controller detected a fault, it would turn on the Failure light and shut down the press. A manual reset would be needed to bring the machine back on line.

The Debugging Journey

Initially, technicians came in to debug the machine. They replace suspect parts until the machine works again. This is a time tested approach that usually does well. But in this case, after 4 different technicians visited, the problem persisted.

The owner of this machine and his father came up with an elegant way to see what was going on. They connected a light across each relay coil. Then they took a video of the machine cycling. By playing back the video one frame at a time, it was possible to see the status every 0.0083 seconds. This turned out to be sufficient resolution although some uncertainly in the data was found.

Understand that the logic is built from large power contactors that run on 120VAC. It would have taken a fair amount of work to build optically isolated translation circuits to make these large logic levels compatible with a standard digital logic analyzer.

When I was brought in, they already had clear videos of non-fault and faulted cycles. After a bit of study, I realized I needed to build a simulator. Then I could see when the relays were not behaving consistent with the schematic. I then realized I was missing the Rotary Limit Switch states to drive this simulator.

In the process of adding lights to the Rotary Limit Switch switches, they discovered that the cams used to accuate these switches were set wrong. One of the technicians had replace this unit but the new one made no different to the overall failure. By swaping out switches within the Rotary Limit Switch one at a time, they were able to build a new Rotary Limit Switch using parts from the original unit and the new unit. At that point, the press was able to turn out almost 1500 parts with no failures.

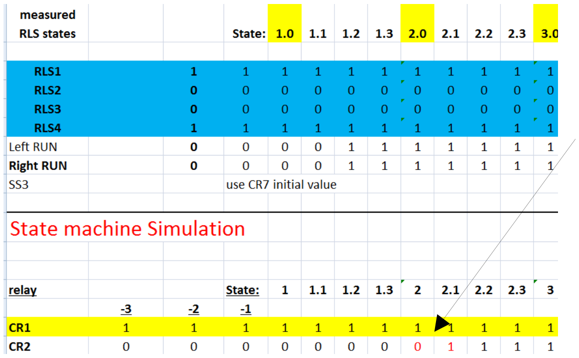
Being that I'm an engineer and not a technician, just making the machine work again is not good enough. I wanted to clearly understand how it worked by perfecting the simulator. When the press fails again, it will be a simple matter to put back the indicator lights, record Rotary Limit Switch states plus relay states, and pinpoint what is not working.

The Simulator

As with any discovery process, the truth comes in at its own pace. I won't bore you with this journey but rather just present all key findings.

Each relay can have 120VAC applied to its coil. About 35 to 50 milliseconds later, the contacts of this relay change state. Care had to be taken to see this time delay. On the other hand, switch contact state changes have no time delay. So, for example, when the Rotary Limit Switch contacts changed state, their effect was immediate. That is also true for the RUN buttons.

The measured Rotary Limit Switch plus relay data defined the number of "official" machine states. Each of these machine states were duplicated 3 times in order to allow time for the relay logic to settle out. You will see, for example, machine states 2, 2.1, 2.2, and 2.3. The number of duplicate states was chosen to insure all relays stopped changing state before the next official machine state was reached.



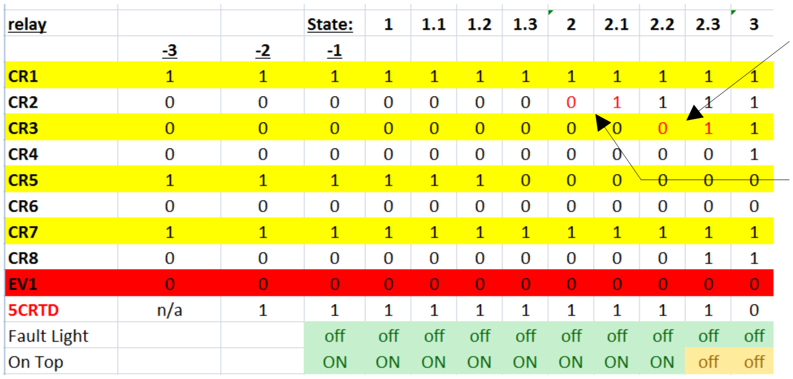
measured RLS states			State:	1.0	1.1	1.2	1.3	2.0	2.1	2.2	2.3	3.0
RLS1		1	1	1	1	1	1	1	1	1	1	1
RLS2		0	0	0	0	0	0	0	0	0	0	0
RLS3		0	0	0	0	0	0	0	0	0	0	0
RLS4		1	1	1	1	1	1	1	1	1	1	1
Left RUN		0	0	0	0	1	1	1	1	1	1	1
Right RUN		0	0	0	0	1	1	1	1	1	1	1
SS3			use CR7 initial value									

State machine Simulation

relay			State:	1	1.1	1.2	1.3	2	2.1	2.2	2.3	3
	-3	-2	-1									
CR1	1	1	1	1	1	1	1	1	1	1	1	1
CR2	0	0	0	0	0	0	0	0	1	1	1	1

One example of this behavior is the state of Contactor Relay (CR) 2 during state 2 (red numbers). During state 2, CR2 is 0. But in state 2.1 CR2 is 1. Therefore, CR2 changes state within official state 2 and not between official state 2 and official state 3.

A more complex example involves the state change of one relay rippling through another. Without a simulator, these sequences quickly lead to a bad headache.



relay			State:	1	1.1	1.2	1.3	2	2.1	2.2	2.3	3
	-3	-2	-1									
CR1	1	1	1	1	1	1	1	1	1	1	1	1
CR2	0	0	0	0	0	0	0	0	1	1	1	1
CR3	0	0	0	0	0	0	0	0	0	0	1	1
CR4	0	0	0	0	0	0	0	0	0	0	0	1
CR5	1	1	1	1	1	1	0	0	0	0	0	0
CR6	0	0	0	0	0	0	0	0	0	0	0	0
CR7	1	1	1	1	1	1	1	1	1	1	1	1
CR8	0	0	0	0	0	0	0	0	0	0	1	1
EV1	0	0	0	0	0	0	0	0	0	0	0	0
5CRTD	n/a	1	1	1	1	1	1	1	1	1	1	0
Fault Light			off	off	off	off	off	off	off	off	off	off
On Top			ON	ON	ON	ON	ON	ON	ON	ON	off	off

