4. Sequential Function Chart (SFC) and Step Ladder Chart

4-1 Introduction The Sequential Function Chart (SFC)

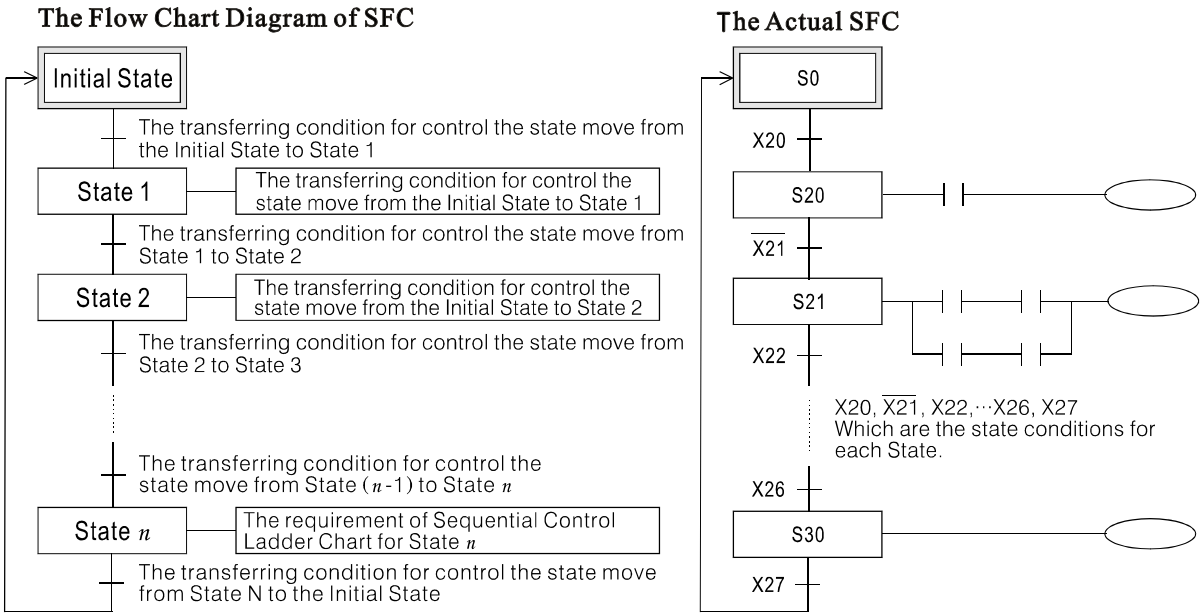
4-1-1 Basic Structure of a SFC

In the universe of Automatic Control, the Electro-Control system should work closely with machine movements to get the result of the Automatic Control, i.e. the synergistic integration technology of Mechatronics, which has become popular in recent years. However, it's quite a difficult job to learn such a complicated sequential control design for machinery engineers, therefor the SFC (Sequential Function Chart) is developed accordingly.

The SFC is designed for create a easily way to understand about the moves of a machine, also it has the following features:

(1) It is not necessary to design the special sequence for constantly state changing of stepladders, the PLC will execute internal links and double coils under different state. Simple sequence design for every state will prompt normal machine works.

(2) Even a person is not the machine designer, who can easily lean all actions and conduct trials, adjustment, error detection and maintenance.



The left diagram is a Flow Chart of SFC and the right diagram is the actual SFC corresponding to the left one. The PLC will execute to start from the Initial State, then complete State 1 → State 2 →... → State n in sequence based on State conditions and achieve a cycle of control.

4-1-2 Basic components of SFC

1. States

(1) Initial State

The first state to execute after PLC runs. Ordinarily the Initial State is achieved by using the startup initial pulse. The Initial State is represented by a frame with double sidelines.

(2) Effective State

The Effective States refer to the execution state of PLC. Under an effective state, PLC will execute the following actions in sequence:

① Driving the coil of the output point, timer or counter relative to the state.

② Resetting the last pasted action, i.e. turning the actions which are relative to the last state into "OFF".

