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Research on design relay control circuit using logic algebra

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ABSTRACT

It is a key problem that design relay control has not a formal and systemic method relaying on the experience of designer. This paper introduces a new approach that digital logic principle is applied to relay control circuit .Under the premise of knowing control object and requirements, the logic function and control circuit diagram are obtained by using logic circuit. Then accomplish the design control circuit. This method which can systemic design control circuit and simplify design process is illustrated by a specific example.

Key words: Logic algebra relay; Karnaugh maps; Circuit design; Constraint condition

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INTRODUCTION

As an electronic control device over one hundred years history, relay is largely used in all kinds of automation fields, such as electrical power system, automobile, household appliance, industrial manufacture, spaceflight, etc.[1][2][3]. PLC (Programmable logic controller) is gradually becoming mature in recent years. But it can't completely replace relay control. Besides, a great many of technicians are used to using ladder diagram, when write PLC software. So relay control circuit still plays an important role.

For a long time, relay control circuit is often used to simple system of single goal. People can draw control circuit only by experience. It leads to the design relay control system has not a formal and systemic design theory and method. However, the complex relay control systems cannot be completed simply by experience. Therefore, in this paper a new method of using logic algebra theory of digital electronic technology to design relay control is introduced which can simplify the design progress.

DESCRIPTION OF LOGIC STATE

In 1849 year,George Boole,English mathematician engineer,initiated the theoretical basis of digital electronic technology[7] when he was researching switch signal. So using the logic algebra to solve the problem for the relay switch is feasible in theory.In order to successfully complete the design,must first describe the logic state of various objects involved in the control circuit.

There are many types of relays,like ac contactor,intermediate relay,time relay,etc[8].Different types of relays differ only in the operating conditions.Structurally,they can be divided into corresponding to the operation condition of the coil and to the output of the contact set[9].For ease of explanation behind, provisions is special for the following.Relay names with KM_A, KM_B, KM_C ,etc.Its energized state is a logic value "1"and its de-energized state of the logical value "0". The relay names of variable and subscript indicates the driven contacts by relay coil.It is "1" when contact is open and it is "0" when it is off,such as KM_{A-1} represents the normally open contacts of relay KM_A, $\overline{KM}_{A-1}$ represents the normally closed contact.So the description of the relay KM_A can be described as follows.If the relay KM_A is energized,the normally open contacts close,and the normally closed contact disconnect.That is to say if KM_A =1,then $KM_{A-1}=1$, $\overline{KM}_{A-1}=0$.If the relay KM_A is loss of power,the normally open contacts disconnect,and the normally closed contact close.That is to say if KM_A=0,then $KM_A=0$, $\overline{KM}_{A-1}$ =1.

The button is the operation object of operator,named SB_A, SB_B, SB_C etc.It is made up of key s and contacts.Its logical description is similar to that of relay.

Unlike ordinary control object,electric motor has three operating state.It is a multiple-valued logic devices [10][11].The operating state of electric motor M can be defined as follows."1" represents forward state, "-1" represents reverse state and "0" represents stop state.Apparently,the state of the electric motor depends on whether the relay KM_A of control forward and the relay KM_B of control reverse are energized.Constraint relation is that KM_A and KM_B cannot be simultaneously energized,but can simultaneously loss power.So the logic of electric motor can be described as:

$$M = KM_A - KM_B \quad (1)$$

Which constraint is $KM_A * KM_B = 0$.

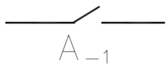
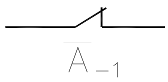
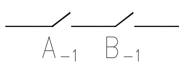
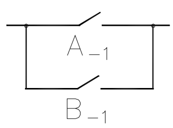
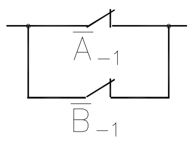
To summer up,the majority logic of control object can be described as follows."1" represents the energized state of control object"0" represents the power loss state. "1" represents the contact closure. "0" represents the contact off.

CONVERSION BETWEEN THE RELAY AND LOGIC CIRCUITS

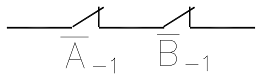
The relay contacts respectively correspond to the high and low electrical level in gate circuits of digital circuits.Logically,Relay coils are the input variables of relay,and the contacts driven by coil equivalent to the output variable.The relationship between relay A,as well as its driving normally open contacts A_{-1} and normally closed contacts $\overline{A}_{-1}$ can be written as:

$$A = A_{-1}, \overline{A} = \overline{A}_{-1} \quad (2)$$

Table1. The correspondence table of logical relationship and the relay circuit

Logical relationship	Corresponding circuit
$y = A$	
$y = \overline{A}$	
$y = AB$	
$y = A + B$	
$y = \overline{A \bullet B} = \overline{A} + \overline{B}$	

$$y = \overline{A+B}$$
$$= \overline{A} \bullet \overline{B}$$



Common gate circuit also includes and-or-not gate,xor gate and XNOR gate.They can correspond to the relay circuit in the same way,not to list in this.Note that a gate can be connected to multiple other gates in the fan leaves coefficient.The relay contacts can only be used once in the circuit.So if a logical variable is used several times,it should use the same number of contact groups to achieve.