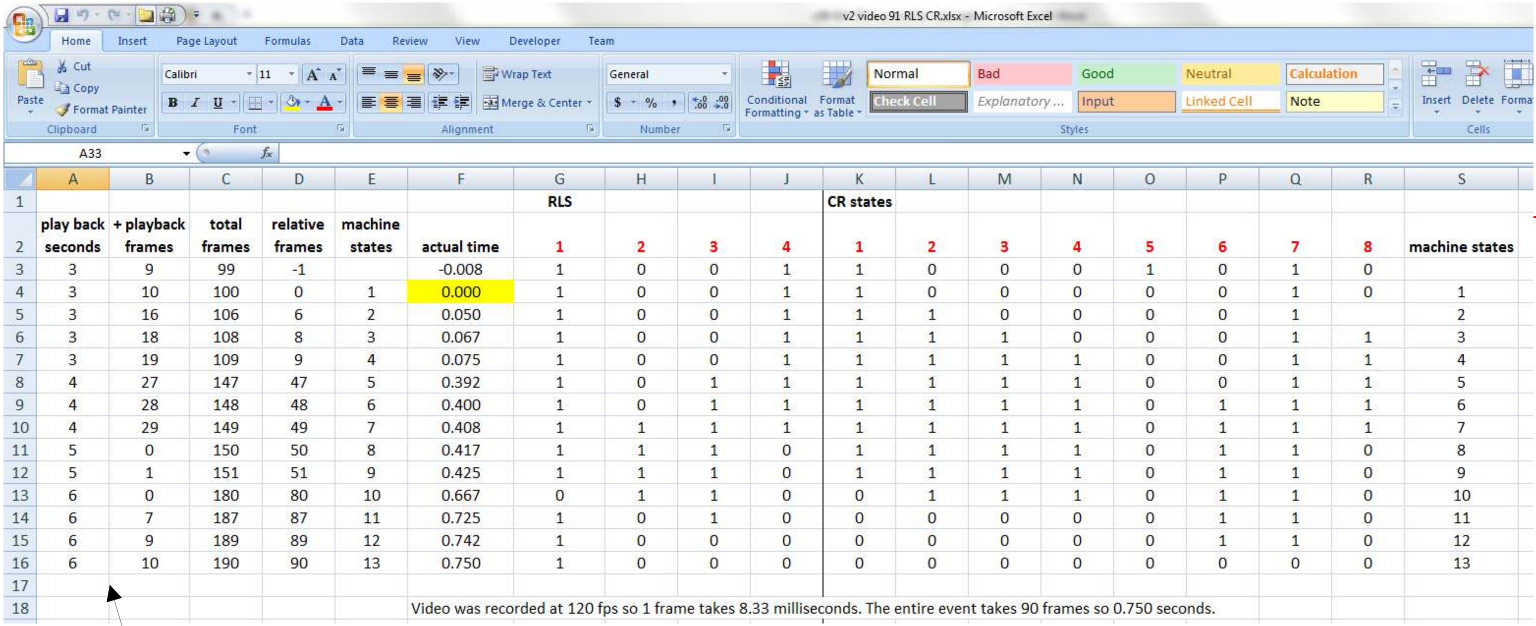
See that in state 2.2 we have CR3 at 0 but in 2.3 it becomes a 1.

This was due to CR2 going from 0 in state 2 to a 1 in state 2.1.

Excel does have logic functions but I found them cumbersome. Instead I used multiplication for the AND function and addition for the OR function. In some cases, the resulting value was either 0 or a number equal to or greater than 1. By using an IF statement, I was able to force a result of 0 or 1.

Translating from schematic to equation is error prone. A lot of time was spent checking these equations to be sure they were correct.

Measured Data



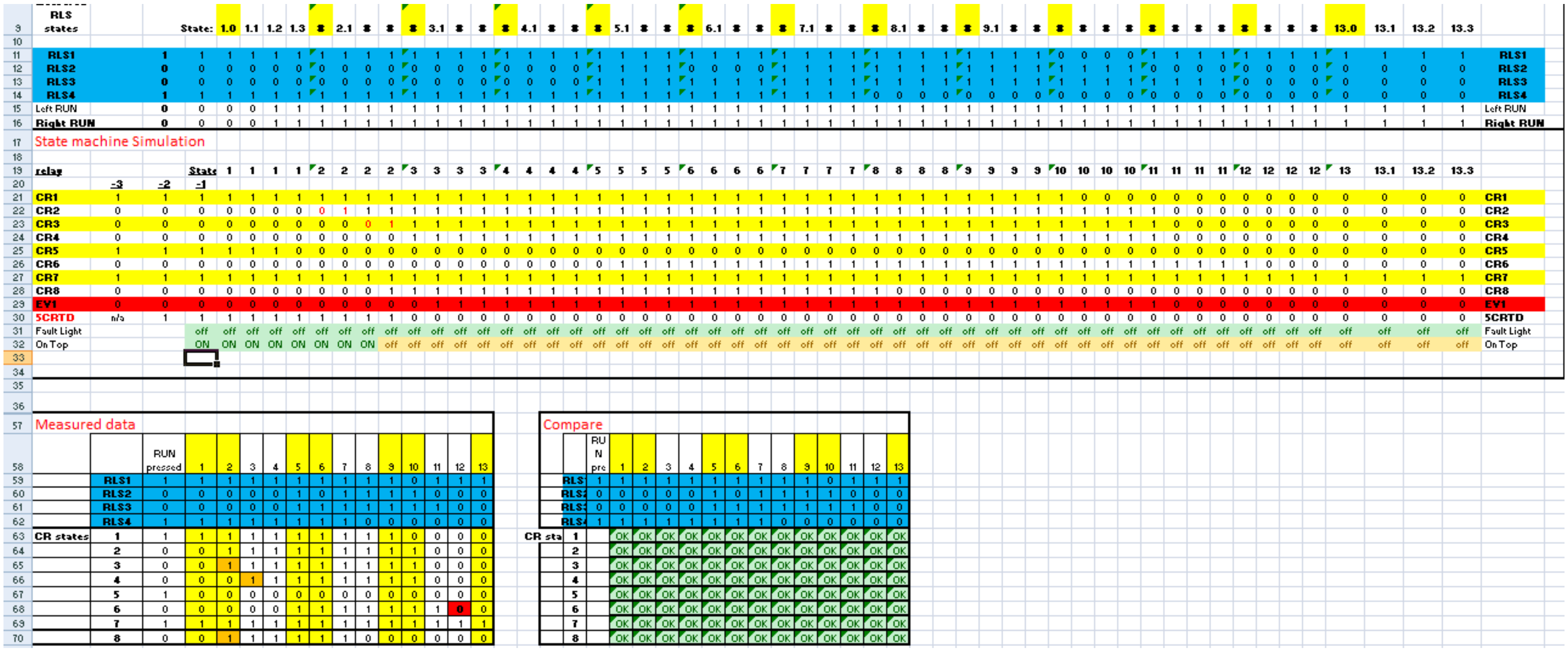
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1							RLS				CR states								
2	play back seconds	+ playback frames	total frames	relative frames	machine states	actual time	1	2	3	4	1	2	3	4	5	6	7	8	machine states
3	3	9	99	-1		-0.008	1	0	0	1	1	0	0	0	1	0	1	0	
4	3	10	100	0	1	0.000	1	0	0	1	1	0	0	0	0	0	1	0	1
5	3	16	106	6	2	0.050	1	0	0	1	1	1	0	0	0	0	1		2
6	3	18	108	8	3	0.067	1	0	0	1	1	1	1	0	0	0	1	1	3
7	3	19	109	9	4	0.075	1	0	0	1	1	1	1	1	0	0	1	1	4
8	4	27	147	47	5	0.392	1	0	1	1	1	1	1	1	0	0	1	1	5
9	4	28	148	48	6	0.400	1	0	1	1	1	1	1	1	0	1	1	1	6
10	4	29	149	49	7	0.408	1	1	1	1	1	1	1	1	0	1	1	1	7
11	5	0	150	50	8	0.417	1	1	1	0	1	1	1	1	0	1	1	0	8
12	5	1	151	51	9	0.425	1	1	1	0	1	1	1	1	0	1	1	0	9
13	6	0	180	80	10	0.667	0	1	1	0	0	1	1	1	0	1	1	0	10
14	6	7	187	87	11	0.725	1	0	1	0	0	0	0	0	0	1	1	0	11
15	6	9	189	89	12	0.742	1	0	0	0	0	0	0	0	0	1	1	0	12
16	6	10	190	90	13	0.750	1	0	0	0	0	0	0	0	0	0	0	0	13
17																			
18						Video was recorded at 120 fps so 1 frame takes 8.33 milliseconds. The entire event takes 90 frames so 0.750 seconds.													