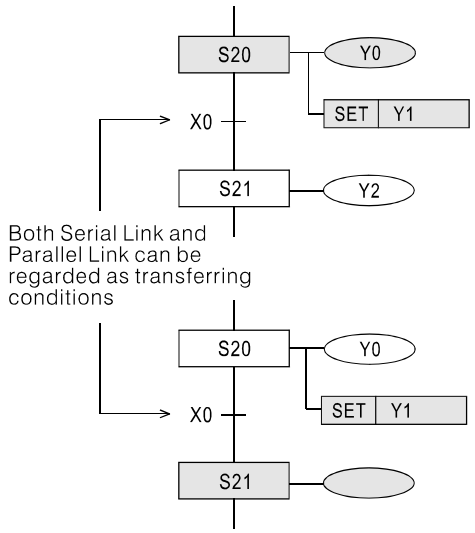
③ Transferring the machine action to the next state when the transferring condition is authorized. In generally there is a connecting line to connect the states, and it indicates the direction of the signal.

2. Transferring Condition

There is a line segment connecting the states, and on the line put a perpendicular short line which is used to express the related conditions driving the states transferred.

4-1-3 State and Action of SFC

Under an effective state, if the action of SFC uses a output coil, the difference between using the instructions OUT and SET to drive the output coil will be:



When S20= "ON", Y0 and Y1 are also "ON"

When X0 (the transferring condition)= "OFF" → "ON", the effective state will be transferred from S20 to S21 (When S21= "ON", then S20= "OFF").

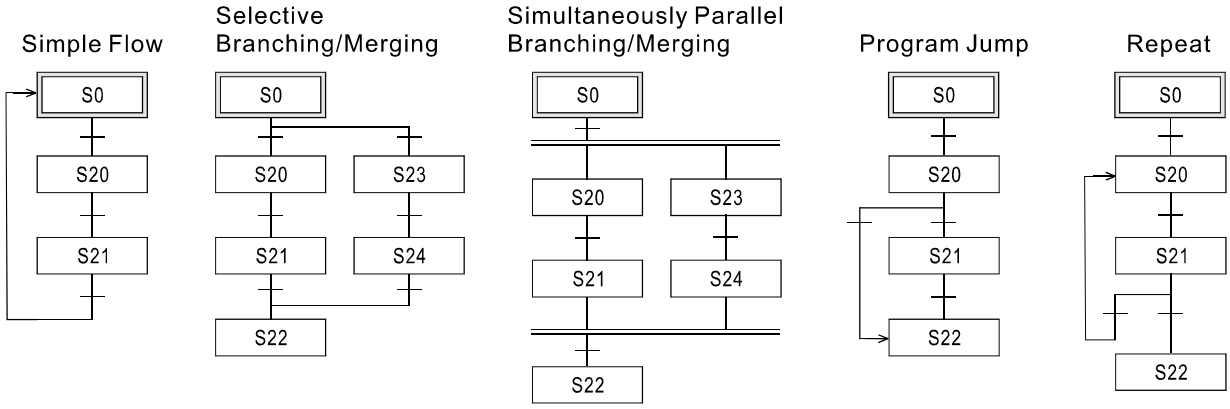
When S21= "ON", Y2 will be "ON" and Y0 becomes "OFF". But, because Y1 is driven by the SET instruction, so Y1 still keeps "ON".

Attention!

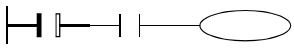
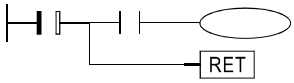
When the effective state transferring from S20 to S21, there will be one scan time both status of S20 and S21 are "ON".

4-1-4 Types of SFC

According to flow control methods, SFC has 5 basic types:



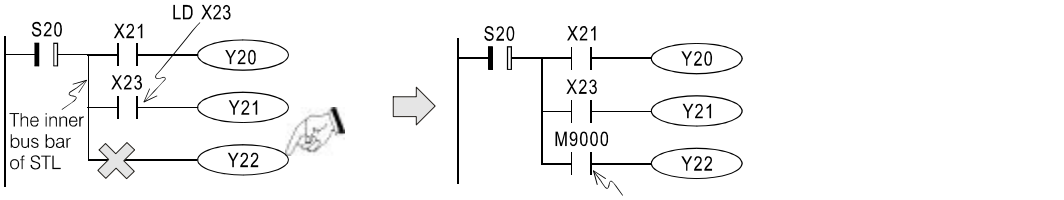
4-2 Step Ladder Instruction

Mnemonic	Format	Devices	Function
STL		S	STep Ladder starts
RET		—	RETurning to standard ladder, Step Ladder ends.

