Karnaugh maps approach to understanding control implementation behind digital pneumatics

1.ª Parte

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ABSTRACT

Industrial processes need to be changed quickly so that different products can be produced. The response to these changes requires a reconstruction of the pneumatic control according to the new requests, that is, reconstruction of the control machine. To solve this problem, we present an alternative way to develop dual control for double-path sequence using Karnaugh Maps. In practice, we propose an approach to developing pneumatic control system in complex cases when there are two variants of the control sequence. The equations obtained by Karnaugh Maps (KM) simplified the elaboration of the command of the circuit, be it electro or pneumatic control, guaranteeing not only the realization of the two sequences combined, but as well as minimizing the command variables needed for a digital circuit. A practical example to understand the implementation of the control will be presented. The equations required to control the circuit will be also used in a programmable logic controller (PLC) that will control the circuit. This is an easy methodology to understand and implementing control digital pneumatics.

Keywords: digital pneumatic control; industrial automation; Karnaugh Maps; ON/OFF control; pneumatic sequential circuits

I. INTRODUCTION

Compressed air is one of the oldest sources of energy. Its distribution and use, under different working pressures, has become widespread and is currently an element that is present in all productive and service sectors. The controlled use of this energy source was called pneumatic (*Pneuma*), a Greek term meaning blow or breath.

Numbers are the applications that use compressed air as an energy source. Operations such as drilling, tapping, etc., are perfectly fit in mechanization and process automation, replacing the human force, as a work producer, by a constant and uniform external force capable to maintaining high productive rhythms. In this sense, the use of the pneumatic, as a source of energy, will be next to the mechanics, electricity or electronics and hydraulics. This integration will require a more comprehensive knowledge of the technologies to be applied in any process of automation not only from the point of view of the transmission of energy but also the control. Therefore, pneumatic control can be performed pneumatically (use of pneumatics as power source and control), electrically (pneumatic as power source and electricity as control, relay technology), electronically (pneumatics as power source and electronics as control, e.g., PLC) or combined with the hydraulics acting as power source and control and vice versa.

In pneumatics, the translational and rotational movements are obtained by the alternating introduction of air in the actuator chambers. In order to control this distribution, directional control valve are used which alternately direct the airflow to the chambers of the actuators, also ensuring the escape of the air from the opposing chamber. Then, the control of these directional movements has as objective the execution of the sequences of movements, be they combinational or sequential cycles. Therefore, to build a pneumatic circuit control system, we have three possible approaches [1]:

- *First*: control performed using an intuitive methodology where the designer tries to combine pneumatic signals to solve the problem. Highly complex methodology for the implementation of the control for combinatory or sequential cycles.
- *Second*: control performed using Cascade methodology. This methodology is used to solve any potential problem of the control for combinatory or sequential cycles. Electric control is a complex task.
- *Third*: control performed using KM's methodology. This methodology is also used to solve any potential problem of the control for combinatory or sequential cycles and for the drawing of the electric control.

Other methodologies of control may be used to solving automation control problems of which we can highlight: the Quickstepper FSS-12 Pneumatic/mechanical controlling sequences that, receiving information from sensors, and gives orders to ensure correct sequencing. This receives limit switch control signals to make the transition to the next phase of the sequence [8], or by a Programmable Step Sequencer Control and/or air logical control. In this paper, we will devote our attention to the implementation of the control of complex sequential cycles, based on set of optimized logical equations, obtained by the KM that enables the control of an electro or pneumatic circuit. This methodology is an application of the digital control (ON/OFF) to the control of pneumatic circuits and it will guarantee not only the control of the desired cycle, but that the equations of command are minimized [2].

In previous work [2][3][4], the authors presented a few set of generic rules for the construction of KM's, flow signal plotting sequence and for logical equation minimization and your applicability to the control of complex electro or pneumatic circuits. References [2] and [4] presented also the transcription of the equations to Ladder Diagram language (electro-pneumatic control based on Programmable Logic Controller, PLC). In this work, authors present a new approach to solve complex sequential cycle of pneumatic circuit with double-path and the associated points to the divergence and convergence to keep the synchronization of all the movements. Control is also implement in a programmable logic controller.