The playback was time stamped in seconds. By incrementing one frame at a time, it was possible to divide each playback second into 30 frames. A total of 90 frames holds the event. The video was taken at 120 frames per second so each frame represents $\frac{1\ second}{120\ frames} = 8.33\ milliseconds$ per frame. Given 90 frames at 8.33 milliseconds per frame, one cycle took 0.75 seconds.

Initally I recorded just the number of playback seconds and number of frames until I saw a change in RLS or CR states. I knew that when CR5 released, it was the start of the machine cycle so called this machine state 1 (yellow box). I also recorded the RLS and CR states for the time interval before state 1.

Thirteen unique machine states were observed. Within each machine state the 8 relays would interact until they arrived at a stable configuration. Remember, there is no master clock here. It therefore became clear that I needed to provide space in the simulator to permit the relays to change. This was done by "Over Sampling" the measured data. Each machine state was repeated 3 more times. By the time we got to the third copy, the relays were done moving.

Once the machine states have been defined along with the measured RLS and CR states, they are fed into the simulator. The spreadsheet then takes the RLS values, calculates the expected CR states, and compares them to the measured CR states. In this run, all values matched.



9	RLS states			State:	1.0	1.1	1.2	1.3	#	2.1	#	#	#	3.1	#	#	#	4.1	#	#	#	5.1	#	#	#	6.1	#	#	#	7.1	#	#	#	8.1	#	#	#	9.1	#	#	#	#	#	#	#	#	#	#	#	#	#	#	13.0	13.1	13.2	13.3	
11	RLS1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	RLS1
12	RLS2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	RLS2
13	RLS3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	RLS3
14	RLS4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	RLS4
15	Left RUN		0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Left RUN
16	Right RUN		0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Right RUN
17	State machine Simulation																																																							
19	relay			State	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	6	7	7	7	7	8	8	8	8	9	9	9	9	10	10	10	10	11	11	11	11	12	12	12	12	13	13.1	13.2	13.3	
20		-3	-2	-1																																																			
21	CR1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	CR1
22	CR2	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	CR2
23	CR3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	CR3
24	CR4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	CR4
25	CR5	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	CR5
26	CR6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	CR6
27	CR7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	CR7
28	CR8	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	CR8
29	EV1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	EV1
30	SCRTD	n/a	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	SCRTD
31	Fault Light			off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	Fault Light
32	On Top			ON	ON	ON	ON	ON	ON	ON	ON	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	On Top

57	Measured data														
58			RUN pressed	1	2	3	4	5	6	7	8	9	10	11	12	13
59		RLS1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
60		RLS2	0	0	0	0	0	1	0	1	1	1	1	0	0	0
61		RLS3	0	0	0	0	0	1	1	1	1	1	1	1	0	0
62		RLS4	1	1	1	1	1	1	1	1	0	0	0	0	0	0
63	CR states	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
64		2	0	0	1	1	1	1	1	1	1	1	1	0	0	0
65		3	0	0	1	1	1	1	1	1	1	1	1	0	0	0
66		4	0	0	0	1	1	1	1	1	1	1	1	0	0	0
67		5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
68		6	0	0	0	0	0	1	1	1	1	1	1	1	0	0
69		7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
70		8	0	0	1	1	1	1	1	1	0	0	0	0	0	0

Compare															
		RU N pre	1	2	3	4	5	6	7	8	9	10	11	12	13
	RLS1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
	RLS2	0	0	0	0	0	1	0	1	1	1	1	0	0	0
	RLS3	0	0	0	0	0	1	1	1	1	1	1	1	0	0
	RLS4	1	1	1	1	1	1	1	1	0	0	0	0	0	0
CR sta	1		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	2		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	3		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	5		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	6		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	7		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	8		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