A step point is composed of an STL instruction and a device S. An STL instruction occurring in the program refers that the program has already entered into the STL state controlled by Step Flows. The RET instruction indicates the end of the Step Ladder Chart. Subsequently the initial logical operation is reset to an ordinary SLC state. An SFC completed should be converted into a Step Ladder Chart, and the following importances should be noted during the conversion:

(1) Output Driving Method

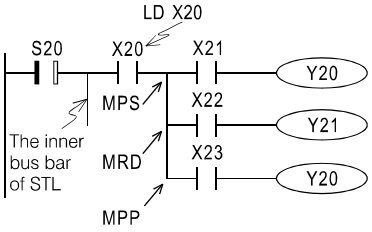
As in the left diagram referred below. If inside the Step point has an LD or LDI instruction, a output coil can not directly connected with inner bus bar of the STL.



Must insert an always “ON”, “a” contact

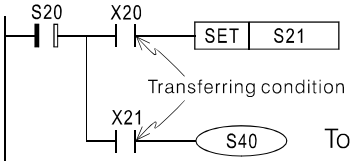
(2) Location of Instruction MPS, MRD and MPP

The MPS, MRD and MPP instructions can not be directly used for Step point’s inner bus bar, unless an LD or LDI instruction has been used previously.



(3) Transferring Method of Step Point

As in the diagram referred below, these two instructions, SET S21 and OUT S40 are the instructions driving another Step point, and when the command is transferred to another Step point, the previous Step point itself will be reset to “OFF” automatically. The difference is that the SET instruction is used to drive an immediately following STL step point, but the OUT instruction is used for loops and jumps to drive a Step point which is not immediately following.



To drive an immediately following STL step, which typically will have a larger STL state number than the current step.

To drive a Step point which is not immediately following.

(4) Function of Instruction RET

Since the RET instruction represents the end of a step, the RET instruction will appear eventually after a series of Step points. A program may be written many Steps, each Step should put an instruction RET in the end. The instruction RET can be used as many times as required.

(5) Applicable Basic Instructions for Step Ladder Chart

Basic instructions can be used between two of STL instructions or used between STL instruction and RET instruction.

Operational State		LD, LDI, AND, ANI, OR, ORI, SET, RST, PLS, PLF, OUT, NOP, LDP, LDF, ANDP, ANDF, ORP, ORF, INV	ANB, ORB MPS, MRD, MPP	MC, MCR
Initial State General State		✓	✓	×
Branching State Merging State	Output Processing	✓	✓	×
	Transfer Process	✓	×	×

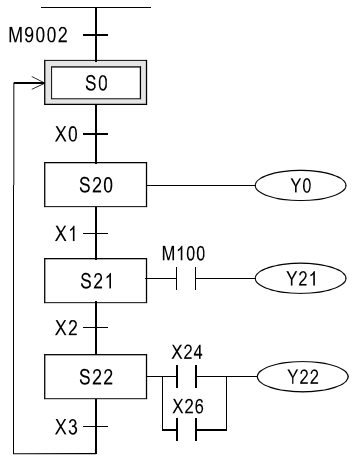
- STL instructions are prohibited in subprograms.
- Instruction CJ is not prohibited in Step Ladder Chart but it makes the program more complicated, so it's recommended that do not use the CJ instruction in Step Ladder Chart.

