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Discuss the Programming Method of Sequential Control with Ladder Diagram

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Abstract: Sequence function chart is the preferred language for sequential control system design, but its audience is not as wide as ladder diagram. In order to realize the standardization and high efficiency of ladder diagram sequence control design, based on the program structure of sequence function chart of GBT 15969.3-2017 programming language, the design method using ladder diagram is summarized, supplemented and standardized. Firstly, according to the function of the instructions used, the six sequential control design methods of the ladder diagram are divided into three categories: set / reset instruction class, step instruction class and data register operation class. Secondly, according to the development rules of sequential function diagram, a new programming method for sequential control design according to jump class instructions is developed. According to the program execution flow analysis, this method is closest to the execution process of sequential function chart program. Finally, it compares the performance gap of the same sequence function chart from three aspects: the influence on the program scanning cycle, the repeatability of components in the program, whether it is easy to force, package and macro step structured programming. The results show that the jump instruction class programming method can effectively avoid the defects such as waste of component resources, long scanning period and contradictory conversion conditions, and retain the advantages of sequential control design method, which is more obvious than other programming methods. The research results can provide selection conditions and standard methods for the design of ladder diagram sequential control system.

1. Introduction

The basic principle of the sequential control design method is the step-type principle, which consists of several sequential connected steps (steps) to connect the entire working cycle of the sequential control system. It in accordance with the production process of the sequence of requirements, using the role of input signals, according to the system internal state or time sequence, so that a plurality of executive agencies according to the process of automatic operation. According to the part of GBT159699.3-2017 programming language sequence function diagram, the sequence control process is completed by the basic item step, transformation, directed line segment structure and transformation according to the grammar rules and progress rules. In this way, the design of the program

only focuses on the action of each step and the design of the conversion conditions. The program has the advantages of high fault tolerance and easy to realize structured programming, which greatly improves the efficiency of program design and makes it very convenient to debug, modify and read the program[1].

Programmable Logic Controller (PLC) is one of the important tools of automated manufacturing. Among the five standardized programming languages of programmable controller GBT159699.3-2017, ladder diagram and instruction table are the basic languages. Among them, ladder diagram and relay control circuit are similar, intuitive and easy to program, so it is the most widely used language in the automation industry. Sequential Function Chart (SFC) is a higher level graphical description language. SFC elements define that as a programming language, it is closer to describe objects, implement the principle of step by step the preferred language is sequential function chart (SFC), also has the program scan cycle has nothing to do with the process capacity, the characteristics of the internal components to allow reuse, this is the international electro technical commission (IEC) will be recommended for sequential function chart of PLC programming language of choice for the reason.[2-3]

As a graphical configuration language, SFC is applied to industrial process control with complex logic flow, which can effectively deal with the difficulties of PLC software scale expansion. After many years of research and development, the programming mode of upper computer graphical language is more and more favored by users. The existing achievements in engineering application are mostly focused on ladder diagram, such as the realization of ladder diagram, the conversion of ladder diagram to instruction table, etc. [4].Sequential function diagram (SFC) is after all a high-level professional language, its audience is not as wide as ladder diagram and function module diagram, so in many limited conditions, often use ladder diagram or function module diagram language, rely on the principle of step programming.

In this paper, according to the characteristics and properties of step-by-step sequential control system design based on ladder diagram, a new classification method is divided into three categories: 1.2. Step instruction class;3. Data register operation class; The fourth kind of design method: jump instruction class is proposed.

The following discusses the realization and characteristics of the sequential control system design and programming method based on the stepping principle of these four types of ladder diagrams from the perspective of universality.

2. The Programming Method of the Set/Reset Instruction Class

Set/reset instruction principle is in different conditions after the conversion of the step, the use of SET command, such as Mitsubishi FN2N series PLC L (latch) or SET (SET), Siemens S7 series PLC and Omron CPM1A series PLC S (SET) instruction to SET the following step;For the active step before conversion, the reset command is adopted, such as U (unlock) or RST (reset) in Mitsubishi FN2N series PLC, R (reset) command in Siemens S7 series PLC and Omron CPM1A series PLC to reset the previous step.