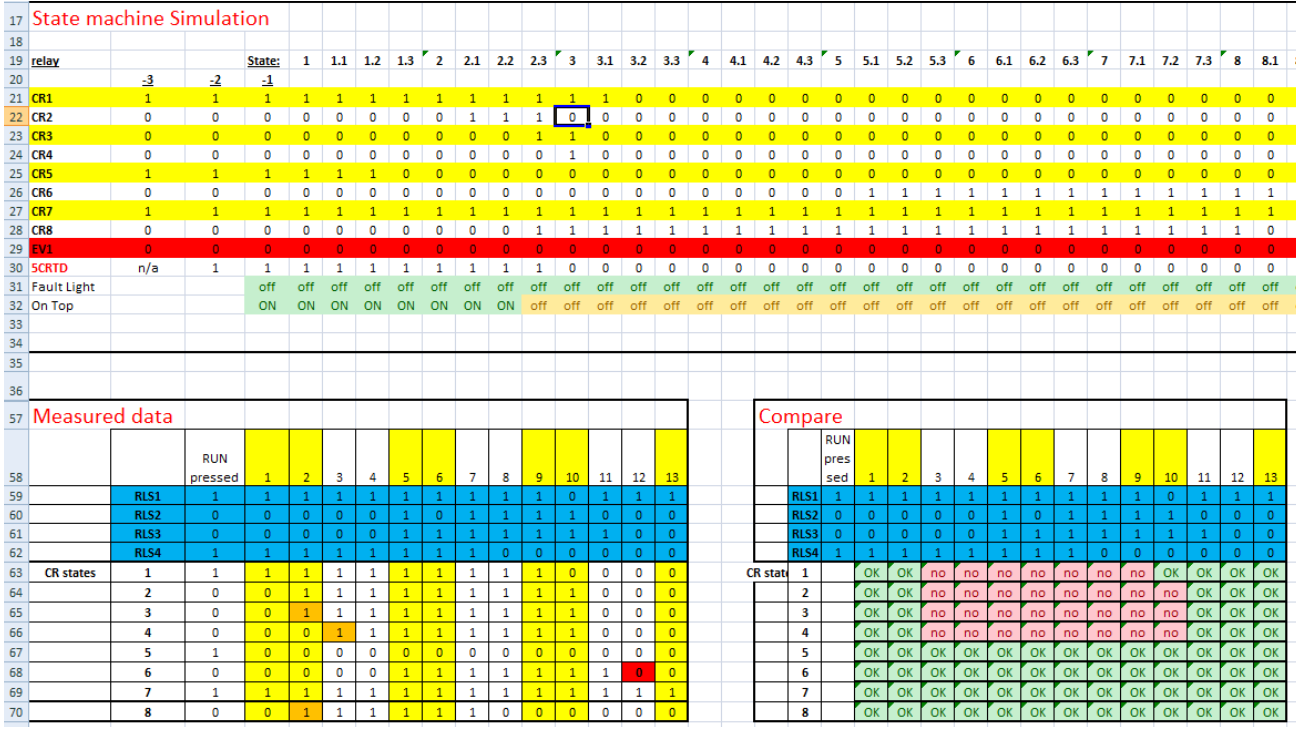
Four measured data points need explaination. Relay states were measured by looking at coil voltages and assuming that related contacts would be in their correct state after two time delays for an operate and after one time delay for a release. This apparently was not always true.

In States 2 and 3 I have changed three data points from 0 to 1 because the simulator said they did not agree (orange boxes). In all of these cases I took the other relay states for that machine state and compared them to what was shown in the schematic. This showed me that the neon bulb associated with the relay coil did not correspond to actual contact states during that 8.33 millisecond frame. Although more difficult, it would have been better to directly monitor one of the contacts on each relay rather than the coil.

In state 12 for CR6 (red box) the neon bulb is on yet the simulator said the coil was not receiving power. Upon closer inspection, I could see that the bulb was on due to energy stored in the coil immediately after power was removed. See the appendix for details.

Given these four changes to the measured data, the simulator does match reality in all 104 data points.

In this next run I have intensionally changed CR2's state during machine state 3.0 from 1 to 0. Note the Compare table on the lower right indicates many errors. This is why it can be so difficult to debug one of these circuits. A single fault generates a large number of observed errors.



State machine Simulation

relay			State:	1	1.1	1.2	1.3	2	2.1	2.2	2.3	3	3.1	3.2	3.3	4	4.1	4.2	4.3	5	5.1	5.2	5.3	6	6.1	6.2	6.3	7	7.1	7.2	7.3	8	8.1
	-3	-2	-1																														
CR1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR2	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR3	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR5	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
CR7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CR8	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
EV1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5CRTD	n/a	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fault Light			off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off
On Top			ON	ON	ON	ON	ON	ON	ON	ON	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off

Measured data

		RUN pressed	1	2	3	4	5	6	7	8	9	10	11	12	13
	RLS1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
	RLS2	0	0	0	0	0	1	0	1	1	1	1	0	0	0
	RLS3	0	0	0	0	0	1	1	1	1	1	1	1	0	0
	RLS4	1	1	1	1	1	1	1	1	0	0	0	0	0	0
CR states	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	2	0	0	1	1	1	1	1	1	1	1	1	0	0	0
	3	0	0	1	1	1	1	1	1	1	1	1	0	0	0
	4	0	0	0	1	1	1	1	1	1	1	1	0	0	0
	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	1	1	1	1	1	1	1	0	0
	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	8	0	0	1	1	1	1	1	1	0	0	0	0	0	0

Compare

		RUN pressed	1	2	3	4	5	6	7	8	9	10	11	12	13
	RLS1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
	RLS2	0	0	0	0	0	1	0	1	1	1	1	0	0	0
	RLS3	0	0	0	0	0	1	1	1	1	1	1	1	0	0
	RLS4	1	1	1	1	1	1	1	1	0	0	0	0	0	0
CR stat	1		OK	OK	no	no	no	no	no	no	no	OK	OK	OK	OK
	2		OK	OK	no	no	no	no	no	no	no	no	OK	OK	OK
	3		OK	OK	no	no	no	no	no	no	no	no	OK	OK	OK
	4		OK	OK	no	no	no	no	no	no	no	no	OK	OK	OK
	5		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	6		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	7		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	8		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

Machine Details

The controller is first put into one of 4 states via the selector switch to define how it will operate:

1. OFF
2. INCH - manual control that lets the user "inch" the machine through its cycle
3. SING - run a single cycle and then stop
4. CONT - run continuously under the control of the RUN buttons

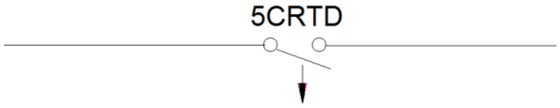
The bar switch is not used and it left in the open state.