4-3 Relation between SFC and Step Ladder Chart

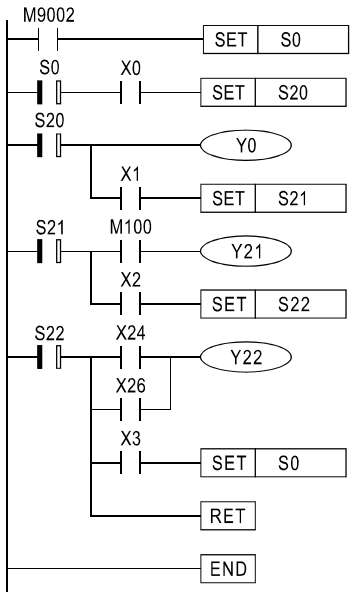
4-3-1 Simple-flow SFC and Step Ladder Chart

Simple Flow: A flow without branching and merging

(a) SFC



(b) Step Ladder Chart Format



(c) Instruction Format

```
LD      M9002
SET     S0
STL     S0
LD      X0
SET     S20
STL     S20
OUT     Y0
LD      X1
SET     S21
STL     S21
LD      M100
OUT     Y21
LD      X2
SET     S22
STL     S22
LD      X24
OR      X26
OUT     Y22
LD      X3
SET     S0
RET
END
```

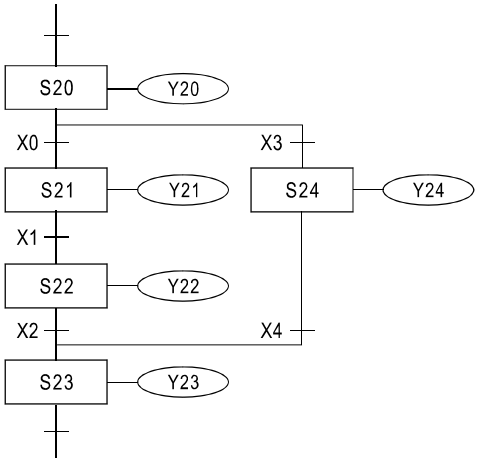
In Diagram (a) of SFC, each state provides three functions: driving processing for loading, assigning transferred devices and transferring conditions. Such SFC, in the format of Step Ladder Chart, is displayed as in Diagram (b), in which we adopt —┫┣— as the symbol for use of STL instructions, and these instructions are provided with transferring and auto reset functions.

4-3-2 Selective Branching / Merging SFC and Step Ladder Chart

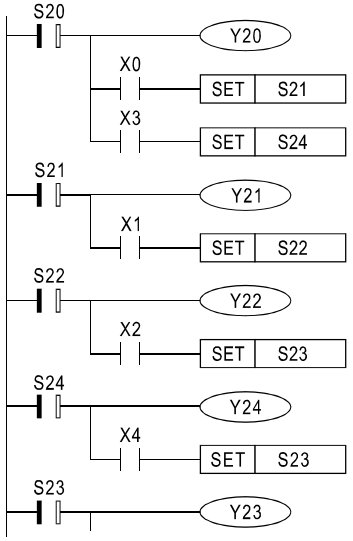
Selective Branching: To select one of the branching flow for state transferring.

Selective Merging: To join branching flows into a simple flow.

(a) SFC



(b) Step Ladder Chart Format



(c) Instruction Format

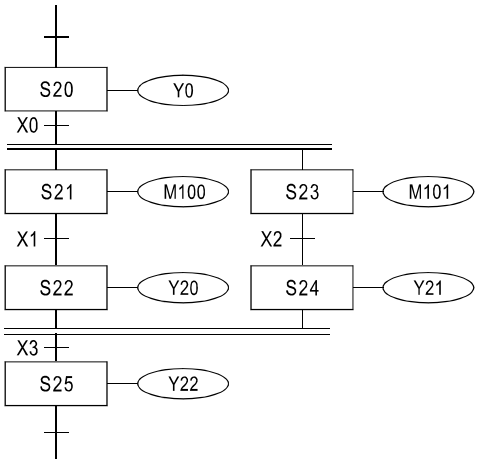
```
STL     S20
OUT     Y20
LD      X0
SET     S21
LD      X3
SET     S24
STL     S21
OUT     Y21
LD      X1
SET     S22
STL     S22
OUT     Y22
LD      X2
SET     S23
STL     S24
OUT     Y24
LD      X4
SET     S23
STL     S23
OUT     Y23
```

