REALIZING SEQUENTIAL PROCESSES USING PROGRAMMABLE LOGIC CONTROLLERS (PLCS)

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Abstract: The paper investigates the design of sequential discrete control system using PLCs. Five different programs are designed and investigated to simulate five sequential patterns, commonly used in industry. It was found that it is possible to utilize programmable monostable timer to divide any number of pulses of any required integer number, realizing by that any required ratio between the periods of cyclic processes. More over, the function of the leading edge differentiation was utilized to convert the OFF to ON transition of the output to a one scan duration pulse which was fed to the counting input of the PLC up counter. Thus a designed PLC clock contact was used to simulate symmetrical or asymmetrical square waves.

Keywords: Sequential process, PLC, up-counter, monostable timer, square wave.

INTRODUCTION

In order to carry out any industrial operation discrete control systems usually implement a series of predefined simple operations (steps) with specific conditions for each. When the discrete operation has a begin and an end and a specific control mode, it is defined as a sequential operation [Bateson, 1993]. Sequential operations could be time-driven or event-driven systems [Hasebrink and Kobler, 1978]. For a time driven system every step begins at a specific instant of time or after the elapse of an interval of time. Concerning event driven operations every step is initiated by the occurrence of an event (This is also called a finite-state approach [Clements-Jewery and Jeffcoat, 1996]). The event could be a single action or a combination of several actions. In the majority of cases sequential operations include both mentioned types. When investigating a sequence we are interested with the transfer of an output (Final element) from one of its two positions (high or low, ON or OFF) to the other position a specific number of times. In order to have at the output a complete product with the required specifications many sequences have to be repeated the required number of times. Taking into consideration the recent developments in the software and hardware of PLCs, and the continuous decline of their cost, they found unlimited areas of applications in automated technological processes [Webb and Reis, 1995]. In this work we will investigate the design of a number of PLC programs related to sequential operations using PLC, type ELC-2001 [Gavazzi, 1996].

TYPES OF SEQUENTIAL OPERATIONS

The types of sequential operations which are considered in this work are:

1- Repetition of sequential operation for a given number of times. This means that the system final element (P010) will change its state from OFF to ON and from ON to OFF a given number of times. An example is to outstroke a cylinder rod, stop it, and instroke it to its initial position for the given number of times.
2- Repetition of a sequential operation for a number of cycles. Each cycle is considered as a set of sequences (P011).
3- Repetition of a sequence of different sets in one complete cycle, then the cycle repeats for the given number of times (P012).
4- Realization of a number of sets of sequences, with different numbers of repetition for different outputs, (P013), (P014), and (P015).

The patterns of the above mentioned sequences are shown in figure 1.

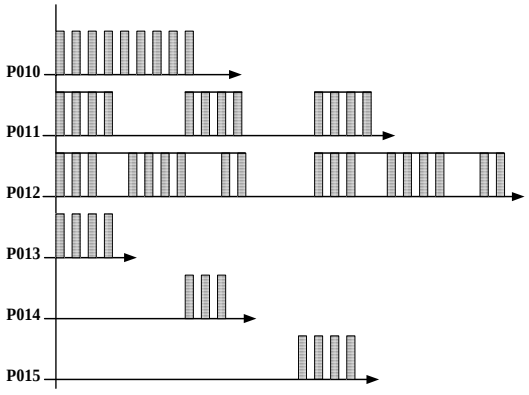

Figure 1: Patterns of sequential processes

DESCRIPTION OF PROGRAMS

Program 1, shown in figure 2, realizes the first type of sequential operations. An operation is initiated by pressing an external pushbutton (P000). The internal clock contact F096 with a period of 20 seconds puts the output (P010) ON for (10) seconds and OFF for (10) seconds and the period will repeat continuously. This program drives a pneumatic cylinder in a transfer station which is used to remove materials from conveyor belt [Hasebrink and Kobler, 1978], or to transfer parts from a warehouse. The up counter CTU-C004 is used to count the number of times the output (P010) is put ON. When the count in the counter register reaches the value of 5, the internal flag M001 is put ON. This way, its normally closed contact opens and the output (P010) is put OFF. A leading edge differentiating function (D017) is used to generate a one scan duration pulse which increments the counter by one each time the output (P010) is put ON. So, when (P010) is ON a pulse is applied to the internal flag (M003), and this pulse appears at the count input of the counter. Step No (0011) resets the counter when it is necessary.