The set/reset instruction classes include:

1) The programming method of using the auxiliary relay to represent the step state

The auxiliary relay is used to represent the state of the step, which refers to the subsequent step of setting (SET) with transition conditions. Therefore, the condition of setting is that the previous step is the active step and the transition conditions are met.Reset the previous step with the subsequent step state (RST), so the reset condition is

that the subsequent step becomes an active step. Actions and commands connected to a step are directly connected to the state contacts of that step and are implemented using the OUT instruction. This is often used for drivers that distribute the movement of a step across the transition step. The following use of FX2N series PLC as an example to introduce the ladder diagram structure.

The sequential function diagram of a single sequence with cyclic structure and the program realized by ladder diagram are shown in Figure 1 (a) and (b).

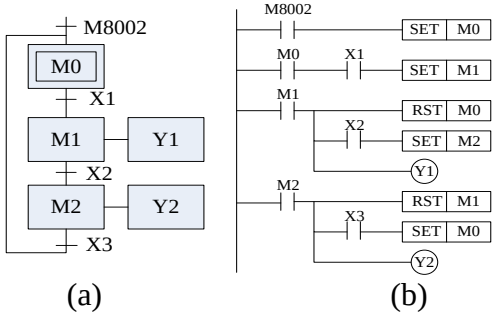

Figure 1 The Auxiliary Relay Realizes a Single Sequence with a Cycle Structure

The initial pulse M8002 makes M0 set as the active step;If the transition conditions X1 = 1, the M1 is setting, realize the conversion from M0 to M1, M0 are reset, at the same time, M1 driver output coil Y1, X2 = 1 if the conversion conditions, the M2 is setting, realize the conversion from M1 to M2, M1 are reset, at the same time M2 driver output coil Y2, X3 = 1 if the conversion conditions, M0 be setting step becomes active, realize the conversion from M2 to M0, program into the next cycle.

2) The programming method that progresses according to the transformation condition

According to the transition condition, refers to the step state contacts and the transition conditions connected by the step are connected in series to judge, when their conditions are met, the transition from the previous step to the subsequent step is realized.

The sequence function diagram of a single sequence with cyclic structure and the program realized by ladder diagram are shown in Figure 2 (a) and (b).

The output relay coils can be centrally programmed to avoid conflicting results in subsequent cycles. When multiple steps are to excite the same relay coil, the state contacts of these steps can be directly connected in parallel and then connected in series with the coil.

3) The programming method with hold function instruction or latch relay instruction

This method and the use of auxiliary relay on behalf of the state of the programming method of the idea is basically the same, but many PLC can be directly used to maintain the function of the instruction or latch relay instruction.

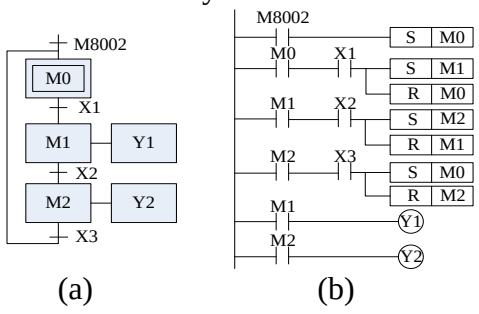

Figure 2 The Transformation Condition Progresses to Achieve a Single Sequence with a Cyclic Structure

For example, Omron CPM1A series PLC has a KEEP relay instruction KEEP. The ladder diagram symbol is shown in Figure 3.The left end interface of the component is the set end, the lower end interface is the reset end, and the digits below the KEEP letter are the relay region address in CPM1A in bits.

The sequence function diagram of a single sequence with cyclic structure and the program realized by ladder diagram are shown in Figure 3 (a) and (b).