Then, with the motor running and stock placed under the ram, the operator pushed one RUN button with each hand to initiate a cycle. The cycle starts at 0°. When it reaches around 180 ° the part is struck. At this point the ram retracts to 360° even if the operator removes their hands from the large buttons. When the ram reaches 360°, it is at the start of the next cycle.

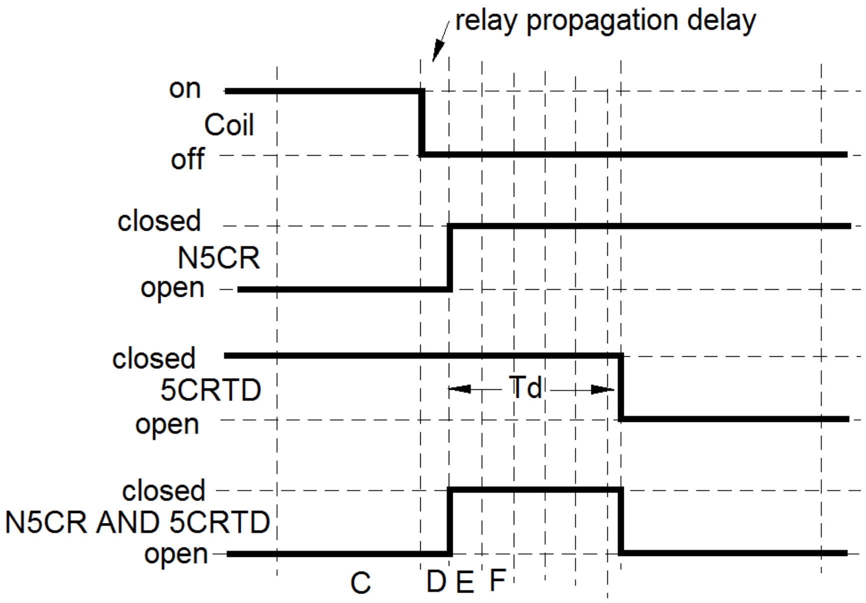
There are 8 contactor relays (CR). When 120V AC is applied to one of these relay coils, it takes time for the armature to operate and change the state of its contacts. I call this the relay propagation delay. For simplicity in the simulator, I have assumed all relays have the same delay.

CR5 has two parts. The first part is a normal contactor with normally open (5CR) and normally closed (N5CR) contacts. When the coil is powered up, 5CR closes and N5CR opens after the relay propagation delay is over.

The second part is a timer. The schematic of this contact shows:

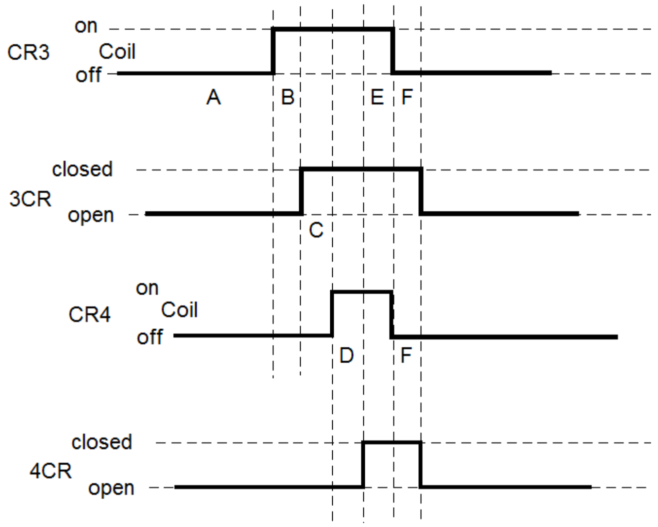


It is a normally open contact but with a delayed.

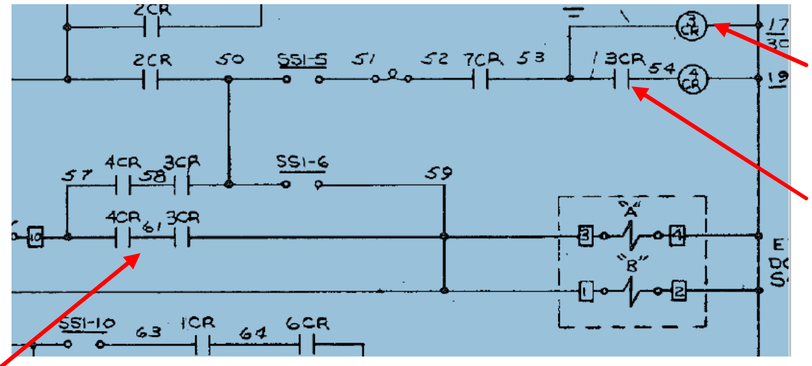


When CR5's coil has been on for a long time, Normally Closed contact (N5CR) is open and 5CRTD is closed.

During time period C, the coil is on. At the end of C power is removed from the coil. During D the coil discharges but N5CR does not change state yet. At the end of D, N5CR changes from open to closed and 5CRTD begins its T_d delay interval. After $T_{d,}$ 5CRTD opens. There is a dial on the front of this relay for setting the time delay.



CR3 and CR4 form a delay relay. When CR3 operates, one of its contacts closes which operates CR4. When CR3 is released, CR4 releases at the same time.