DESIGN EXAMPLE

The following is an example of electric motor reversing circuit introducing designing progress.

Control demand:Press the forward button and he motor will be transferred.Press the reverse button and the motor will reverse.Press the stop button and it will stop.Pressing forward and reverse buttons at the same time is illegal operation.Circuit does not respond and maintain the original state.

Design steps:

1. Determine the state of the control object motor M

M=1, the motor is transferred;M=0, the motor is stopped;M=-1, the motor reverses.

2. Determine the operating variables

SB_A is forward button. SB_B is reverse button. SB_C is the stop button.

3. Determine execution object

The execution object is namely the relay to be used.Number is N.The number of the control object (motor) state is M.They should satisfy the relation: 2N≥M.The number of motor state is M=3, so N=2. KM_A Can be set toforward relay and KM_B is reversing relay.They should satisfy the constrains: $KM_A * KM_B = 0$.

4. Determine the logic unit state table of the motor control system

In case of that pressing forward and reverse button cause a short circuit in the using process. When SB_A =”1”and SB_B =”1”, except SB_A =”1”and SB_B =”1”is illegal, the rest remain the originalstate.The system does not respond.That is to say when KM_A =1, KM_B =0, the motor is transferred;when KM_A =0, KM_B =1,the motor is reversing(The illegal state * is forbidden to use).

5. Paint and simplify Karnaugh map

Table2. Motor control logic state table

SB_A	SB_B	SB_C	KM_A	KM_B	M
0	0	0	0	0	0
0	0	0	0	1	-1
0	0	0	1	0	1
0	0	0	1	1	*
0	1	0	0	0	-1
0	1	0	0	1	-1
0	1	0	1	0	-1
0	1	0	1	1	*
1	0	0	0	0	1
1	0	0	0	1	1
1	0	0	1	0	1
1	0	0	1	1	*
1	1	0	0	0	0
1	1	0	0	1	-1
1	1	0	1	0	1
1	1	0	1	1	*
*	*	1	*	*	0

Containing five input variables Table 2 makes the relevant Karnaugh map complicated. Decreasing dimension can reduce the difficulty of simplification[12].Based on past experience, SB_C stop button in the control circuit should be connected in series .Due to the fixed connection,the design cannot be considered.In this way,the control circuit is only SB_A , SB_B , KM_A and KM_B four variables. In design, draw Karnaugh map [13]of the energized(namely not press the stop button, SB_C =0) control system, and simplify it.Then control functions can be achieved. Karnaugh map is shown in Figure 1.

KM_AKM_B / SB_ASB_B	00	01	11	10
00	0	-1	*	1
01	-1	-1	*	-1
11	0	-1	*	1
10	1	1	*	1

Fig.1 Control circuit Karnaugh map

“1” in Karnaugh map corresponds to the condition of the motor M=1(forward),namely it is the energized condition of relay KM_A .“-1” in Figure 1 corresponds to the condition of the motor M=1(inverted),namely it is the energized condition of relay KM_B “0” in Figure 1 corresponds to the stop condition of the motor ,namely KM_A and KM_B are both in the power failure condition.“*”is disabled operation or constraints.According to the Karnaugh map to simplify,the expression of forward and reverse relays energized condition can be achieved.The expression for the motor forward is:

$$[SB_A\overline{SB}_B+(SB_A+\overline{SB}_B)KM_A]\overline{SB}_C \quad (3)$$

The expression of motor reversal is:

$$[\overline{SB}_ASB_B+(\overline{SB}_A+SB_B)KM_B]\overline{SB}_C \quad (4)$$

Based on the past experience in the design,relay energized or not is determined by the button and relay contacts connected in a certain way.So the relay KM should be a status relay contacts and the contacts button function.This is similar to the sequential logic circuit design.when writing,put equation (2) into (3) and (4).That is changing KM_A, KM_B to the corresponding relay contacts KM_{A-1} and KM_{B-1} .Then can separately get the control equation of forward relay KM_A and reverse relay KM_B :

$$KM_A=[SB_A\overline{SB}_B+(SB_A+\overline{SB}_B)KM_{A-1}]\overline{SB}_C \quad (5)$$

$$KM_B=[\overline{SB}_ASB_B+(\overline{SB}_A+SB_B)KM_{B-1}]\overline{SB}_C \quad (6)$$

Put the equation (5) and (6) into (1) can get the motor control equation (7):

$$M=\{[SB_A\overline{SB}_B+(SB_A+\overline{SB}_B)KM_{A-1}]-[\overline{SB}_ASB_B+(\overline{SB}_A+SB_B)KM_{B-1}]\}\overline{SB}_C \quad (7)$$