Section 2 gives a brief description of control techniques for pneumatic circuits. The rules to representing pneumatics circuits and conventionally representation for the movements, orders and limit switch. A description of the Cascade and KM's methodology is also presented. A case study is presented, to show the advantages in relation to the manipulation of KM's, involving a complex double-path pneumatic circuit control is given in Section 3. Section 4 presents pneumatics implementation and the conversion of the equations obtained by the KM's into control signals based on electrical contacts and a PLC electro-pneumatic implementation. Section 5 concludes the paper.

II. PNEUMATIC CONTROL TECHNIQUES

A set of directional control valve assembly and a cylinder perform control pneumatic. This combination of these two elements is the basis of the control system and as such, the most important combination of a pneumatic system. To this set of elements will be added many more that will be used as a guarantee that the distribution of compressed air will be performed at the exact moment.

Conventionally the indication of the actuators name is made by capital letters and limit switch, position of the actuators, by lowercase letters. So, we can represent, in a sequence, by A+ the forward movement and by A- the backward movement of a cylinder called A. The associated directional control valve, to control cylinder, will have the same name (A) and the forward order of the cylinder correspond to state A+ and the backward order to state A-. At the ends of the cylinder positioning we will call a_0 to the return distributor valve and a_1 to the advanced distributor valve, to which the states 0 and 1, respectively. Figure 1 shows a simplified representation of a pneumatic circuit. It should be noted that this representation, was made to understanding the association of the variables used, is not in accordance with the most recent conventions that recommend the use of numbers [9] or letters associated with numbers [10][9], instead of letters.

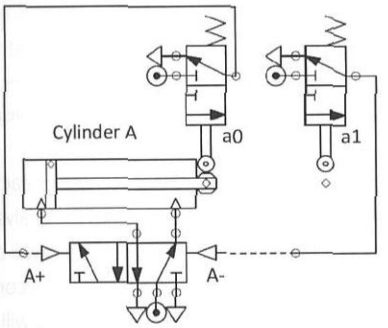

Figure 1. Simplified representation of a pneumatic circuit.

Then, the description of a sequential movement of cylinders should be represented in a simple and comprehensible way that translates the operation cycle of the cylinders. So, the representation of the movements of the advances and return of two cylinders (A and B) could be made as follows: A+\ B+\ A-\ B-. Another way to representing movements of the cylinder can be made using a displacement diagram (step diagram), i.e., a sequential or temporal diagram of movements or both. A sequential diagram represents sequential movements of cylinder and temporal diagram represents temporal path of the cylinders as show in Figure 2.

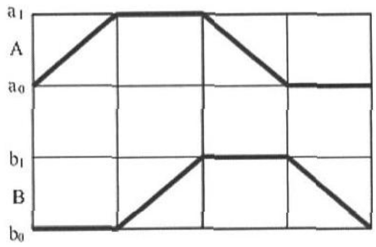

Figure 2. Step diagram for the sequence A+\ B+ \A- \B- [1].

A. Pneumatic Cascade Method

Pneumatic Cascade Method is used to solve complex pneumatics sequential cycles that require the use of memory's. The control of the power parts (cylinders) is made according to the state of the information present and the knowledge of the past actions (obtained by combinations of primary and secondary variables or memory's). Memory's are connected in cascaded to form the pressure group control allowing that, at each instant, only one of the groups will be active, i.e., under pressure, see Figure 3. To application these methods, it unnecessary to analyses the speed or course of stakeholder's cylinders because it is irrelevant to the materialization of the command sequence.

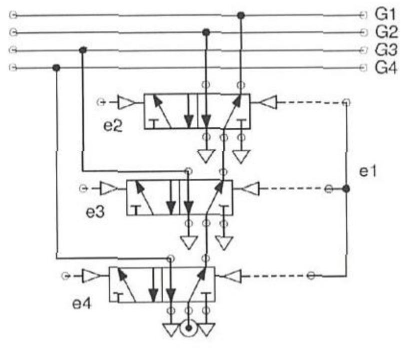

Figure 3. Cascade control pressure group (four groups).