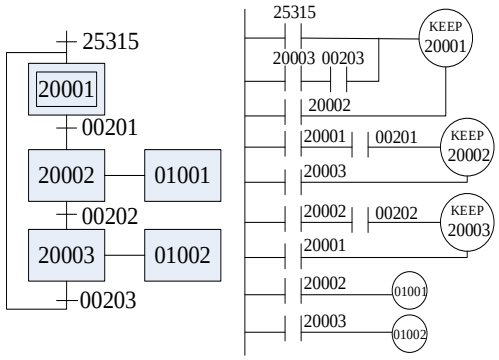

Figure 3 The Hold Function Instruction Implements a Single Sequence with a Loop Structure

The features of programming with hold function instruction are as follows:

a) For more complex conversion conditions, intermediate relay contacts can be used to simplify the program and facilitate the understanding of the program.

b) The conditions for a step to be an active step and an inactive step are implemented at the same step, that is, the set and reset conditions are at the same step, and the actions and commands connected by the step can be designed after the step.

4) Start - protect - stop programming method

The start and hold stop circuit is referred to as the start and protect power off circuit for short. It uses the self-hold contact in parallel with the start circuit to realize the memory hold function, which can be understood as the set function. The normally closed contact of the subsequent step is in series with the coil of the previous step, as the stop circuit, which can be understood as the reset function.The characteristic of the power off circuit is that the programming can be completed only with contact instructions and coil instructions, and no other components are needed as intermediate tools [5].The ladder diagram prepared is long, easy to master, strong applicability, is the most basic programming method.

3. Programming with Step Instruction Classes

Some PLCs provide step instructions: Mitsubishi FX series step contact instruction STL instruction, step back instruction RET; Siemens S7 series of sequential state start instruction SCR, state transfer instruction SCRT, sequential state end instruction SCRE; Omron CPM1A series STEP definition instruction and STEP start instruction SNXT. These instructions can complete the smooth control process programming.

This part takes Mitsubishi FX series as an example to introduce the programming method. Figure 4 illustrates the relationship between STL statements and the sequential function diagram.

Figure (a) is a single sequence sequence function diagram; Figure (b) is a ladder diagram program designed with step instruction; Figure (c) is the symbolic form of the STL instruction in the ladder diagram;Figure (d) is a statement table program using STL instructions.

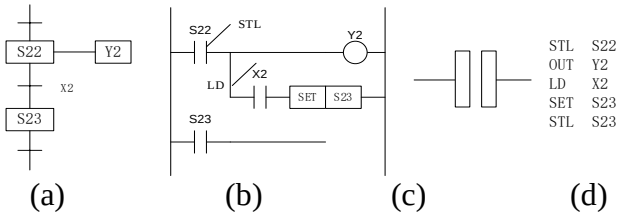

Figure 4 Sfc and Stl Instructions

After the establishment of the STL flag bit, the starting contact connected with the STL needs to use LD or LDI instructions. It is equivalent to the establishment of a new bus in the STL statement, called the sub-bus to distinguish it from the original bus. This bus does not lose power until the next STL instruction or RET instruction occurs [6].At least one step function has to be written after a series of STL instructions to end the RET instruction. The LD dot returns the bus, so there is no need to use the reset instruction for the previous step.

The sequence function diagram of a single sequence with cyclic structure and the program realized by ladder diagram are shown in Figure 5 (a) and (b).

