Chapter 8: THE GRAFCET

GRAFCET : **GRA**phe **F**onctionnel de **C**ommande **E**tape **T**ransition

SFC :Sequential Function Chart

At the end of this course, the learner will be able to:

- Describe graphically, according to specifications, the different behaviors of the evolution of a sequential automation.
- Represent the operation of any production system using GRAFCET.
- Understand the operation of an automated machine.
- Know how to implement a GRAFCET using on/off electronic components (gates and flip-flops).

Prerequisites:

- Automated production systems.
- Combinational logic systems.
- Sequential logic systems.

1. Introduction :

The graphical representation allows for an unambiguous description of the sequential operation of an automated system in a way that is understandable to all categories of personnel, from engineers to technical sales engineer salespeople. Indeed, the human eye can grasp a sequentially represented evolution graphically at a glance. Among the possible methods, we find **flowcharts** and **GRAFCET**, which is the subject of this chapter. It has been standardized internationally since 1988 under the name "Sequential Function Chart (**SFC**)" (**IEC 848 standard**).

2. History

In 1975, a group of academics and industry professionals from the "Logical Systems" section of AFCET (**A**ssociation **F**rançaise de **C**ybernétique **E**conomique et **T**echnique) set themselves the objective of defining a formalism adapted to the representation of the sequential evolutions of a system and having the following characteristics:

- Simple

- Universally accepted
- Understandable by both designers and operators
- Potentially providing ease of transition to a hardware and/or software-based implementation of the specified automation.

Initially, the work consisted of drawing up a state of the art of the different approaches to modeling the behavior of such automations. Three major classes of modeling tools were identified:

- **Flowcharts**
- **Petri Nets**
- **Statecharts**

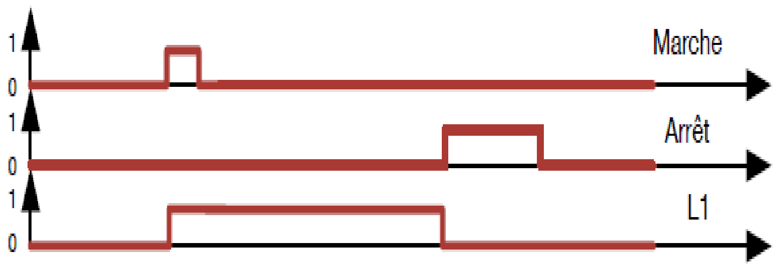
The analysis of the advantages and disadvantages of these tools led, in 1977, to the definition of **GRAFCET**, so named to both signify the origin of this new modeling tool "**AFCET**" and its identity "**G**RAphe **F**onctionnel de **C**ommande **E**tapes–**T**ransitions" (Functional Graph of Control Steps-Transitions). The results of this work were the subject of an official publication in the journal "Automatique et Informatique Industrielle" in December 1977, a date that the community today considers to correspond to the effective date of birth of GRAFCET, and it was standardized in June 1982.

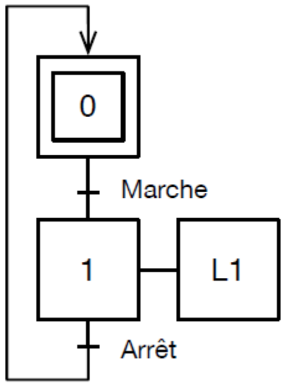
3. Definitions:

- GRAFCET is a mode of representation and analysis of an automation system, particularly well-suited for systems with sequential evolution. It is a graphical translation of the specification document. This representation is standardized:
  French Standard NF C 03-190. It consists of a set of:
  1. Steps associated with actions.
  2. Transitions between steps associated with transition conditions (receptivities).
  3. Oriented connections between steps and transitions.
- GRAFCET is a graphical tool for describing the behaviors of a logical system. It is commonly used for the implementation of Programmable Logic Controllers (PLCs) in industrial automation.
- GRAFCET is a graphical tool for describing the expected behavior of the Control Part. It describes the relationships across the isolation boundary between the Control Part and the Operative Part of an automated system.
- The establishment of a GRAFCET requires the prior definition:

1. of the system.
2. The PO-PC boundary, specifying the Control Part.
3. Inputs and Outputs of the Control Part.

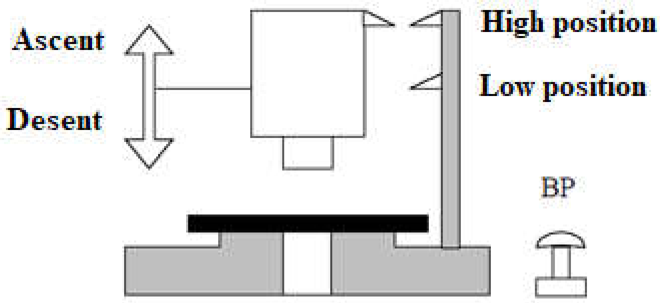
Example 1: The GRAFCET below turns on the lamp L1 when the Start button is activated and turns off lamp L1 when the Stop button is activated.





Example 2: The Semi-Automatic Punching Machine

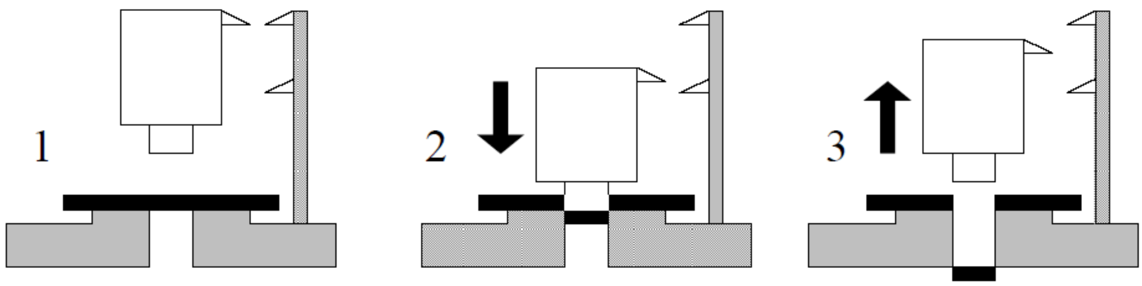
- Let's consider the punching machine in its initial resting position (high position).



The operator giving the "on" information by pressing the "BP" push button automatically causes the punch to descend to the low position followed by its rise to the high position,

→ **The punching machine has completed a CYCLE.**

- This machine has 3 different behaviors:

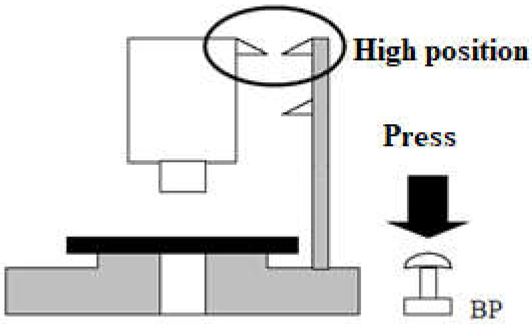


- The punching machine is at rest or in the high position (1).
- The punch descends (2).
- The punch ascends (3).

→ each behavior is called STEP.

- In addition, it is necessary to specify what causes a change in the behavior of the machine, that is to say the logical conditions which determine the passage from one step to another:

→ The transition from one step to another is called a TRANSITION.