Pressure groups are obtained by dividing the sequence into several consecutive groups of motions so that, in the same group, the motions of any one cylinder are not repeated, i.e., without repetition of letters in the group. So, the sequence presented in Figure 2 is divide in two group: A+ B+ | A- B-, group 1 and group 2.

B. Pneumatic and Electro-pneumatic Karnaugh Maps

Karnaugh Maps are, normally, used to simplify and minimize Boolean functions [5]. Industrially KM's can be used to develop control for sequential pneumatic or electro-pneumatic circuit. Let us consider now the sequence A+ B+ B- A-, sequence in "L" (double-crossing point), with two cylinder independents and double effect. So, the correspondence between the states of actives variables, limit switch, and the orders to give, control of the directional control valve (see Figure 1), give as the initial configuration of the KM's, 2^n cells (n is the number of cylinders) [2]. Initial order is giving in the upper left corner of the maps and the remaining orders are mapped according to the path plotting of the sequence [2][6]. Karnaugh Maps for this sequence (cycle in L) is presented in Figure 4.

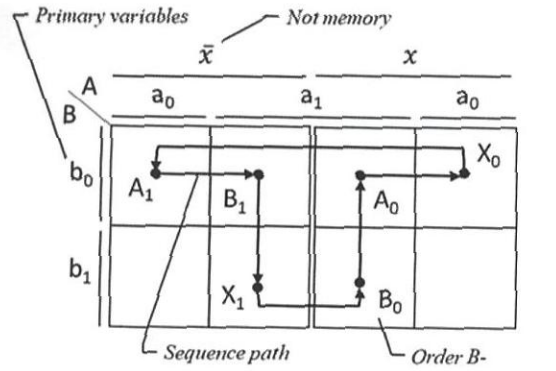

Figure 4. Karnaugh Maps for two cylinders (A and B) with one memory.

III. KARNAUGH MAPS FOR COMPLEX SEQUENTIAL CYCLE

The scheme shown in Figure 5 represents a drilling machine used in the production of the configurations shown in the figure. Three of the cylinders produce oblong holes (cylinders B and D in simultaneously, followed by the C) while the fourth (cylinder A) is used to perform the longitudinal drilling in top of the part.

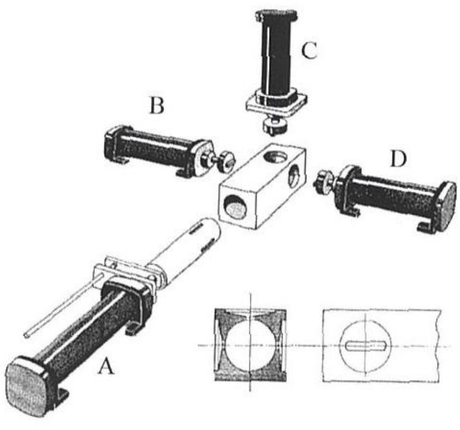

Figure 5. Drilling machine [7].

Due to the manufacturing needs, the system has been prepared to work in two distinct modes, push-button S1 and S2. In the first mode (S1) all cylinders work while in the operating mode S2 cylinder C is suppress, maintaining the sequence of the remaining movements. From these conditions, it follows that the sequence has a common path diverging and/or converging at specific points. Table 1 shows the sequences of push-button S1 mode and S2 mode.

Table I. Sequence of Movement for S1 and S2 Mode.

S1	S2
A+	A+
B+ D+	B+ D+
C+	
A-	A-
B- D-	B- D-
C-	

Representing movements of a sequence is made by an algebraic form, more usual form, or by a displacement diagram. In presented case, we have two sequence, although we have two different paths, normally, the representation must be confined to the more complex movement only because part of the sequence is overlap. However, in order to make the overlap of movements more understandable, we choose representing the movements in a separate step-diagram. Figure 6 shows the displacement diagram for this two sequence. Black path represents the overlap movements, green and red paths represents the remaining sequence path. Note that although with different trajectories, part of the green and red paths is also an overlap.