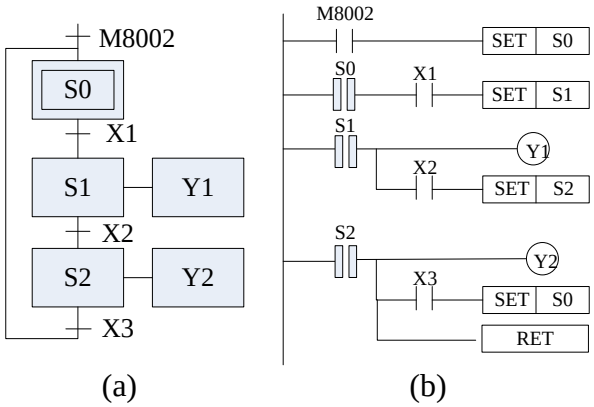

Figure 5 Step Instruction Implements a Single Sequence with a Loop Structure

The initial pulse M8002 sets S0; Then STL instruction sets S0 as STL step. If conversion condition X1=1, STL instruction sets S1 as STL step to realize conversion from S0 to S1 and drive output coil Y1. If conversion condition X2=1, S2 is set as STL step to realize conversion from S1 to S2. When S2 becomes STL step, the output coil Y2 is driven. If the conversion condition X3=1, S0 is set and the program completes one cycle.

The final STL command is to use the RET instruction to indicate that the program returns the bus * (Note: different versions of Mitsubishi programming use STL statements in different ways).

The characteristics of STL step instruction programming method:

1)STL contact is the normally open contact connected with the left bus. When an STL contact is connected, the corresponding state is active step;

2)2) Do not use STL instructions in interrupt routines and subroutines.

3)3) Because the CPU only executes the instructions in the circuit block driven by the STL contacts in the active state, the dual coil output is allowed when using the STL instructions (the parallel control program can drive the same coil several times in different steps);When there is no parallel structure, only one STL contact is connected, so STL instruction can be reused component resources, significantly shorten the execution time of the user program, improve the PLC input, output response speed.

4. Using Data Register Arithmetic Class Programming Method

There are two kinds of programming methods using data register operation class, one is to use the data transfer instruction MOV, the other is to use the shift register instruction.

The idea of using the shift register for sequence control design is to use the bit of the shift register to correspond to the step in the sequence function diagram.In PLC programming, shift instruction is a group of high frequency instruction, including left shift instruction, right shift instruction, cyclic left shift, cyclic right shift and other shift instructions. Its function is to move all the bits in the target operand in the specified way, and the result is stored in the target operand [7].

The shift register can be used according to the instruction characteristics of the shift register. If one of its bits is set to be 1, the rest are set to be 0.Thus the corresponding step becomes an active step. According to the transition condition to control the movement of the “bit”, equivalent to the completion of the step conversion, step connection actions and commands will be executed. Many PLC manufacturers have provided the shift register instruction that can be used, for example: Mitsubishi FX series shift register instruction SFTL (bit left), SFTR (bit right);Siemens S7 series shift register instruction shRB; Omron CPM1A series shift register instruction SFT and so on.

The programming idea of using MOV instruction to carry out sequential control design is to use different data values to represent different steps in the system, trigger MOV instruction through the closure of normally open contacts, modify the size of data values, so as to realize step transfer [8].Mitsubishi PLC, Siemens PLC, Omron PLC manufacturers have provided the data transmission instruction MOV can be used.

The following shift register programming method as an example, using Omron CPM1A series of SFT instructions to discuss.

SFT is a shift register instruction, and the ladder symbol is shown in Figure 6 (a). Where in is the data input, SP is the end channel number of shift pulse input bit, st and e must be in the same area and St $\leqslant$ E. When the reset terminal R is OFF, at the rising edge moment of each shift pulse at SP terminal, all data from ST to E channel are moved to the left one bit by bit, the highest bit overflow of data IN E channel is lost, and the lowest bit of data IN SP channel is moved to IN terminal. SP terminal has no shift pulse and does not shift. When the reset terminal R is ON, all channels from ST to E are reset to 0, and the shift instruction is not executed [9].