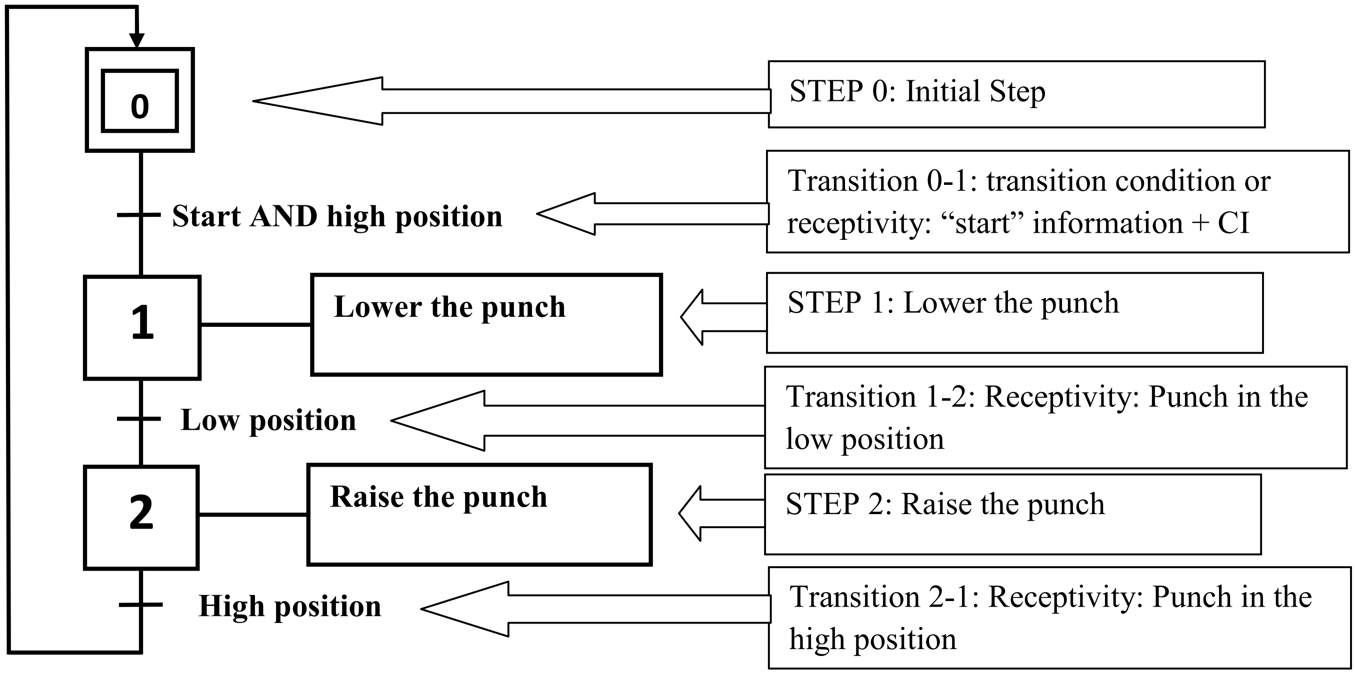


The transition from the rest state to the descent of the punch occurs if:
The operator provides the "start" information by pressing the BP AND the punch is in the high position.

these two pieces of information constitute the transition condition from step 1 to step 2:

→ This condition is called the RECEPTIVITY associated with transition T_{1-2}.

- It is therefore possible to represent the automatic behavior of this punching machine using a GRAFCET. This is based on the concept of steps associated with actions and transitions associated with receptivities.



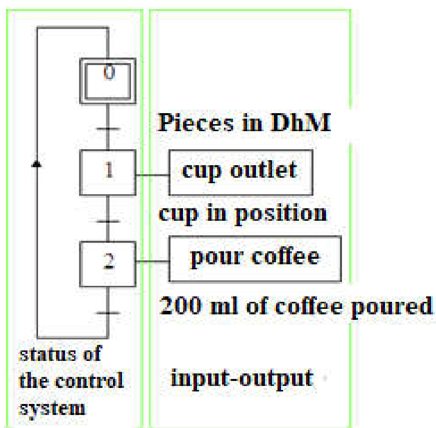
4. TYPES OF GRAFCET:

Depending on the different points of view (user, technical-sales person, designer-implementer, etc.), we can distinguish several types of GRAFCET. To simplify, they are summarized into 2 types:

- GRAFCET Level 1;
- GRAFCET Level 2.

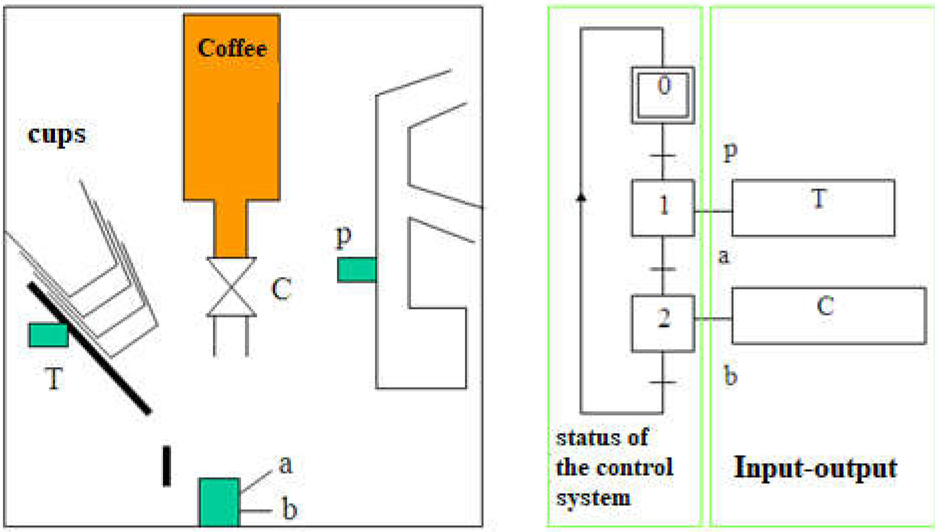
GRAFCET Level 1: Functional Specifications

In this type of GRAFCET, appear the actions to be performed and the information necessary for their execution. This model is purely descriptive (using everyday language). The selection of actuators and sensors has not been made yet (sensor and actuator technology is not defined). It is also referred to as " system perspective GRAFCET " or "**functional GRAFCET**."