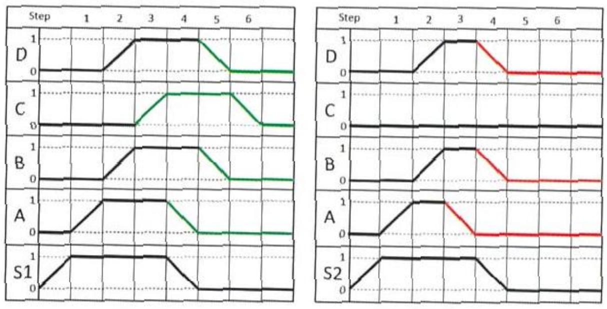

Figure 6. Displacement diagram of the double-path sequence (S1 and S2).

The KM's is drawn considering, first, the sequence with the largest number of cylinders to control (A, B, C and D). On the other hand, and considering the initial movements of the cylinders, initial map will present the configuration shown in Figure 7. So, the initial movement of the sequence will be performed in the upper left corner of the map. Sequence is drawing inside the map by associating the corresponding orders. Maps grows according to the impossibility of performing any of the movements (occupied cell of arrival) through its horizontal/vertical unfolding, as defined in [2]. Black path represents the overlap movements, green and red paths represents the remaining sequence path. Cell $a_1b_1c_0d_1$ is the split cell of the movements (dark yellow, Figure 7). S1 and S2 defines the direction of the sequence, right or left (green or red path).

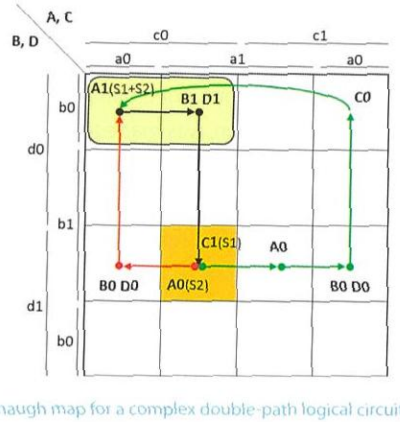

Figure 7. Karnaugh map for a complex double-path logical circuit (S1 and S2).

To obtain the equations it is necessary to isolate each of the sequences and each of the orders. Then, from the analysis of the initial order (upper left corner), it is verified that this will be executed whenever one of the buttons S1 or S2 is pressed, common path of the sequence. However, other considerations will have to be considered since, as this cell is the initial cell of the two sequences, we must ensure that all movements are completed. On the other hand, the active variable or actives variables will have to be present in the equation of motion associated with the A_1 order. In this case, the active variable for sequence S1 is c_0 (previous movement) and b_0d_0 for sequence S2. So, the forward control equation of cylinder A (order A_1, see Figure 7) will be given by:

$$A_1 = (S1 + S2) . c_0 . b_0 . d_0 \quad (1)$$

This control function is part of the result of the minimization of the logical equations obtained from KM, establishing a relation between sensors (limit switch), memory's and cylinders orders.

The remaining control equations are obtained by following the same approach for the order A_1. Therefore, to the sequence S1 we have:

$$A_0 = c_1 \quad (2)$$

$$\begin{cases} B_1 = a_1 \\ B_0 = a_0 \end{cases} \quad (3)$$

$$\begin{cases} C_1 = b_1 . d_1 . S1 \\ C_0 = b_0 . d_0 \end{cases} \quad (4)$$

$$\begin{cases} D_1 = a_1 \\ D_0 = a_0 \end{cases} \quad (5)$$

$$\overline{S1} = c_1 \quad (6)$$

Control equation for C_1, in the split cell (Figure 8), is obtain by the previous movements (active variables b_1 and d_1) and the memorized signal of push-button S1, see (4).