0000	LOAD	P000	*PUSH BUTTON*
0001	OR	M000	
0002	OUT	M000	*Flag*
0003	LOAD	M000	
0004	AND	F096	*Symmetric Contact*
0005	AND NOT	M000	
0006	OUT	P010	*Output*
0007	LOAD	P010	
0008	FUN	017	*One Scan Output*
0009		M003	
0010	LOAD	M003	*Count Input*
0011	LOAD	P007	*Reset Input*
0012	CTU	C004	
0013		6	*Preset Number*
0015	LOAD	C004	
0016	OUT	M001	
0017	FUN	1	*END*

Table 1: Programme 1

In order to realize the second type of sequential process,a scalar is needed to divide the number of pulses by any required number. This is done by using a monostable timer TMON-T008. The timer is put ON by an enable input contact or at the first transition from OFF to ON of a square input wave. After that the timer will no longer be effected by the state of the enable contact or driving square wave. At the instant when the timer is put ON its count begins to decrement until zero, then it is put OFF as shown in figure 3.

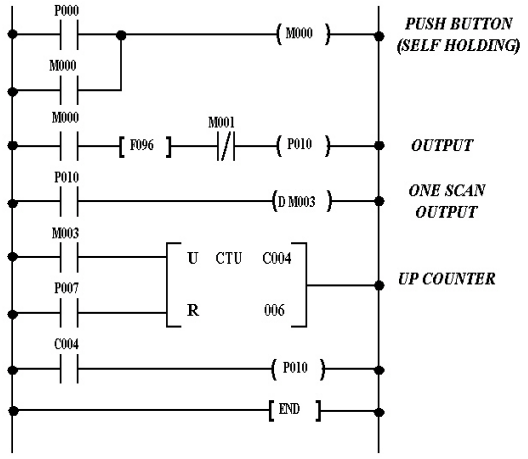

Figure 2: Representation of programme 1

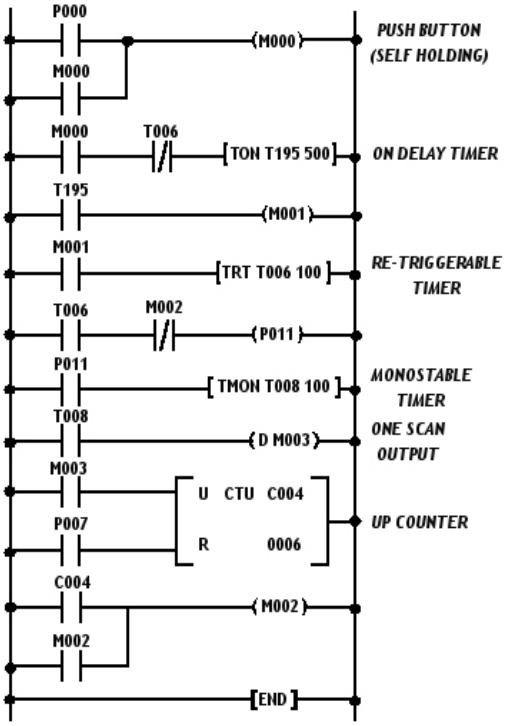

Figure 3: Representation of programme 2

The value of the count written in the timer register could be selected differently. If it is desired to put the timer ON and OFF once for each period of the driving wave, the written time value should be less than the period of the driving wave. If it is required to put the timer ON and OFF one time for every two

periods of the driving wave, then the written time value must be higher one period of the driving wave but smaller than two periods. So, if it is desired to divide the number of pulses generated by the driving wave by (5), the time written in the monostable time register shall be four times higher than the input signal period, but less than six times the driving signal period. The state of the output of TMON-T008 is detected and fed to the count inputs of CTU-C004. The register of CTU-C004 contains the result of the division.