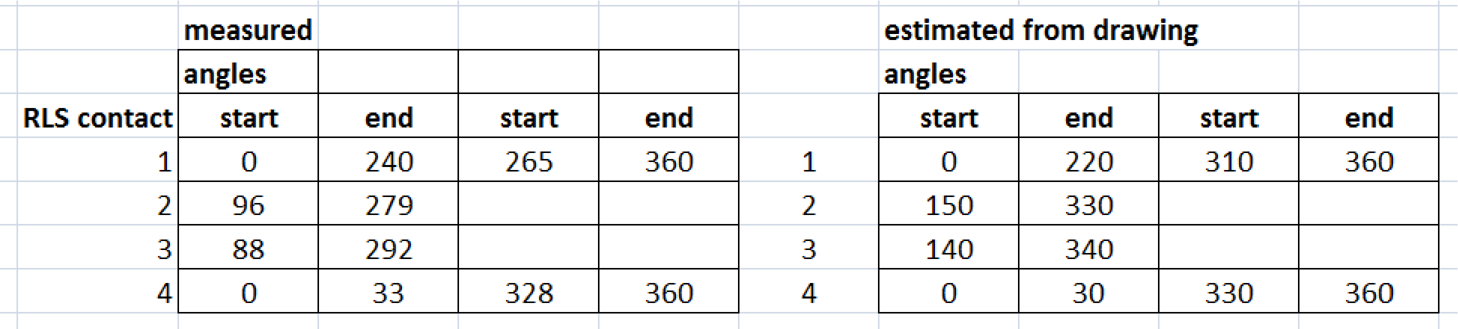
CR4 is slaved to CR3 in an unusual way.
After CR3's coil receives power, its normally open (NO) contacts close. One of these NO contacts is in series with CR4's coil. This series combination is across CR3's coil. The result is that CR4's normally open contacts are guaranteed to close after CR3's normally open contacts. When power is removed from their coils, both relays should release at around the same time.

If you look at the schematic, lines 29 and 30, you will see two cases where CR3's and CR4's normally open contacts have been put in series. When power is applied to CR3 and CR4+contact, there will be a surge of current due to CR3 operating. When this surge is over, there will be a surge from CR4 as its controlling contact closes. In this way the two surges never add. That would stress the driving circuit more than all other places in the circuit.

Looking again at the schematic, you will see that the odd 4CR+3CR NO contact configuration drives the "A" and "B" air solenoids. They likely have a large inductive component. This makes switching a voltage across them very gentle because the initial current is zero. The fireworks occurs when you need to remove power. As the current flowing in these solenoids is removed, the voltage across their coils will rise in an attempt to sustain the current. The result is a very large voltage spike. This spike will attempt to form an arc across the relay contacts that are just starting to open because this is where the gap is smallest. The arcing will at least cause carbon to form on the contact surfaces and at most erode the metal. By placing NO contacts 4CR in series with 3CR, you nominally double the gap and spread out the arc. Given that this machine has worked flawlessly for so many decades, this approach obviously works well.

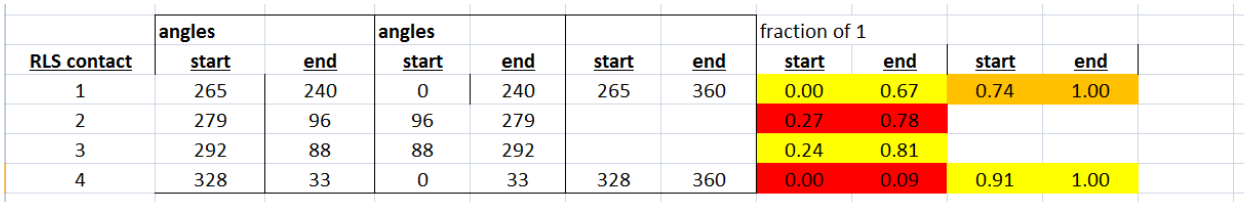
Although I believe my observations are true, I have no way to knowing if that is why the designers chose this configuration.

The Rotary Limit Switch (RLS) reports the ram's position. I saw a granularity of 10° in the drawing. The actual angular position of a working machine was measured to the nearest degree on 9/23/2016.



	measured					estimated from drawing			
	angles					angles			
RLS contact	start	end	start	end		start	end	start	end
1	0	240	265	360	1	0	220	310	360
2	96	279			2	150	330		
3	88	292			3	140	340		
4	0	33	328	360	4	0	30	330	360

Measured:



	angles		angles				fraction of 1			
RLS contact	start	end	start	end	start	end	start	end	start	end
1	265	240	0	240	265	360	0.00	0.67	0.74	1.00
2	279	96	96	279			0.27	0.78		
3	292	88	88	292			0.24	0.81		
4	328	33	0	33	328	360	0.00	0.09	0.91	1.00

The 8 CRs define the states of the machine and are driven by the RLS as long as the operator has their hands on the two bar switches from 0 to 180 degrees.

The state machine only operates if the motor is running.

The two solenoid valves control a clutch that catches the flywheel and channels its energy into the ram at 0°. It is released at 360 ° under normal operation. If a fault occurs, the clutch will release early.

There are two indicator lights light within the press control assembly. A green signals when the ram is at top and stopped. A red light indicates a fault. This fault light is driven by N7CR (read as not CR7 - contact closed when CR7 released) and by the power bus that is only active when the motor is running.

Left and Right RUN must both be pushed during this interval in order to close CR2. If both RUN buttons are not pushed in time, 5CRTD opens again and the The video shows CR5 on at the start and at the end. It goes off in the first step and comes on near the end: CR5 on and then CR1 on.

Acknowledgments

Thanks to Bob and Terry for this opportunity. It was certainly a team effort.

I welcome your comments and questions.

If you wish to be contacted each time I publish an article, email me with just "Article Alias" in the subject line.