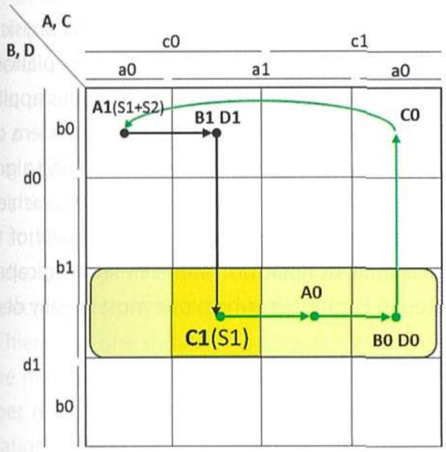

Figure 8. Karnaugh map for sequence S1.

Implementation of this electrical memory (signal for sequence S1) is presented in Figure 9.

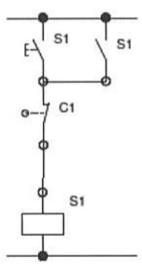

Figure 9. Memory for the push-button S1.

Note that, the limit switch c_1 is a closed contact since its placement in memory must be in the negative form. So, after order C_1 (advance of cylinder C) the memory is not necessary, the activation of c_1 turn off memory S1, and the sequence performs path S1. From this point, it is not necessary to maintain the reference of the sequence (S1) to be performed since it follows a path that will be independent of the sequence S2. In some situations, it will be necessary to maintain the information of the sequence since there may be overlapping orders and, as such, it will be necessary to distinguish the different paths.

For the sequence S2 the equations are obtain following plotting sequence in the new abstraction for KM, Figure 10.

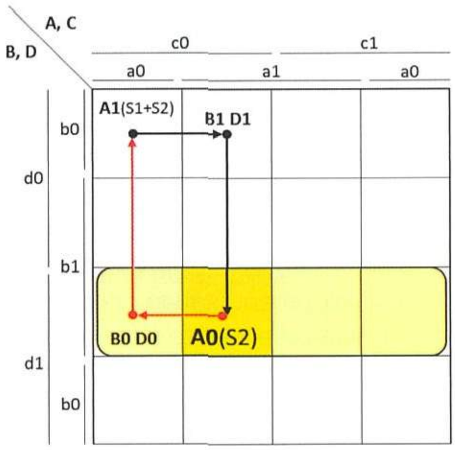

Figure 10. Karnaugh map for sequence S2.

The equation for the order A_1 is the same obtain in the sequence S1 (1) but, the return of this cylinder depends not only one of the active variables but also the memory S2 associated to the divergence cell. So, in this case, the actives variables for the order A_0 in the sequence S2 are b_1 and d_1 (previous movements). So, the return control equation of cylinder A, working in sequence S2, (order A_0, see Fig. 10) will be given by:

$$A_0 = b_1 . d_1 . S2 \quad (7)$$

Cylinder B and D have also de same equations. Cylinder C do not work in S2 and the turn off memory, S2 is made by the active's variables a_0, b_1 and d_1, *after the return of the cylinder A. So, the* equation for deactivating memory S2 is:

$$\overline{S2} = a_0 . b_1 . b_1 \quad (8)$$

The junction of these two paths results in a set of equations that usually is translate into a sequence of repetition of movements and, as such, conditioned to the pressed button S1 or S2. The final set of logical equations is:

$$\begin{cases} A_1 = (S1 + S2) . c_0 . b_0 . d_0 \\ A_0 = c_1 + b_1 . d_1 . S2 \end{cases} \quad (9)$$

$$\begin{cases} B_1 = a_1 \\ B_0 = a_0 + a_0 \end{cases} \quad (10)$$

$$\begin{cases} C_1 = b_1 . d_1 . S1 \\ C_0 = b_0 . d_0 \end{cases} \quad (11)$$

$$\begin{cases} D_1 = a_1 \\ D_0 = a_0 + a_0 \end{cases} \quad (12)$$

$$\begin{cases} \overline{S1} = c_1 \\ \overline{S2} = a_0 . b_1 . b_1 \end{cases} \quad (13)$$