4-3-3 Simultaneously Parallel Branching / Merging SFC and Step Ladder Chart

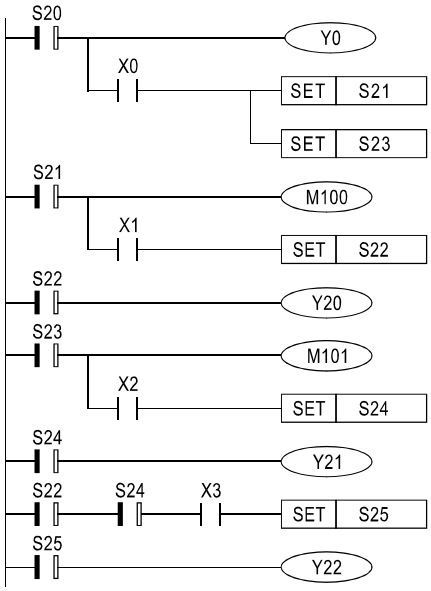
Simultaneously Parallel Branching: The first State of each branching flow becomes effective when the transferring condition is authorized.

Simultaneously Parallel Merging: To transfer the effective state to the next state when the last state of each branching state becomes effective and the transferring condition is authorized.

(a) SFC



(b) Step Ladder Chart Format



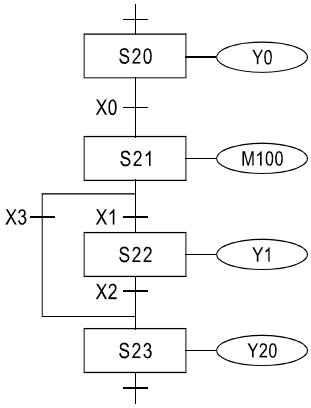
(c) Instruction Format

```
STL     S20
OUT     Y0
LD      X0
SET     S21
SET     S23
STL     S21
OUT     M100
LD      X1
SET     S22
STL     S22
OUT     Y20
STL     S23
OUT     M101
LD      X2
SET     S24
STL     S24
OUT     Y21
STL     S22
STL     S24
LD      X3
SET     S25
STL     S25
OUT     Y22
```

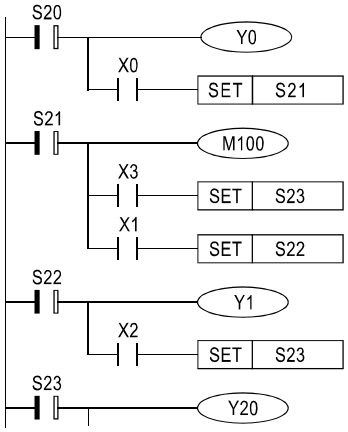
4-3-4 Jump SFC and Step Ladder Chart

Jump: To transfer the effective state to any state forward or any state in other flow.

(a) SFC



(b) Step Ladder Chart Format



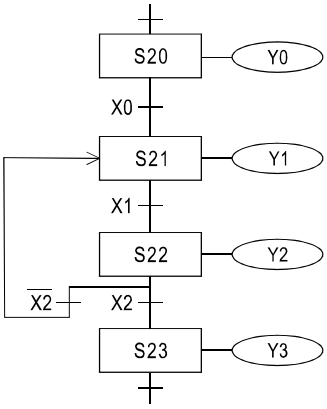
(c) Instruction Format

```
STL     S20
OUT     Y0
LD      X0
SET     S21
STL     S21
OUT     M100
LD      X3
SET     S23
LD      X1
SET     S22
STL     S22
OUT     Y1
LD      X2
SET     S23
STL     S23
OUT     Y20
```

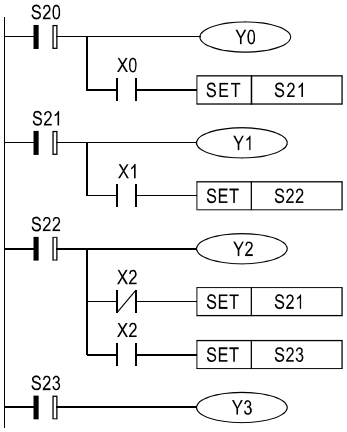
4-3-5 Repeat SFC and Step Ladder Chart

Repeat: When a flow is ended or the transferring condition is authorized, transferring the effective state to the initial state or any state in the front.