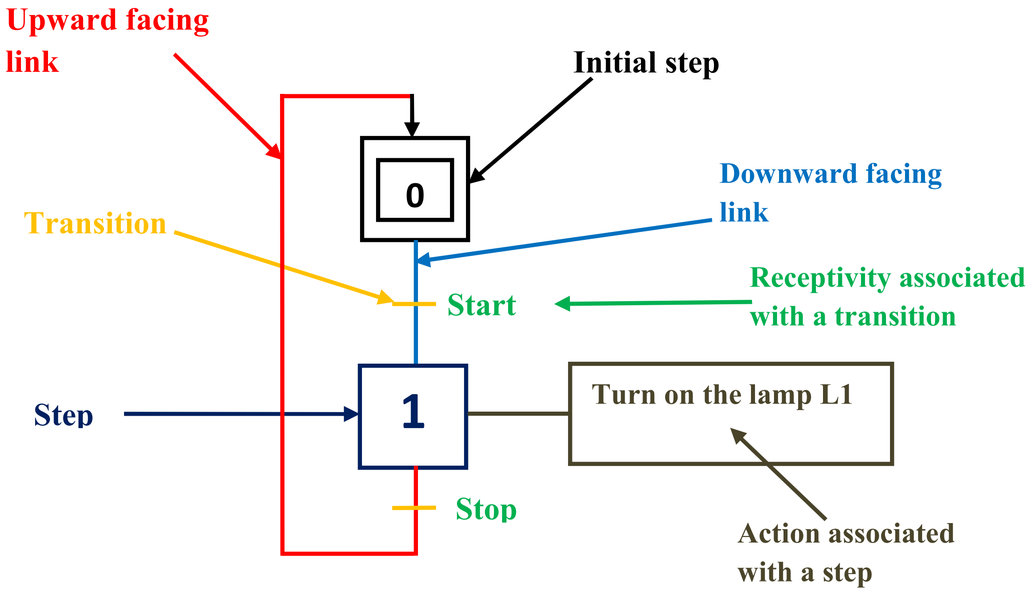


GRAFCET Level 2: Technological Specifications

A detailed study leads to the selection of technological solutions for the operative part (**OP**) and the control part (**CP**) (Using symbols and taking into account sensor and actuator technology). It is also referred to as 'GRAFCET from the OP and CP point of view.



Characteristic elements of GRAFCET:

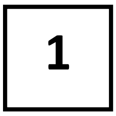
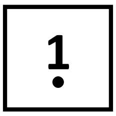
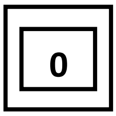
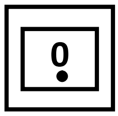


Each directed link connects a step to a transition or a transition to a step. A GRAFCET is read from top to bottom. If this syntax is not strictly followed, there will inevitably be an error in the application. An arrow can complete the connection by indicating the reading direction if there is a risk of confusion.

5. The steps

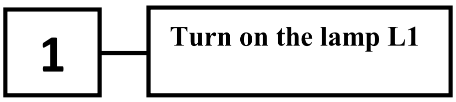
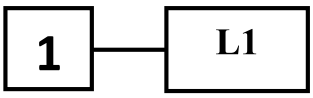
5.1 Graphic Representations of Steps

- The step corresponds to an elementary situation with stable behavior: during a step, the control elements and sensors do not change state.
- The input of a step is always at the top, and the output is at the bottom.
- An active step is identified by a dot at the bottom of the symbol or by a change in color on the screen.
- Initial steps represent the system's state at the beginning of a cycle. They are unconditionally activated at the start of operation.
- There is only one initial step per GRAFCET.

Step	Active step	Initial step	Active initial step
			

5.2 Actions Associated with a Step

These actions are either issuing commands to the operative part (start motor, open a solenoid valve, etc.) or operative functions such as counting, memorizing, assigning a value, equations. The description of actions can be either literal or symbolic.

Literal description	Symbolic description
	
When step 1 is active, lamp L1 lights up.	When step 1 is active, L1=1, the other outputs are at 0 if they are not activated by another step.

6. Transitions

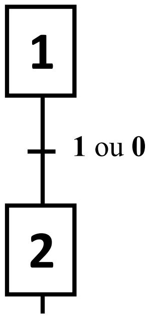
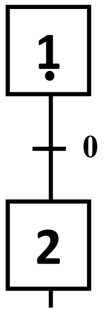
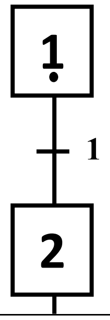
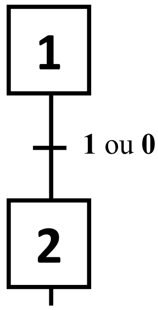
A transition indicates the possibility of evolution between several steps. It is realized when it is crossed, causing a change in the activity of the steps. There should be only one transition between two steps, regardless of the path taken.

6.1 Each transition is associated with receptivity

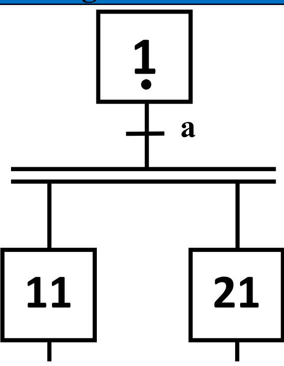
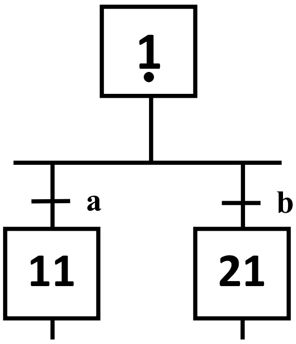
Each transition is associated with a logical condition called receptivity, which can be either true or false.

6.2 Evolution of the Grafcet

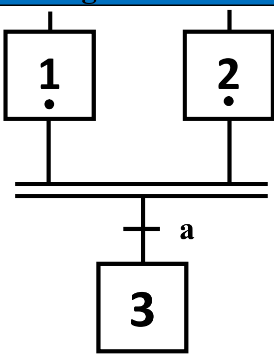
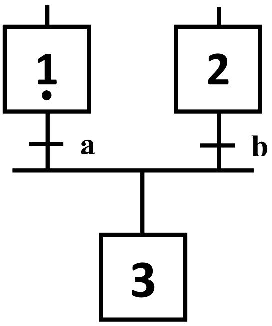
A transition is validated when all the previous steps related to this transition are active. The crossing of a transition occurs when the transition is validated, and the receptivity associated with that transition is true. When these two conditions are met, the transition becomes crossable and must be crossed.

Not validated	Validated	Crossable	Crossed
			

6.3 Divergence

Divergence in AND	Divergence in OR
	
Step **1** is active, as soon as **a=1**, steps **11** and **21** are activated simultaneously, and step **1** is deactivated.	Step 1 is active, if **a=1**, step **11** is activated and step **1** is deactivated. If **b=1**, step **21** activates and step **1** deactivates.

6.4 Convergences

Convergence in AND	Convergence in OR
	
For the transition to be validated, steps **1** and **2** must be active.	For the transition to be validated, step **1** or **2** must be active.

7. The rules of evolution of a GRAFCET:

Rules N°1: Initial situation

Initialization specifies the step or steps that are active at the beginning of operation. It characterizes the initial behavior of the control part towards the operative part. Initial steps are unconditionally activated at the beginning of the cycle.

Rule N°2: Crossing a Transition

A transition is validated when all immediately preceding steps are active. It can then be crossed only when:

- It is validated;
- AND the receptivity associated with the transition is true.

Rule N°3: Evolution of Active Steps

The crossing of a transition leads to the simultaneous activation of all immediately following steps and the deactivation of all immediately preceding steps.

Exercise 01: Milling Machine

Operation:

• Press the milling machine's "Start" button.

• The milling tool descends.