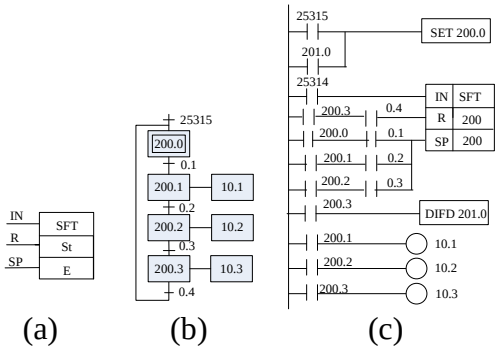

Figure 6 The Shift Register Implements a Single Sequence with a Loop Structure

Figure 6 (B) and (C) Are a Single Sequence Sequence Function Diagram with Cyclic Structure and a Ladder Diagram of the Shift Register Implementation.

The shift register takes channel 200 as the operand and uses the first four bits of channel 200, 200.0-200.3, to represent four steps to form a ring shift register.25315 is the initial start signal. Set the initial step 200.0 to 1.25314 is normal 0, indicating that the lowest order is supplemented by 0 during shift. When 200.0 is the moving step and the conversion condition 0.1 is 1, a shift pulse is input, and the left shift result makes 200.0 0,200.1 to 1.Therefore, 200.1 is an active step; and so on, convert the active step. When 200.3 is 1 and the conversion condition 0.4 is 1, the condition of the two makes channel 200 reset to 0. When 200.3 changes from 1 to 0, a pulse signal is generated at 201.0 by using the descending edge differential instruction, and 200.0 is reset, and the program enters the next cycle. When 200.1-200.3 is an active step, the output coils 10.1, 10.2 and 10.3 are respectively driven to output control commands.

The design principles of the shift register programming method are as follows:

1) Concatenate the state of the step with the condition of the transition to the next step.

2) The displacement of each step follows the above principle, and the state of each step and the corresponding transition conditions should be connected in parallel after the contacts are connected in series to form or form a logical circuit.

3) The input signal of the shift register should be designed to be 1 in the initial step and 0 in any other active step to ensure the start of the shift register; at the same time, the shift register cannot be restarted because another step becomes active.

4) Design of the reset signal of the shift register for the program that runs only once, the program end condition is used as the reset signal; for most applications, the conversion condition of the last step can be used as a reset signal for cyclic operation.

Using data register operation class method design features:

Trapezoidal diagram is relatively simple with few instructions, but it is too inconvenient to design more complex control systems. For example, the design of conditional branches and converges need to be completed by shifting multi-segment branches respectively [10], which has relatively high requirements for programmers, and most of them are applied in a single sequential control circuit with regular regularity.

5. Programming with the Jump Instruction Class

The sequential functional graph has only one active step in the control process without parallel structure, and there are also several active steps in the control process with parallel structure. According to this characteristic, we can innovate a new method to

transform the sequential function diagram into a ladder diagram by using jump instruction.

The JMP/JME instruction in Omron CPM1A series is taken as an example to discuss this programming method. The ladder diagram symbol of the jump instruction is shown in Figure 7 (a).When the JMP execution condition is OFF, skip the program between JMP and JME to execute the program after JME. When the JMP execution condition is ON, the program between JMP and JME is executed. N is the jump number, ranging from 0 to 49.

The completed single-sequence program with cyclic structure uses the step state as the execution condition of the jump in the ladder diagram in Figure 7 (c).When the step is an active step, the program between JMP and JME is executed, that is, the transition condition is monitored. When the transition condition is 1, the operation of subsequent step setting and current step reset is carried out. The state of the remaining steps is 0, and the corresponding program is not executed. Step - driven commands are processed in the last set of the program.