Program 2 is initiated by pressing knob (P000). This enables a non-symmetrical clock contact. The clock contact is realized by utilizing an ON-delay timer TON-T195 and a re-triggerable monostable timer TRTG-T006. After a time delay of 5 seconds flag M001 is put ON and TRGT timer is in operation. Its contact at step (0004) opens and the count written in the timer register begins to decrement. After 10 seconds its output is in the OFF state and its contact in step (0004) is closed again, and as a result of that TON-T195 is ON again and the cycle repeats. According to this program the ON time-duration depends on the value of the number written in T006, which is in this case 10 seconds, while the duration of the OFF-time depends on the number written in the register of TON-T195 which is (5) seconds. As a result of the operation of the clock-contact the output (P011) works in a periodic mode with a period interval of 15 seconds. Timer TMON-T008 is used to realize the required division process. So, if it is required to stop the output (P011) after it carries out six sets, each of them consisting of 5 sequences, a time constant greater that 75 and smaller than 90 seconds needs to be written in the register of T008. If the sequence is to be repeated six times, the number 6 needs to be written in step (0027).

Such a program could be used in sequential operations relevant to definite production batches. For example when a given number of bottles needs to be placed in each box, and the conveyor needs to be moved when a specified number of boxes has been filled.

In program 3 the number of periods is counted and divided by (2) and by (4). The results are found in counters C0004, C005, and C006. The square wave is created by using generator F103 which is programmed by the function FUN-205. When the program is run the three counters start counting simultaneously. C004 is incremented for each period of F103, while C005 is incremented every (2) periods of F103, and C006 is incremented every (4) periods of F103. It is important to note that these ratios are realized depending on the selected constants of T008 and T009. For this purpose it is important to remember that the time constant of T008 is smaller than the period of F103. Because the PLC scan time is 4.8 ms, the period of F103 is equal to $2\times4.8\times100 = 960$ ms. Consequently number (6) was selected in step (0019) which is equivalent to 600 ms realizing by that inequality 600 ms < 960 ms. By using the same approach numbers (16) and (38) were selected in steps (0034) and (0058). Very often it is required from one output (final control element) to carry out several different sequences in series, then they have to be repeated for a definite number of times.

An example is drilling process. Suppose that it is required to drill at first (5) holes in a board, then after rotating an indexing table it is required to drill another (4) hole, and after rotating the indexing table again it is required to drill (7) other holes.

0000	LOAD	P000		0017	LOAD	P001	
0001	OR	M000		0018	TMON	T008	*Monostable timer*
0002	OUT	M000		0019		100	
0003	LOAD	M000		0020	LOAD	T008	
------	-------	------		------		------	
0004	AND	T006		0022	FUN	017	
0005	TON	T195		0023		M003	
0006		500	*5 Sec*	0024	LOAD	M003	*Count Input*
0008	LOAD	T195		0025	LOAD	P007	*Reset Input*
0009	OUT	M001		0026	CTU	C004	*Up Counter*
0010	LOAD	M001		0027		6	*Pre-set Value*
0011	TGTR	T006		0029	LOAD	C004	
0012		100	*10 Sec*	0030	OR	M002	
0014	LOAD	T006		0031	OUT	M002	
0015	AND	M002		0032	FUN	1	
0016	OUT	P011					