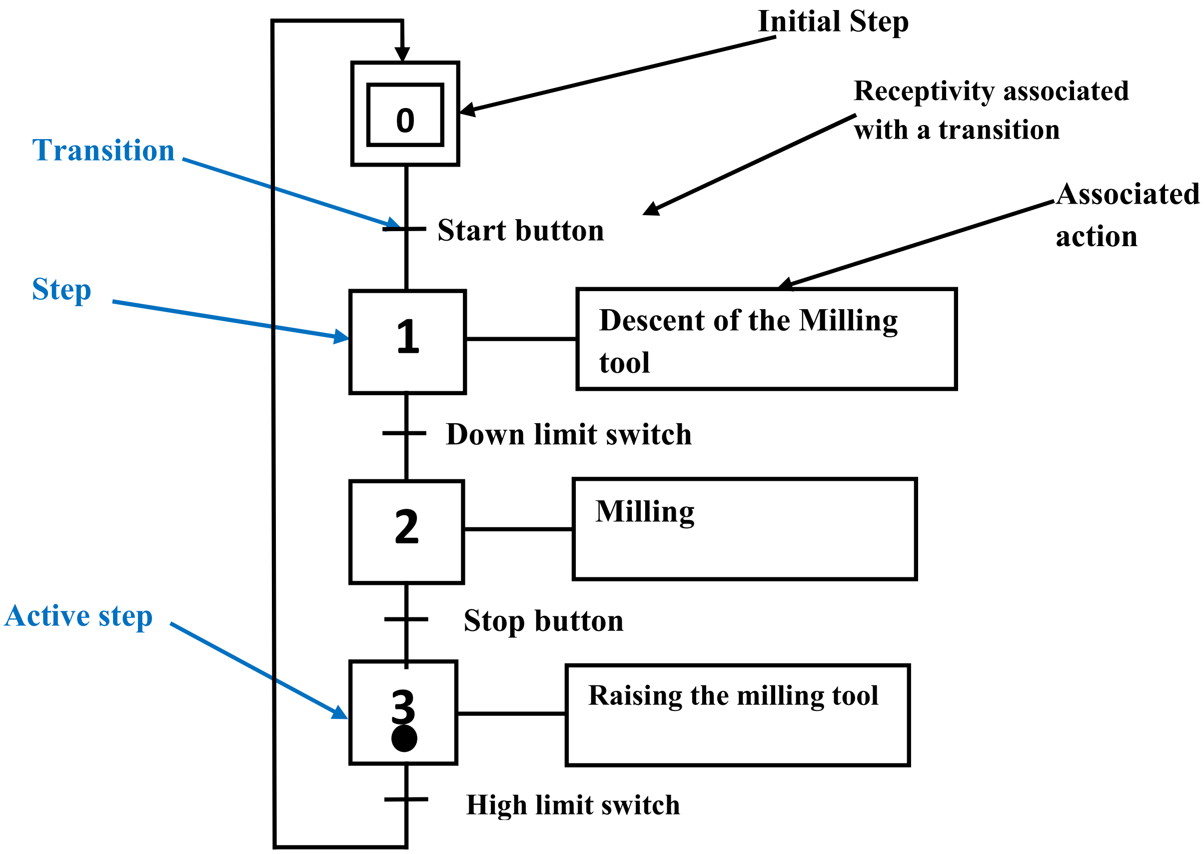
• Once the lower position is reached, milling begins.

• Press the "Stop" button.

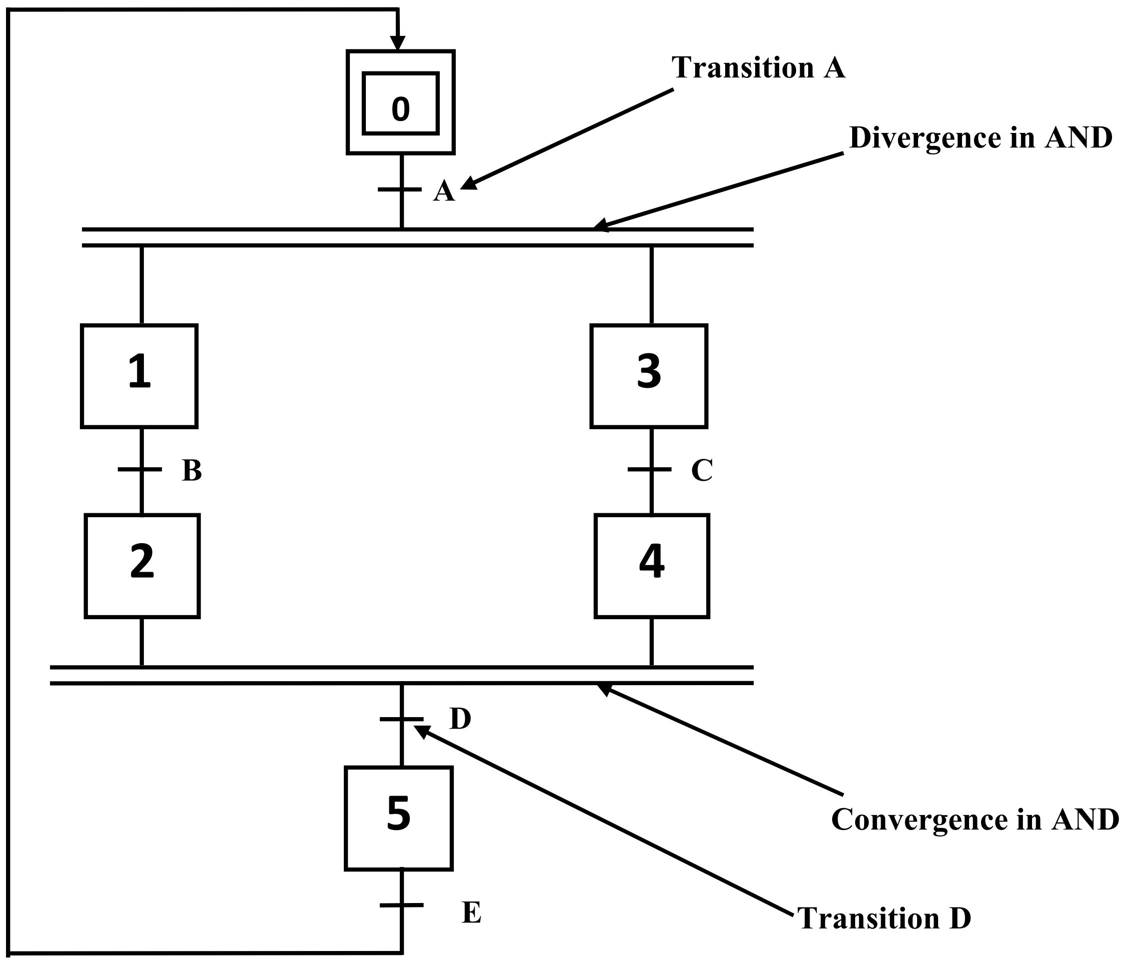
• Milling stops, and the milling tool ascends.

• Once the upper limit switch is reached, the milling machine is in the initial position.

What will be the simple representation to illustrate and understand the operation?