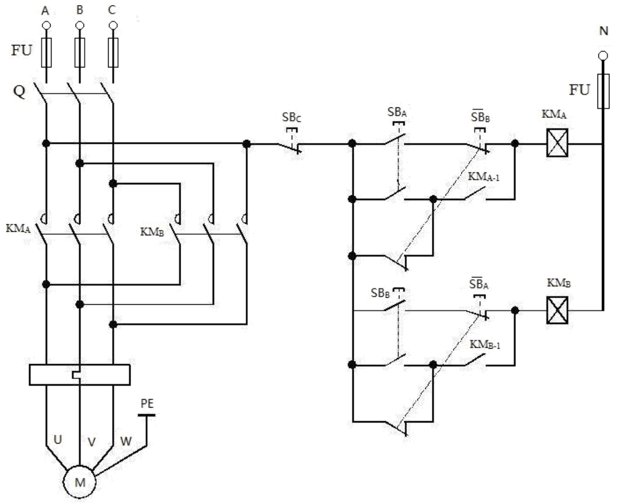


Fig.2 Motor control circuit diagram

8. Improve the control circuit

Further studies can find that system can meet the control requirements in normal circumstances.But if make KM_A and KM_B simultaneously energized by mistake,since the forward reverse buttons are not pressed,this situation will remain energized and cause the motor main circuit shorted.The control circuit exists risk problem caused by mishandling the bound terms.Observing Karnaugh map in Figure can know the third column of KM_A and KM_B both "1" is labeled "*" as a bound term exists.In order to make control function most simplified,these "*" are circled into the circle of solid lines representing forward and the circle of dashed line representing reverse.This causes the control circuit to continue energized after a power failure,leading to a short circuit accident. In order to eliminate the phenomenon of adventure,the bound term can be re-processed.For security,when KMA and KMB are energized at the same time,the system should stop and the corresponding motor should stop.The corresponding Karnaugh map after improving scheme is shown in Figure 3.

KM_AKM_B / SB_ASB_B	00	01	11	10
00	0	-1	0	1
01	-1	-1	0	-1
11	0	-1	0	1
10	1	1	0	1

Fig. 3 The improved control system Karnaugh map

Based on the same method,the control function of improved scheme can be get from the Karnak map.The control function of KM_A and KM_B relay is:

$$KM_A = [SB_A\overline{SB_B}\,\overline{KM_{A-1}} + (SB_A + \overline{SB_B})KM_{A-1}\overline{KM_{B-1}}]\overline{SB_C} \tag{8}$$

$$KM_B = [\overline{SB_A}SB_B\overline{KM_{B-1}} + (\overline{SB_A} + SB_B)\overline{KM_{A-1}}KM_{B-1}]\overline{SB_C} \tag{9}$$

Another way is to add the correction function directly. KM_A and KM_B both "1" should be banned.So the correction is:

$$y = \overline{KM_A \bullet KM_B} = \overline{KM}_A + \overline{KM}_B \tag{10}$$

Put the correction function (10) into (7) and then can get the improved control function:

$$M = \{[SB_A \overline{SB}_B \overline{KM}_{A-1} + (SB_A + \overline{SB}_B) KM_{A-1} \overline{KM}_{B-1}] - [\overline{SB}_A SB_B \overline{KM}_{B-1} + (\overline{SB}_A + SB_B) \overline{KM}_{A-1} KM_{B-1}]\}(\overline{KM}_A + \overline{KM}_B)\overline{SB}_C \tag{11}$$

And draw the new control circuit,shown in Figure 4.

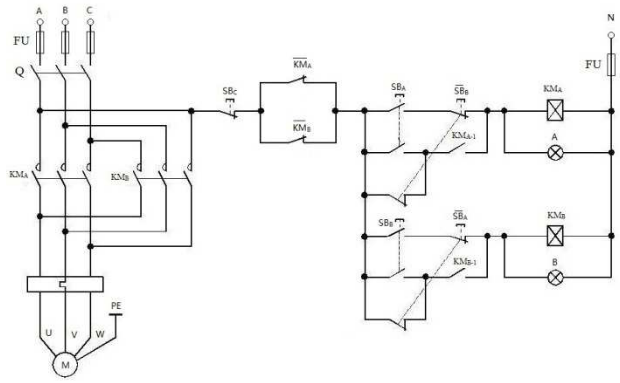


Fig.4. Improved control scheme.

Combined with the actual situation,the control program can also propose other requirements. The above program is designed as the motor can reverse directly.In some case,the motor should stop first and then reverse to avoid motor damage and other problems. In respond to this requirement,change the logic state table.As long as the motor is still in the running state (forward reverse available),except pressing the button stop to the motor ,press another button the system does not respond and can achieve.According to methods previously described,the control function can get.And draw circuit.Here does not describe in detail.

CONCLUSION

Through the above process,the design of relay control circuit completed by using design principles of digital logic circuit.This method differs from traditional design methods in the design ideas.From the theoretical point of view, the design of complex relay control circuit provides a new idea.As long as knowing the control object and control requirements in this method,using the fixed step can quickly and easily design the corresponding circuit and improve design speed.

Furthermore,this design method can also be used for consequential changes of the control circuit depending on the requirements in practical applications.Further improve the design.This method has a strong practical value in the existing relay control system modification or upgrade PLC control systems.

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