Table 2: Programme 2

0000	LOAD	P000		0040	LOAD	F103
0001	OR	M000		0041	TMON	T009
0002	OUT	M000		0042		D0000
0003	LOAD	M000		0044	LOAD	T009
------	-------	--------		------	---------	-------
0004	FUN	205		0045	FUN	017
0005		F103		0046		M004
0007		100		0047	LOAD	M004
0009		100		0048	AND	M005
0011	LOAD	F103		0049	LOAD	P007
0012	OUT	M001		0050	CTU	C005
------	--------	-------		0051		20
0013	LOAD	M000		0053	LOAD	C005
0014	AND	M001		0054	OR	M005
0015	AND	M002		0055	OUT	M005
0016	OUT	P012		0056	LOAD	M000
-----	-------	--------		0057	FUN	110
0017	LOAD	F103		0058		38
0018	TMON	T008		0060		0000
0019		0006		0062		D0001
0021	LOAD	T008		------	-------	--------
------	-------	--------		0064	LOAD	F103
0022	FUN	017		0065	TMON	T103
0023		M003		0066		D000
0024	LOAD	M003		0068	LOAD	T013
0025	AND	M002		------	-------	--------
0026	LOAD	P007		0069	FUN	017
0027	CTU	C004		0070		M003
0028		0040		0071	LOAD	M006
0030	LOAD	C004		0072	AND	M007
0031	OUT	M002		0073	LOAD	P007
0032	LOAD	M000		0074	CTU	C006
0033	FUN	110		0075		10
0034		0016		0077	LOAD	C006
0036		0000		0078	OR	M007
0038		D0000		0079	OUT	M007
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Table 3: Programme 3

After that (20) seconds are required to change the board, then the three sets of sequences will repeat. Program 4 is designed to carry out such a job.

For this reason four up counters are utilized, CTU-C004, CTU-C005, CTU-C007 and CTU-C008. When the count in CTU-C004 reaches five its output is high and internal flag M002 is ON. After the elapse of 10 seconds timer T192 is ON and output P012 is effected again and counter C005 begins to increment. When the count inside it reaches number four flag (M004) is high and timer

T193 begins counting until (10) seconds elapse. At this instant counter C007 begins to increment until the count inside it is equal to (7). At this instant number (1) is registered in CTU - C008, and after 20 seconds all three sequences repeat in the same manner for three times.

The fifth program controls the sequence in multiple actuator systems. This is very often required for coordinated motion control with auxiliary conditions and in complex processes. In such systems the process may need a feed-in cylinder, clamp cylinder, punch cylinder, Eject cylinder and others.

After pressing the pushbutton (P000) the output (P013) begins cycling. The time constant of TMON-T008 is selected in order to make C004 increment once for every period of (P013). When the number of cycles is five the sequence stops and timer TON-T197 is ON. After the elapse of the delay time (20 seconds), the second sequence (P014) begins functioning, and counter C005 is incremented at the beginning of every period. When the number of periods is seven the sequence is stopped and counters C004 and C005 are reset.

0000	LOAD	P000	*PUSH BUTTON*	0023	LOAD	M003	*COUNT INPUT*
0001	OR	M000	*FLAG*	0024	AND NOT	M002	
0002	OUT	M000		0025	LOAD	M009	*RESET INPUT*
0003	LOAD	M000		0026	CTU	C004	*UP COUNTER*
-----	---------	------		0027		5	
0004	FUN	205	*DUTY CYCLE*	0029	LOAD	C004	
0005		F103		0030	AND NOT	T192	
0007		500		0031	OUT	M002	
0009		500		0032	LOAD	C004	
0011	LOAD	F103		0033	TON	T192	*ON DELAY TIMER*
0012	OUT	M001		0034		1000	
------	-------	-------		0036	LOAD	T192	
0013	LOAD	M000		0037	OR	M005	
0014	AND	F103		0038	OUT	M005	
0015	AND NOT	M002		0039	LOAD	M005	
0016	AND NOT	M004		0040	AND	P012	*OUTPUT*
0017	AND NOT	M009		0041	FUN	017	
0018	AND NOT	M011		0042		M006	
0019	OUT	P012	*OUTPUT*	0043	LOAD	M006	*COUNT INPUT*
------	-------	-------	-------	0044	AND NOT	M004	
0020	LOAD	P012		0045	LOAD	M002	*RESET INPUT*
0021	FUN	017	*ONE SCAN*	0046	CUT	C005	
0022		M003		0047		4	