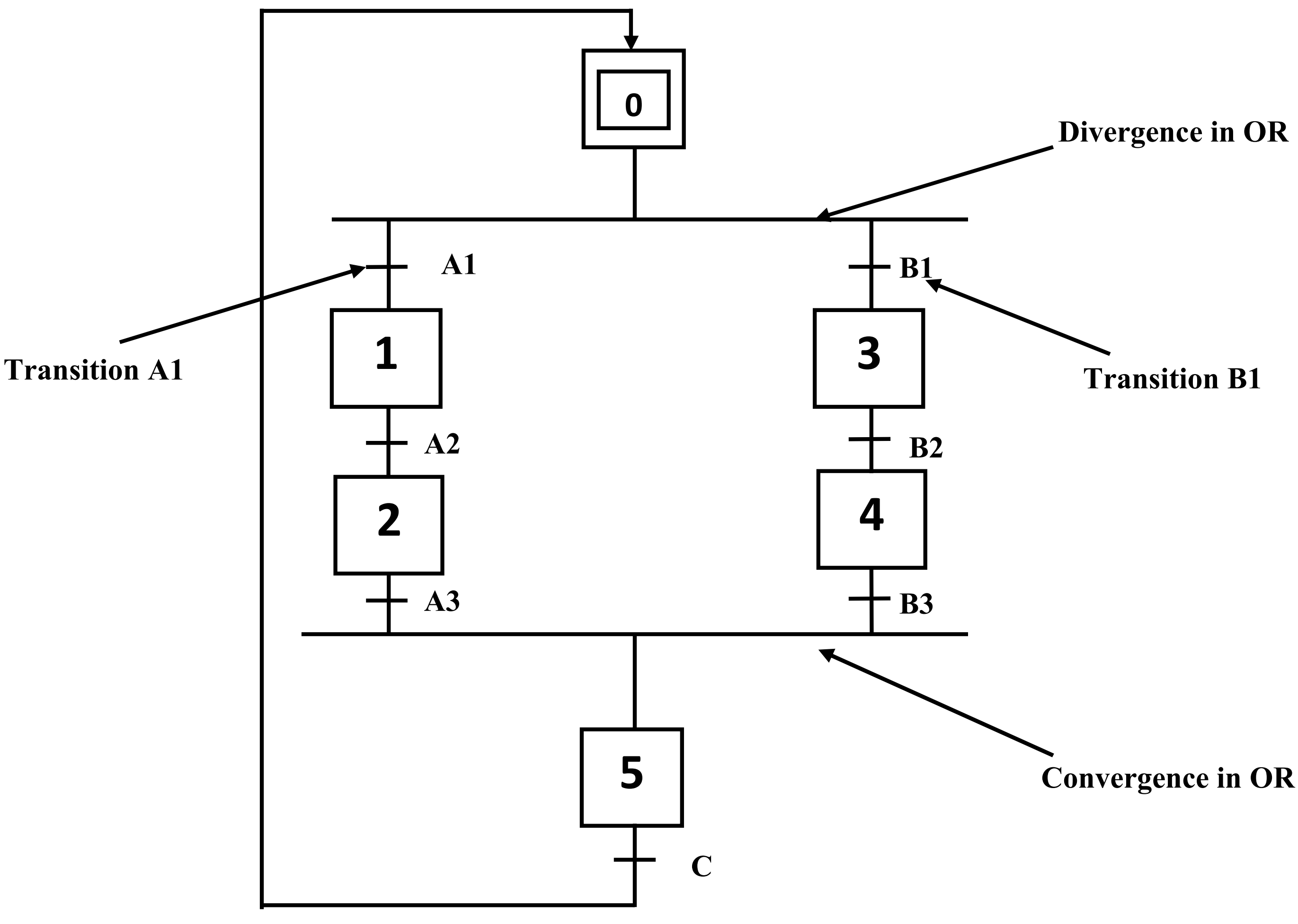
Divergence and convergence in AND



Divergence in AND: represented by 2 identical and parallel lines; when transition A is crossed, steps 1 and 3 become active.

Convergence in AND: Transition D will be active when steps 2 and 4 are active. If the receptivity associated with transition D is true, then it is crossed, and step 5 becomes active, deactivating steps 2 and 4. The number of branches can be greater than 2; after a divergence in AND, there is a convergence in AND.

Divergence and convergence in OR (routing)

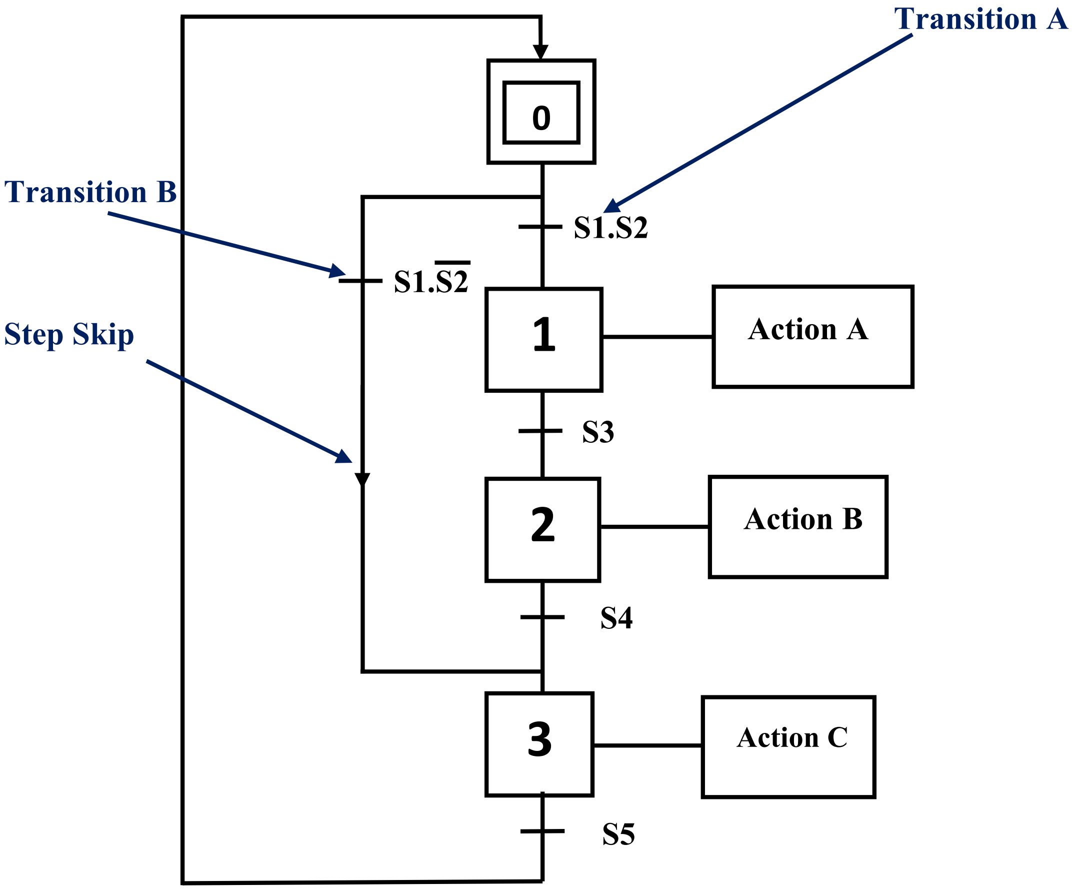


Divergence in OR: the evolution of the system moves towards one of the branches according to the receptivities A1, B1 and their associated transitions.

Convergence in OR: After a divergence in OR we find a convergence in OR towards a common step in the example step 5.

The number of branches can be greater than 2, and A1 and B1 cannot be true simultaneously.