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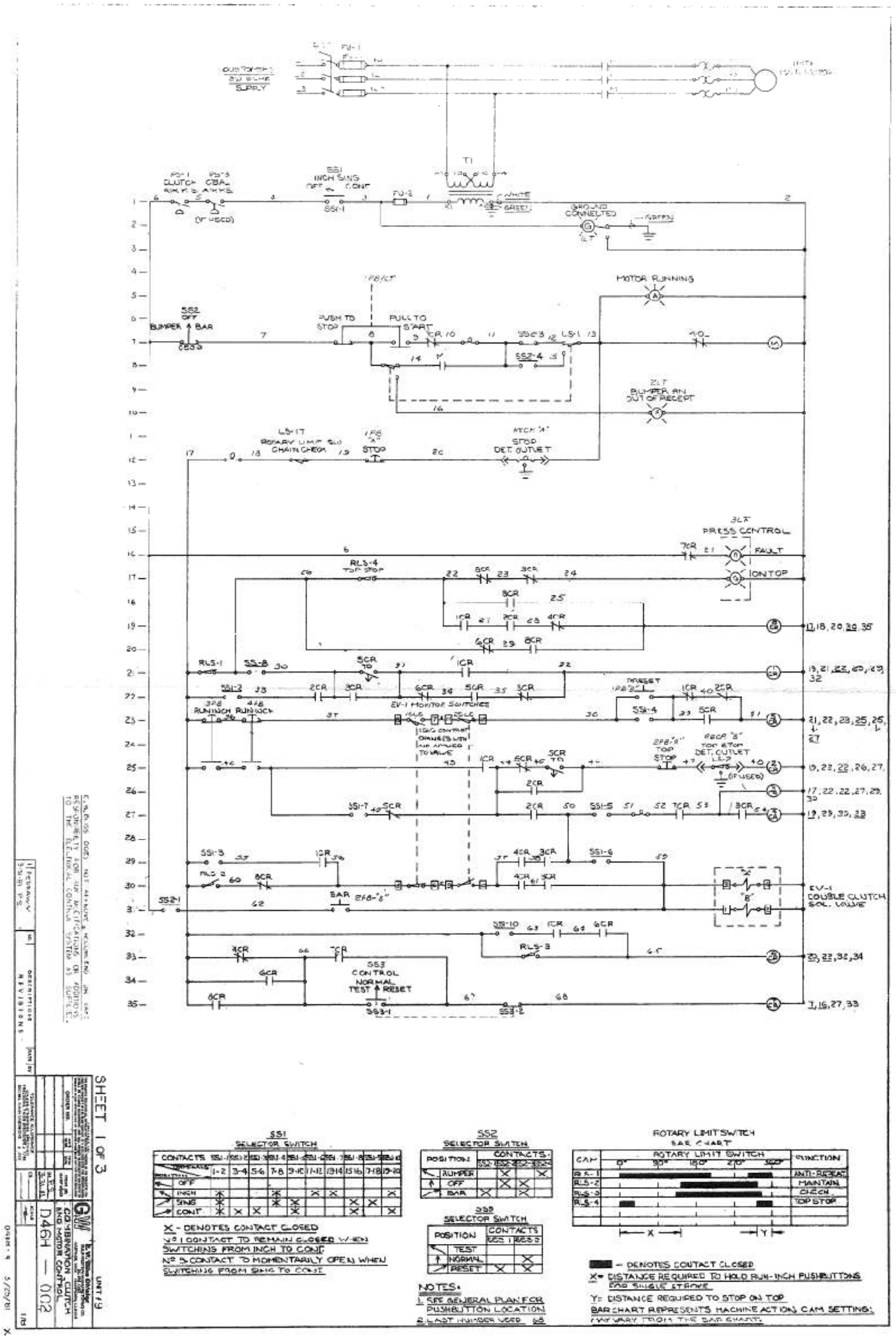
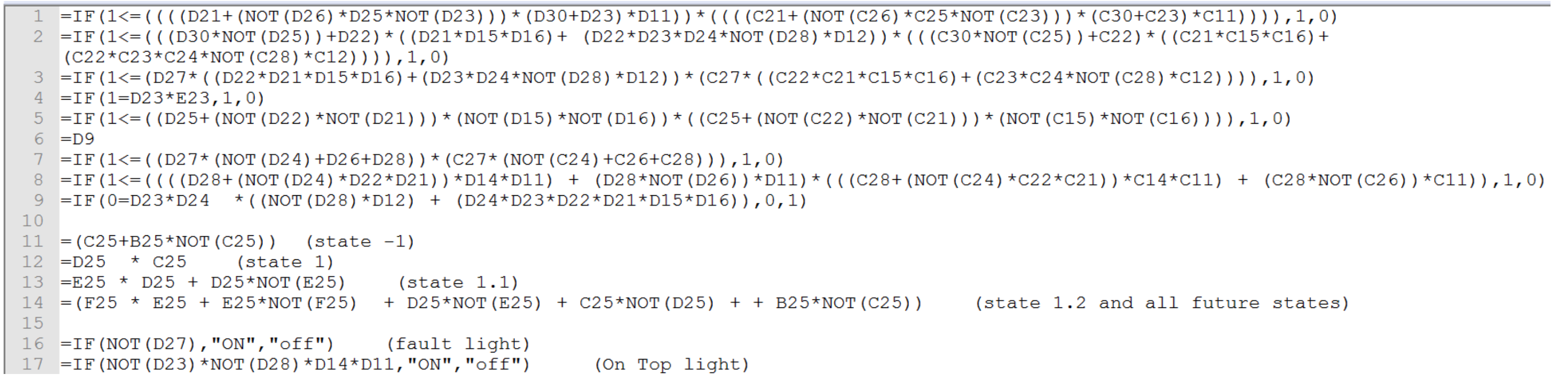
Rick.Sparber.org

Appendix: Full Schematic


MOTOR RUNNING
PUSH TO STOP
PULL TO START
BUMPER ON OUT OF RECEPT
ROTARY LIMIT SW CHAIN CHECK
STOP DET. OUTLET
PRESS CONTROL
FAULT
ON TOP
EV-1 MONITOR SWITCHES
PRESET
TOP STOP
DET. OUTLET
EV-1 DOUBLE CLUTCH SOL. VALVE
SS3 CONTROL NORMAL TEST RESET
SHEET 1 OF 3
COMBINATION CLUTCH AND MOTOR CONTROL
D46H — 002
SS1 SELECTOR SWITCH
CONTACTS
OFF
INCH
SING
CONT
X - DENOTES CONTACT CLOSED
Nº 1 CONTACT TO REMAIN CLOSED WHEN SWITCHING FROM INCH TO CONT.
Nº 5 CONTACT TO MOMENTARILY OPEN WHEN SWITCHING FROM SING TO CONT.
SS2 SELECTOR SWITCH
POSITION
CONTACTS
BUMPER
OFF
BAR
SS3 SELECTOR SWITCH
POSITION
CONTACTS
TEST
NORMAL
RESET
NOTES:
1. SEE GENERAL PLAN FOR PUSHBUTTON LOCATION
2. LAST NUMBER USED 68
ROTARY LIMIT SWITCH BAR CHART
CAM
ROTARY LIMIT SWITCH
0°
90°
180°
270°
360°
FUNCTION
RLS-1
RLS-2
RLS-3
RLS-4
ANTI-REPEAT
MAINTAIN
CHECK
TOP STOP
X
Y
— DENOTES CONTACT CLOSED
X = DISTANCE REQUIRED TO HOLD RUN-INCH PUSHBUTTONS FOR SINGLE STROKE
Y = DISTANCE REQUIRED TO STOP ON TOP
BAR CHART REPRESENTS MACHINE ACTION. CAM SETTING MAY VARY FROM THE BAR CHART.