(a) SFC



(b) Step Ladder Chart Format



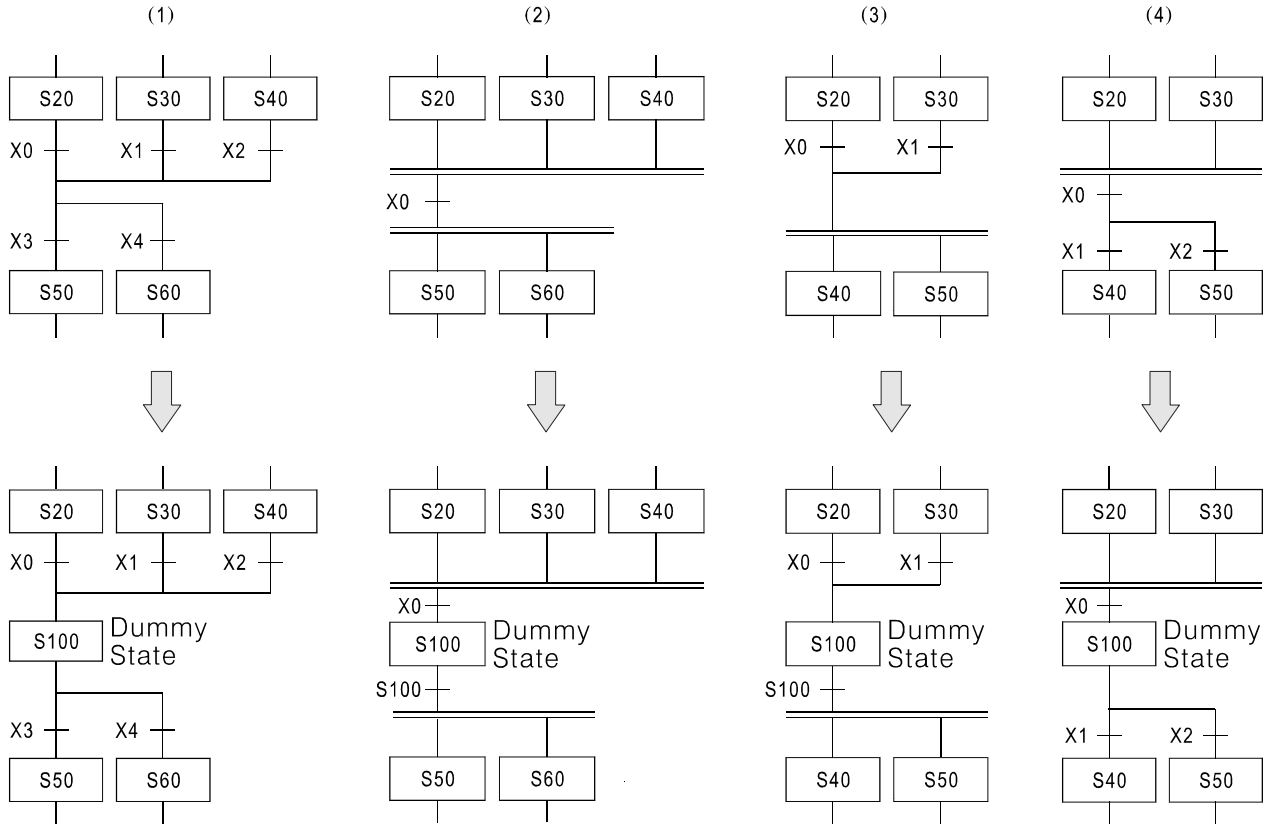
(c) Instruction Format

```
STL     S20
OUT     Y0
LD      X0
SET     S21
STL     S21
OUT     Y1
LD      X1
SET     S22
STL     S22
OUT     Y2
LDI     X2
SET     S21
LD      X2
SET     S23
STL     S23
OUT     Y3
```