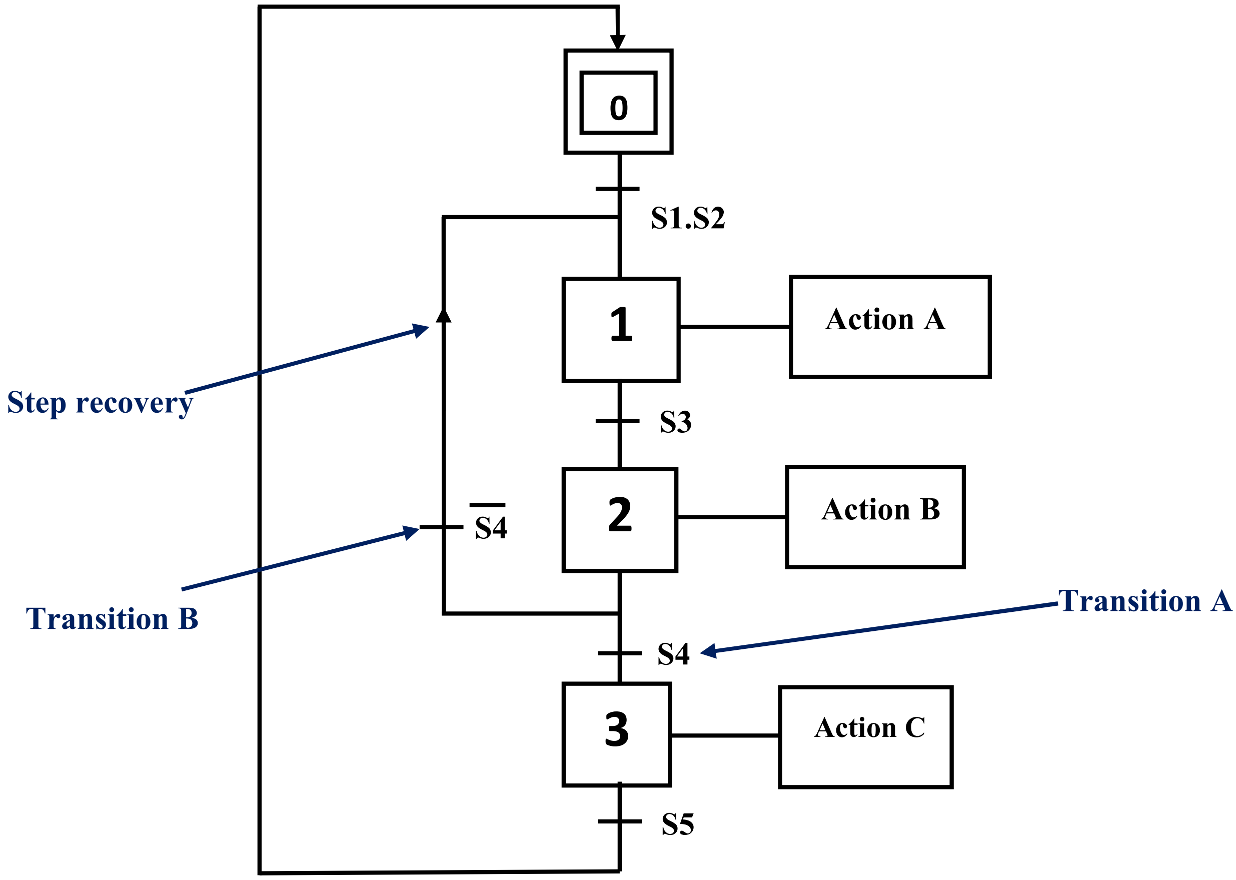
Step Skip:



The step jump allows skipping one or more steps based on the progression of a cycle.

In the Grafcet above, after the initial step 0, a choice between two transitions, A and B, is made. Transition A, with its associated receptivity, allows us to continue the cycle on step 1. Transition B, with its associated receptivity, allows us to move to step 3, steps 1 and 2 are ignored during the cycle.

Step recovery:



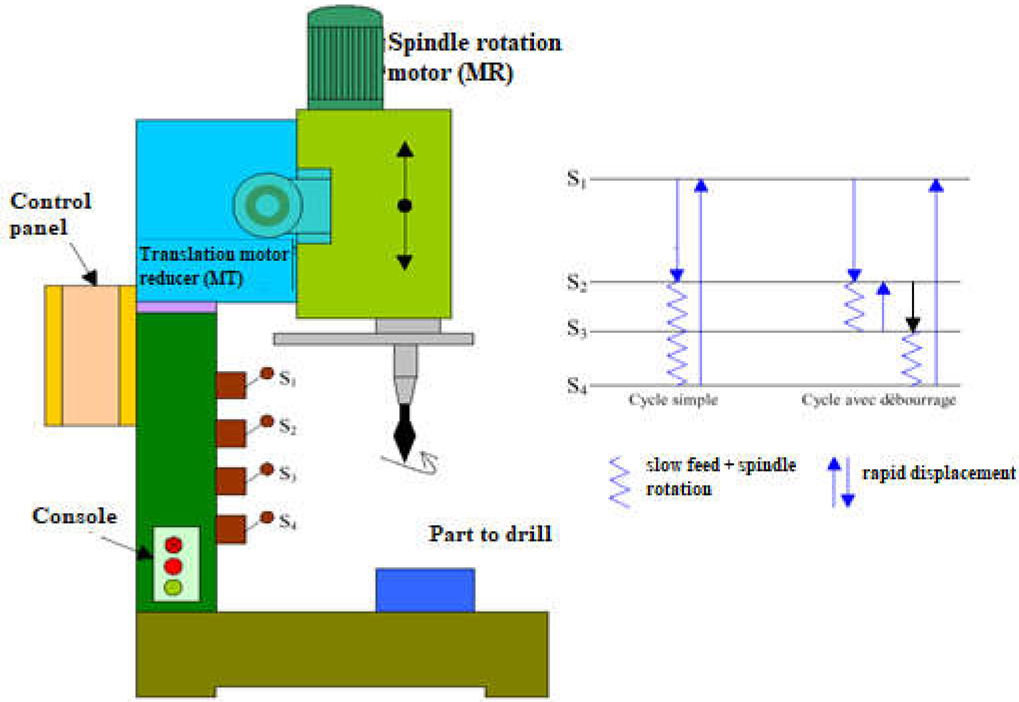
Step recovery allows you not to continue the cycle but to resume a previous sequence when the actions to be performed are repetitive.

In the Grafcet above, after step 2, a choice between two transitions, A and B, is made.

Transition B associated with its receptivity allows us to resume the cycle on step 1, Transition A associated with its receptivity allows us to move on to step 3.

Exercise 02 :

A drilling station allows to make a hole automatically. But as the parts are of different sizes, there is a choice between two drilling cycles: simple or with deburring.



Operation

In the initial position, the drill is in the «high position» (S1), and the spindle motor is stopped.

The start of the operating cycle is initiated by pressing the "cycle start" button (dcy).

Depending on the selected cycle (simple or with deburring) using the rotary button "cycle" (cy), the drill performs the chosen cycle as indicated above. At the end of the cycle, the drill must be in the high position, and the spindle motor stopped.