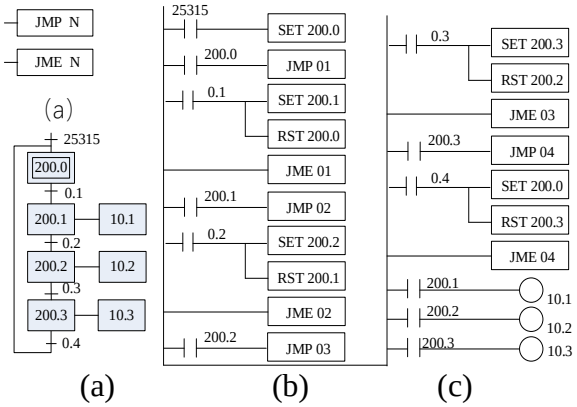

Figure 7 Jump Instruction Implements a Single Sequence with a Loop Structure

Features of programming with jump instructions:

1) The programming structure is clear. Each pair of activity step and transformation condition corresponds to a jump program group. The program is very regular and easy to master

2) When a jump occurs, the program between JMPN and JMEN does not execute and does not occupy the scanning time. All relays, timers and counters remain unchanged before the jump [11].Can shorten the execution time of the program, improve the I/O response speed.

3) Each pair of jump instructions corresponds to the specified jump number, which reduces the design difficulty of complex control system and avoids program conflicts, so the program is highly expandable. Different series of PLC jump numbers are different, so the number of use of jump statements will be limited.

4) Jump instruction can be used for more complex program design, used to optimize the program structure, enhance the function of the program. Jump instruction can make the flexibility of PLC programming greatly improved, according to the judgment of different conditions, choose different program segments to execute the program.

6. Comparison of Four Kinds of Programming Methods

Table 1 Comparison of the four programming methods			
	Can shorten the scanning period	Can reuse internal components	Whether to facilitate the implementation of structured

			programming
Set/reset instruction class	×	×	√
Step instruction class	-	√	√
Data register operation class	×	×	×
Jump instruction class	√	√	√

1) The length of scanning cycle

In the set/reset instruction class, data register operation class and step instruction class, Siemens S7 series programming methods, these programming methods, whether activated or not activated program segments, are scanned and executed in sequence, only the activated program segment is executed according to the statement, the non-activated program segment is executed according to the logic and string logic “0”.

The jump instruction class programming method and the Mitsubishi FX series and Omron CPM1A series step instruction in the step instruction class programming method have a system flag bit for storing the currently active step, that is, the program only scans the program in the currently active step, and the inactive step does not occupy the scanning time. Can effectively shorten the program execution cycle.

2) Component utilization

In step instruction and jump instruction methods, the STL instruction and jump instruction allow different steps to drive the same coil multiple times, since the processor only executes the instructions in the current activation step. Therefore, these two programming methods use more components than other methods, which can significantly shorten the execution time and response speed of the program. The other programming methods avoid multiple coil outputs.

3) Implementation of structured programming

In the part of GBT159699.3-2017 programming language sequence function diagram, in addition to the basic item step, transformation and the structure composed of directed line segments, there are other advanced functions such as forcing, encapsulation and macro step [12].Structured programming to realize these functions is also one of the important criteria to evaluate the sequential control design method.

Data register arithmetic programming method uses special data register instructions, and it is very inconvenient to design complex control system, and it is not convenient to realize structured programming. Set/reset instruction class and step instruction class, simple programming, clear thinking, but will make the ladder diagram program is longer, increase the execution time, indirectly cause the program is not easy to read, modify the trouble, can complete appropriate structured programming. The jump instruction class programming method can be used for the design of more complex programs. It is not only simple to program, short scan cycle, but also can optimize the program structure and realize advanced sequence control function, which is very convenient for structured programming.

7. Conclusion

The design idea of sequence control design method can effectively deal with the complex sequence control situation. Compared with the empirical design method, it is more concise, effective and reliable, and is very popular among automatic control

designers. Programmers can consider the use of these four kinds of programming methods according to their actual situation.

The jump instruction class programming method proposed in this paper effectively avoids the disadvantages of component resource waste, too long scanning cycle and contradictory conversion conditions, retains the advantages of sequential control design method, is easy to express the process progress and easy to communicate ideas with each other, and is worth learning.

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