4-4 Complex Branching, Merging Flows

4-4-1 Dummy State

It's recommended to set a null step point between merging and branching, when the branching processes right after merging. The null step point is called "Dummy State", because the Step point is only used for connection. Proper use of Dummy State will make SFC programming easier. The application of Dummy State is shown as below:




```
STL   S20
LD    X0
SET   S100
STL   S30
LD    X1
SET   S100
STL   S40
LD    X2
SET   S100
STL   S100
LD    X3
SET   S50
LD    X4
SET   S60
```

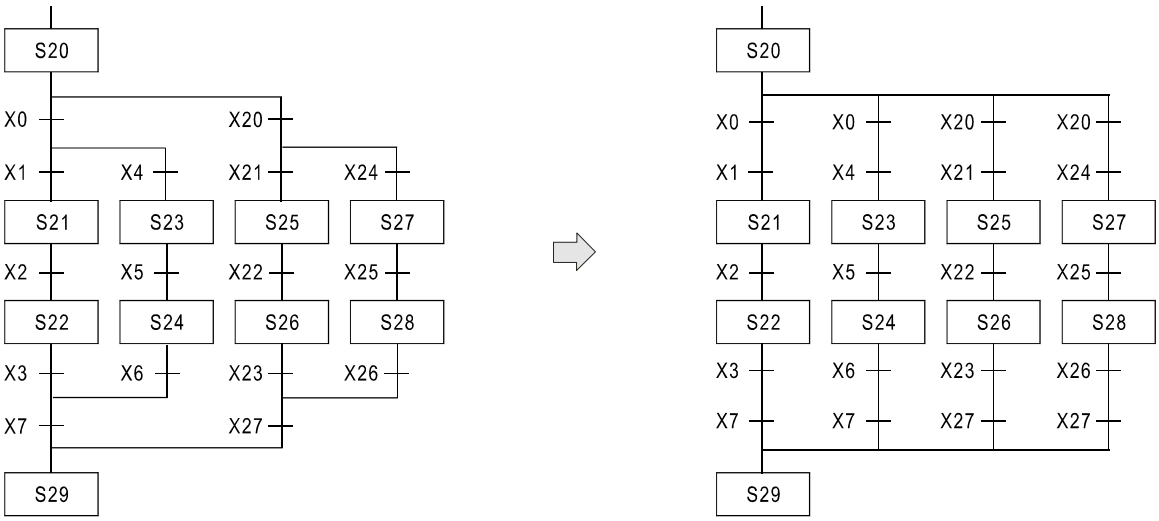
```
STL   S20
STL   S30
STL   S40
LD    X0
SET   S100
STL   S100
LD    S100
SET   S50
SET   S60
```

```
STL   S20
LD    X0
SET   S100
STL   S30
LD    X1
SET   S100
STL   S100
LD    S100
SET   S40
SET   S50
```

```
STL   S20
STL   S30
LD    X0
SET   S100
STL   S100
LD    X1
SET   S40
LD    X2
SET   S50
```

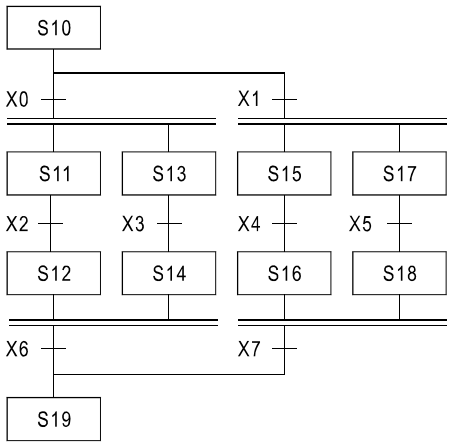
4-4-2 The Special Note for Branching and Merging

(1) If the original SFC is similar to the left side of SFC diagram, please rewrite it as the diagram as in the right.