MR: Spindle Rotation On

MTLB: Slow Downward Translation Movement On

MTRB: Fast Downward Translation Movement On

MTRH: Upward Translation Movement On

Here is the cycle without deburring previously described, including the following movements:

- Fast descent to S2
- Slow descent to S4
- Fast ascent to S1

%I0.0 : dcy
%I0.1 : cy
%I0.2 : S1
%I0.3 : S2
%I0.4 : S3
%I0.5 : S4

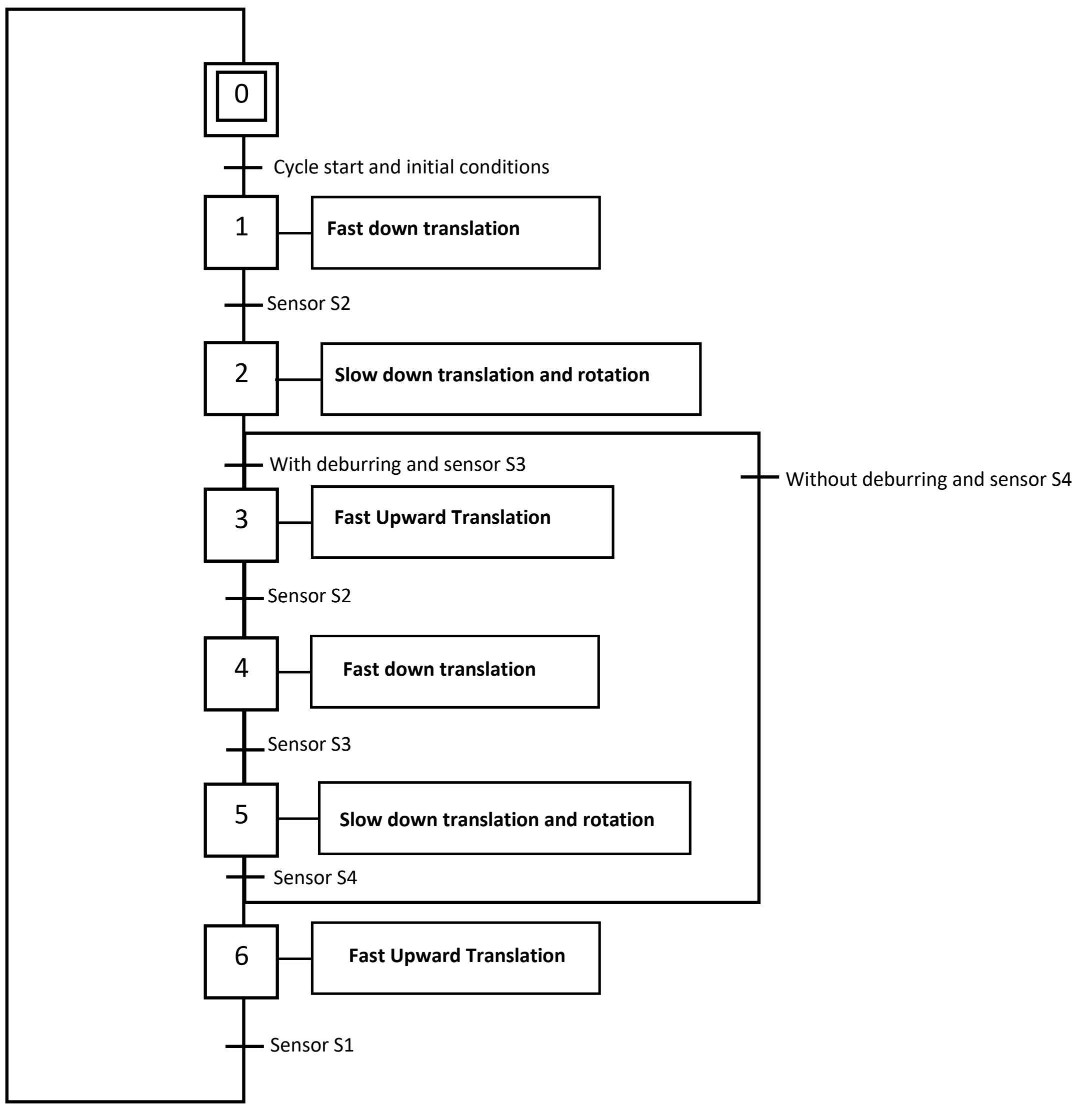
%Q0.0 : MR
%Q0.1 : MTLB
%Q0.2 : MTRB
%Q0.3 : MTRH

Here is the cycle with deburring, which raises the spindle to an intermediate position to clear the drill before completing the already started drilling. This cycle is as follows:

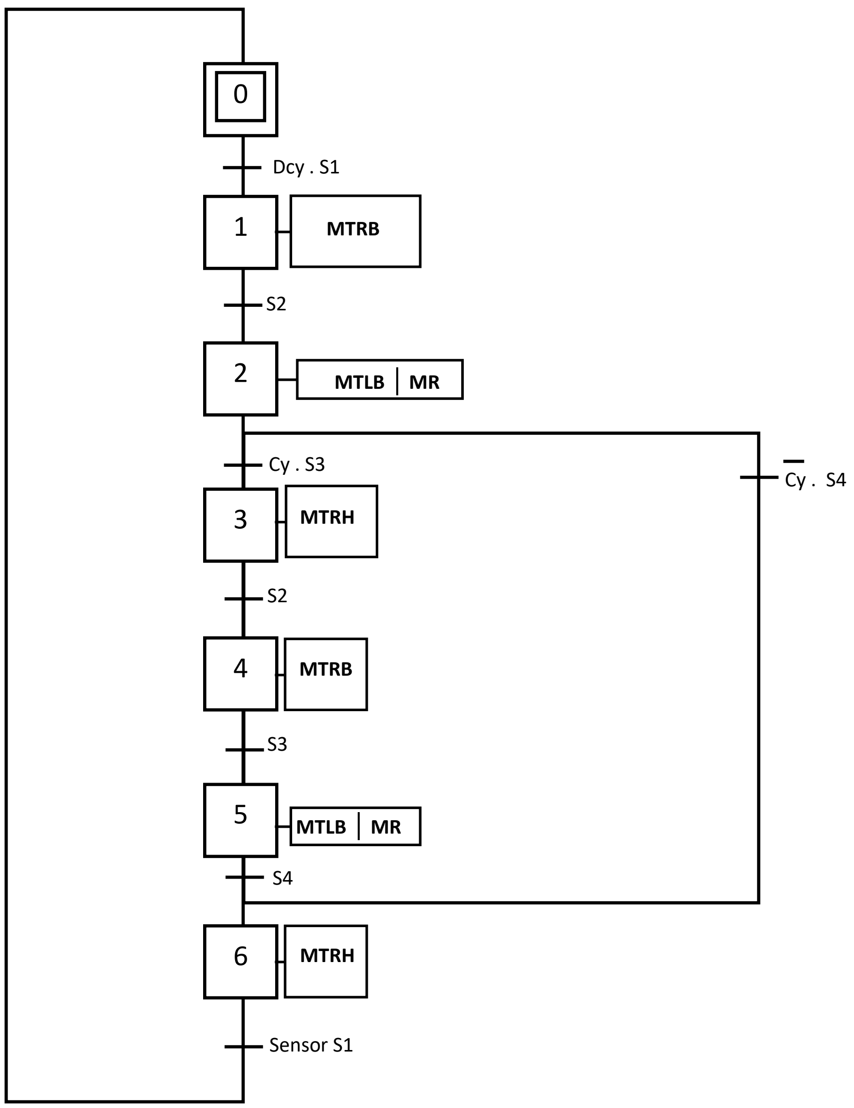
- Fast descent to S2
- Slow descent to S3 and rotation
- Fast ascent to S2
- Fast descent to S3
- Slow descent to S4 and rotation
- Fast ascent to S1