Table 4: Programme 4

0049	LOAD	C005		0069	LOAD	C007	
0050	AND NOT	T193		0070	AND NOT	T194	
0051	OUT	M004		0071	OUT	M009	
0052	LOAD	C005		0072	LOAD	C007	
0053	TON	T193		0073	TON	T194	
0054		1000		0074		2000	*20 Sec*
0056	LOAD	T193		0076	LOAD	T192	
0057	OR	M007		0077	LOAD	M009	
0058	OUT	M007		0078	FUN	017	
0059	LOAD	M007		0079		M010	
0060	AND	P012		0080	LOAD	M010	
0061	FUN	017		0081	LOAD	C008	
0062		M008		0082	CTU	C008	
0063	LOAD	M008	*COUNT INPUT*	0083		3	
0064	AND NOT	M009		0085	LOAD	C008	
0065	LOAD	M004	*RESET INPUT*	0086	OR	M011	
0066	CTU	C007	*UP COUNTER*	0087	OUT	M011	
0067		7		0088	FUN	1	

Table 5: Programme 4 (continued)

0000	LOAD	P000	*PUSH BUTTON*	0044	LOAD	P014	
0001	OR	M000	*FLAG*	0045	TMON	T009	*Monostable Timer*
0002	OUT	M000		0046		0010	
0003	LOAD	M000		0048	LOAD	T009	
0004	FUN	205		0049	FUN	017	*One Scan output*
0005		F103	*DUTY CYCLE*	0050		M004	
0007		100		0051	LOAD	M004	*Count input*
0009		100		0052	AND NOT	M006	
0011	LOAD	F103		0053	LOAD	M006	*Reset input*
0012	OUT	M001		0054	CTU	C005	*Up-counter*
0013	LOAD	M000		0055		0007	
0014	AND	M001		0057	LOAD	C005	
0015	AND NOT	M002		0058	OUT	M006	
0016	AND NOT	M006		0059	FUN	013	*JMP 00*
0017	OUT	P013	*OUTPUT*	0060	LOAD	M000	*Flag*
0018	LOAD	P013		0061	AND NOT	M006	
0019	TMON	T008	*MONOSTABLE TIMER*	0062	LOAD	M006	
0020		0010		0063	TON	T198	*On Delay Timer*
0022	LOAD	T008		0064		2000	*20 Sec. DEL*
0023	FUN	017	*ONE SCAN OUTPUT*	0066	LOAD	T198	
0024		M003		0067	AND	F095	*Clock Cntact 10 Sec.*
0025	LOAD	M003		0068	AND NOT	M007	
0026	AND NOT	M002		0069	OUT	P015	*Out Put*
0027	LOAD	M006	*RESET*	0070	LOAD	P015	
0028	CTU	C004	*UP COUNTER*	0071	TMON	T007	*Monostable Timer*
0029		5		0072		10	
0031	LOAD	C004		0074	LOAD	T007	
0032	OUT	M002		0075	FUN	017	*One Scan Output*
0033	LOAD	M000		0076		M008	
0034	AND NOT	M002		0077	LOAD	M008	*Count Input*
0035	FUN	012	*JMP 00*	0078	AND NOT	M007	
0036	LOAD	M002		0079	LOAD	M007	*Reset Input*
0037	TON	T197	*ON DELAY TIMER*	0080	CTU	C006	*Up Counter*
0038		2000		0081		4	
0040	LOAD	T197		0083	LOAD	C006	
0041	AND	F094	*Clock Contact 2 Sec*	0084	OR	M007	
0042	AND NOT	M006		0085	OUT	M007	
0043	OUT	P014	*Out Put*	0086	FUN	0001	*END*

Table 6: Programme 5

CONCLUSION

Taking in consideration the recent developments in the software and hardware of PLCs, the utilization of PLCs for realizing different sequential processes is the best choice. In order to simulate that in program (2) a clock contact was developed by using internal PLC timers.

By using the monostable timers, it is possible to realize the frequency division of two different square waves.

Five different common programs are designed and investigated in order to realize single actuator and multiple actuator sequential processes.

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