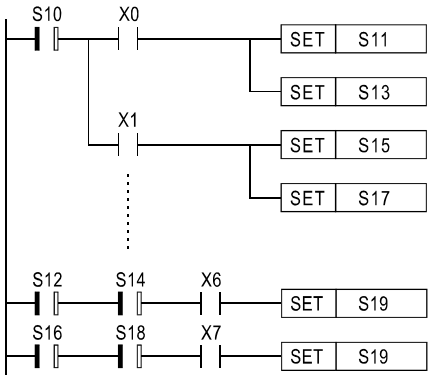


(2) For converting the left SFC to a Step Ladder Chart format, the branching and merging flows are rewritten as follows:

(a) SFC



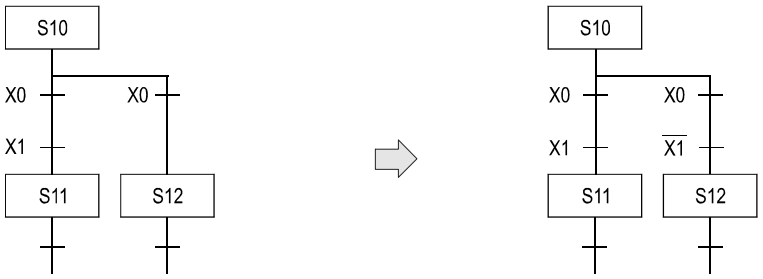
(b) Step Ladder Chart Format



(c) Instruction Format

```
STL   S10
LD    X0
SET   S11
SET   S13
LD    X1
SET   S15
SET   S17
      :
STL   S12
STL   S14
LD    X6
SET   S19
STL   S16
STL   S18
LD    X7
SET   S19
```

(3) To write a SFC program, the condition setting of transfer must be well-defined. For example, the diagram shows in the left side, which is unclear to indicate it as a Selective Branching or a Simultaneously Parallel Branching. Please rewrite the SFC as the right side diagram.



4-5 The Special Notes for Programming with Step Ladder Instructions

(1) If two states are using a specific Timer and the states are not next to each other. The Timer (which is using a same ID. number in two states) can be assigned different setting values in two states.

(2) It is available to use any Serial / Parallel links for the output of each state.

(3) It is also available to use Serial / Parallel link for the transferring condition of each state.

(4) If using an OUT instruction to drive an output in a state, the output status would be turned "OFF" after the effective state has been transferred.
If using a SET instruction to drive an output in a state, the output status would be still "ON" after the effective state has been transferred.

(5) When transferring the effective state between two states, there will be a scan time in which these two states are "ON".

(6) If there is a Counter put after an STL contact point, the Counter will execute the reset function only when the STL contact point is "ON".

(7) STL instructions are only effective to Step coil S. Step coil S can be used as general Auxiliary coil. But, after STL contact points, SET and RST are only two effective instructions for Step coil S.

(8) After STL contact points, MC and MCR instructions are not allowed to use.

(9) When designing a Step Ladder Chart, the sequence and ID. numbers of Step coils are unrelated.

(10) There is no limit on the number of Selective Branching, but at most 8 transferring states can be merged for Simultaneously Parallel Branching on a merging point, while the remaining states should be merged by another merging points in the program.

(11) A Step coil cannot use STL instructions repeatedly.

(12) The MPS instruction cannot be used directly after STL contact points.

(13) STL instructions are not allowed to use in subprograms.

(14) Although for STL instructions, the Jump instruction is not restricted to use. Because it would make processing procedures of programs more complicated, it is recommended avoid to use.

4-6 Special Coil and Special Register Related to SFC

In the table below, the symbol "■" represents that itis not allowed to use the instruction to drive the coil or write the data to the program.

Special Coil

Coil ID. NO.	Instruction of Function
M9040	STL transfer is prevented. When M9040= "ON", the STL state transfer function is disabled.
■ M9046	STL state is "ON". When M9047= "ON" and any coil of S0~S899="ON" than M9046= "ON".
M9047	STL monitoring is enable. D9040 ~ D9047 will be active only when M9047= "ON".

Special Register

Register ID. NO.	Instruction of Function	
■ D9040	1st (the lowest) active STL step	When M9047="ON", the step point ID. numbers which are in action will be stored in D9040 ~ D9047. Where the smallest one will be stored in D9040, the second smallest one will be stored in D9041 and so forth.
■ D9041	2nd active STL step	
■ D9042	3rd active STL step	
■ D9043	4th active STL step	
■ D9044	5th active STL step	
■ D9045	6th active STL step	
■ D9046	7th active STL step	
■ D9047	8th active STL step	