Appendix: Corresponding Excel Equations



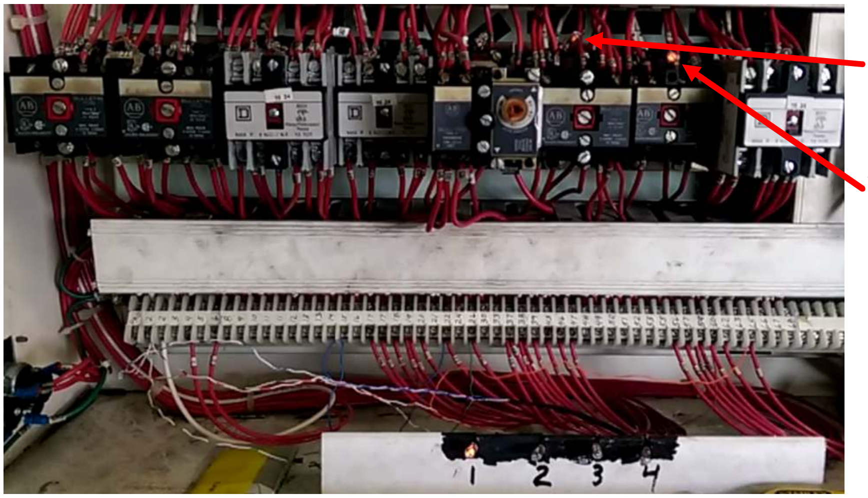
```
 1 =IF(1<=((((D21+(NOT(D26)*D25*NOT(D23)))*(D30+D23)*D11))*((((C21+(NOT(C26)*C25*NOT(C23)))*(C30+C23)*C11)))),1,0)
 2 =IF(1<=(((D30*NOT(D25))+D22)*((D21*D15*D16)+  (D22*D23*D24*NOT(D28)*D12))*(((C30*NOT(C25))+C22)*((C21*C15*C16)+
   (C22*C23*C24*NOT(C28)*C12)))),1,0)
 3 =IF(1<=(D27*((D22*D21*D15*D16)+(D23*D24*NOT(D28)*D12))*(C27*((C22*C21*C15*C16)+(C23*C24*NOT(C28)*C12)))),1,0)
 4 =IF(1=D23*E23,1,0)
 5 =IF(1<=((D25+(NOT(D22)*NOT(D21)))*(NOT(D15)*NOT(D16))*((C25+(NOT(C22)*NOT(C21)))*(NOT(C15)*NOT(C16)))),1,0)
 6 =D9
 7 =IF(1<=((D27*(NOT(D24)+D26+D28))*(C27*(NOT(C24)+C26+C28))),1,0)
 8 =IF(1<=((((D28+(NOT(D24)*D22*D21))*D14*D11)  +  (D28*NOT(D26))*D11)*(((C28+(NOT(C24)*C22*C21))*C14*C11)  +  (C28*NOT(C26))*C11)),1,0)
 9 =IF(0=D23*D24  *((NOT(D28)*D12)  +  (D24*D23*D22*D21*D15*D16)),0,1)
10
11 =(C25+B25*NOT(C25))   (state -1)
12 =D25  * C25    (state 1)
13 =E25 * D25 + D25*NOT(E25)     (state 1.1)
14 =(F25 * E25 + E25*NOT(F25)   + D25*NOT(E25)  + C25*NOT(D25)  + + B25*NOT(C25))     (state 1.2 and all future states)
15
16 =IF(NOT(D27),"ON","off")     (fault light)
17 =IF(NOT(D23)*NOT(D28)*D14*D11,"ON","off")      (On Top light)
```

Lines 1 through 8 are for CR1 through CR8. Line 9 is the air solenoid EV1.

Line 11 through 14 are the CR5 time delay contact equations. Line 11 is at machine state -1, line 12 is at machine state 1, line 13 is at machine state 1.1 and line 14 is at all states beyond that point.

Line 16 is for the fault light and line 17 is for the Top light. It indicates when the ram is at 0° or the top of its stroke.

Appendix: False Relay State Analysis



This is state 12. RLS-3 just went to 0 but notice that CR6 looks like it is still on. But look closer at the light, it is not as bright as CR7. I believe the light is on because of the inductive kick in the coil and the contacts have already opened.

Lets take a closer look. The following numbers are in the format T:F where time is in playback seconds and F is the number of frames before T increments. So 6:6 means 6 seconds plus this is the sixth frame.

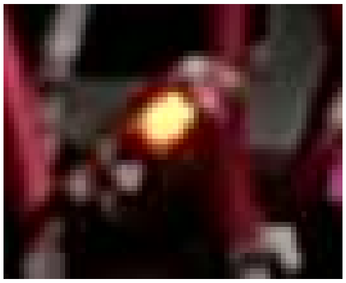
6:6

6:7

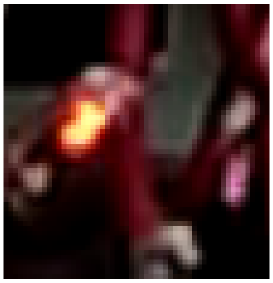
6:8

6:9

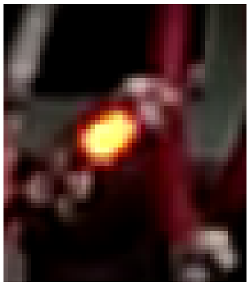
6:10



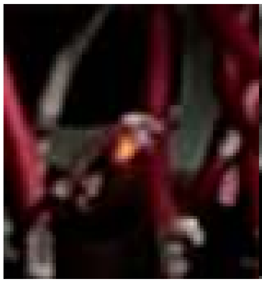
6:6



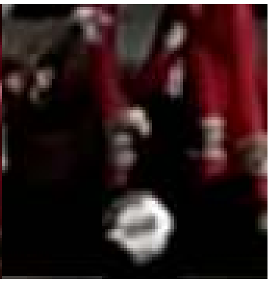
6:7



6:8



6:9



6:10

Frames 6:6 through 6:8 show normal brightness of bulb which says power is being applied to the coil. Frame 6:9 is dimmer which implies that the bulb is being lit by the inductive kick of the relay coil and the coil is not being powered. In 6:10 the bulb is dark.

Therefore, I have changed state 12, CR6's value from 1 to 0.