1. **Establish the operational grafcet.**
2. **Establish the grafcet from a control point of view.**
3. **Establish Automated Point of View grafcet.**

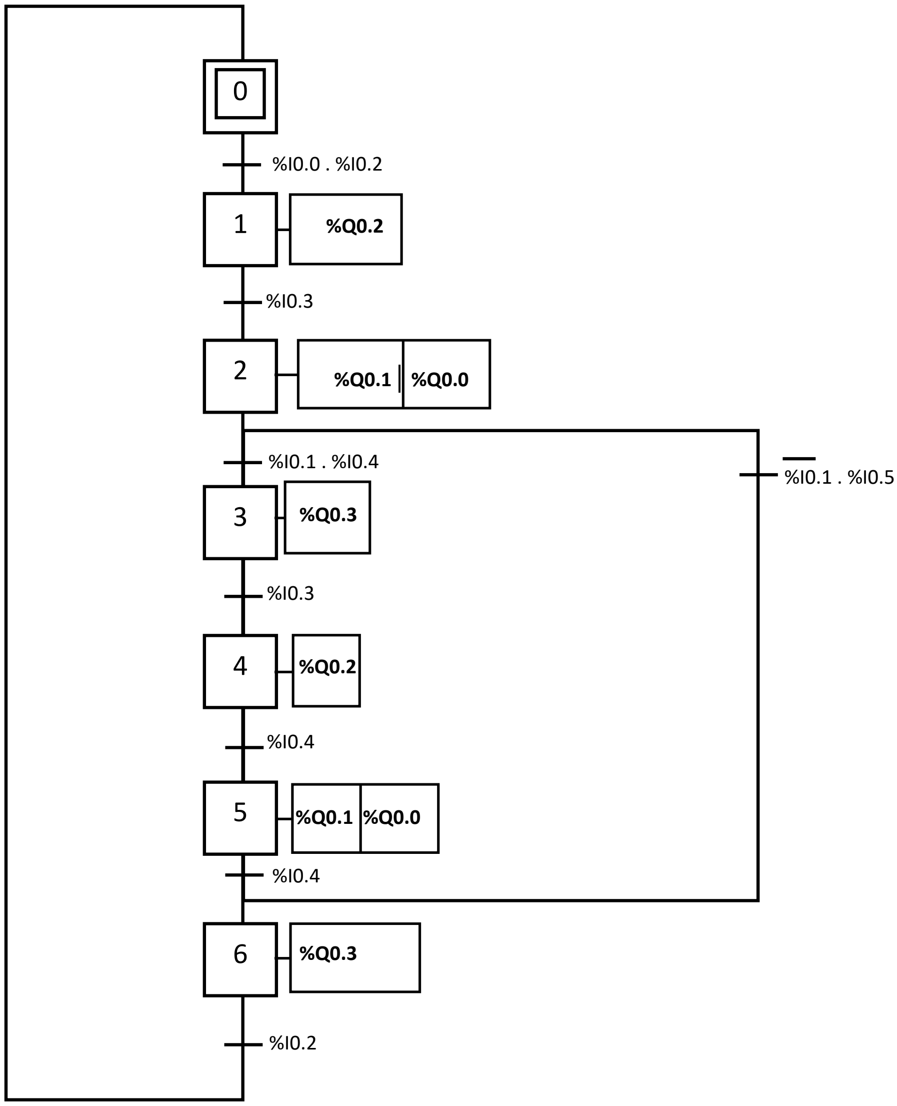
Grafcet Operational part point of view



Grafcet Control part point of view



Automated Point of View grafcet



Exercise 1 :

Two optical barriers, ***e*** and ***s***, control access to the entrance (***e***) and exit (***x***). The opening can occur either after validation (***v***) of the confidential code entered on the keyboard by the incoming driver or after detection by the optical barrier (***x***) that a vehicle wants to exit, in addition to pressing a button ***bs*** by the outgoing driver.

Once the barrier is in the fully raised position, it closes after 3 seconds (an external timer is used). During the descent of the barrier, if it detects that a vehicle wants to exit (***x***) or wants to enter (***e***), the barrier automatically raises.

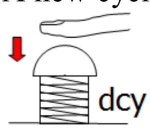
The barrier is actuated by a two- directions motor, controlled by two contactors: ***MU*** (up) and ***MD*** (down). The end positions are detected by two contacts: ***br*** (barrier raised) and ***bl*** (barrier lowered).

Give the Level 2 Grafcet modeling the control.

Exercise 2 :

Specifications:

After pressing the "dcy" cycle start button, the carts depart for a round trip. A new cycle start can only occur if both carts are on the left side.



CH1, CH2: Cart 1, Cart 2

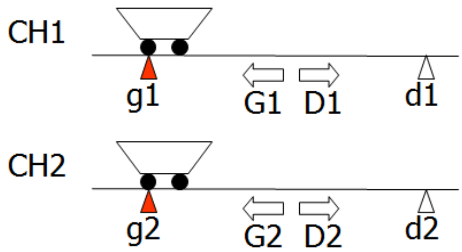
g: "left position" sensor

d: "right position" sensor

G: action "go left"

D: action "go right"

Provide the Level 2 Grafcet modeling the command.



Exercise 3 :
Automatic drill

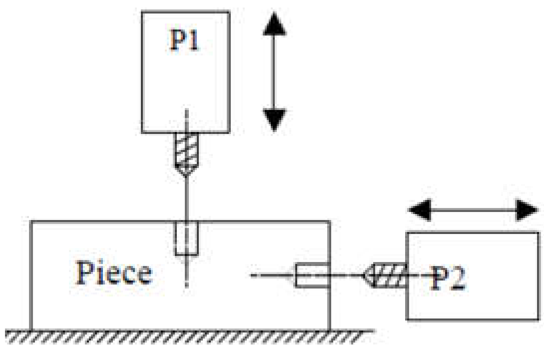
Specifications:

Two drills each perform a drilling operation on the same piece simultaneously, as shown in the figure opposite.

Drilling time 1: 10 seconds.

Drilling time 2: 15 seconds.

To avoid this operation taking too much time, it is decided to operate both drills at the same time, allowing the



drilling to be completed in 15 seconds rather than 25 seconds in the case of independent operation.

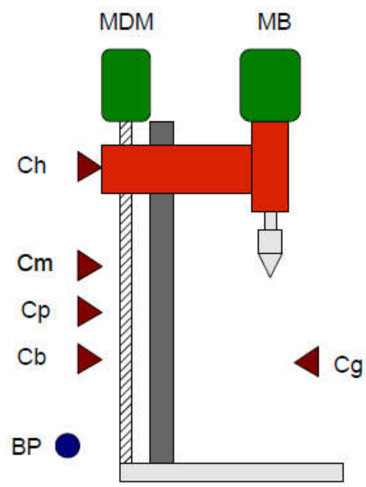
The start command is activated using a push button.

Establish the Grafcet for the operation of this system.

Exercise 4 :

Automatic drill. It performs a drilling operation and returns to the initial position. It is powered by two motors, one for the spindle and the other for raising or lowering the drill bit. The extreme positions are determined by two position sensors. The start command is given by a push button.

Specifications :



The drill is used to machine two types of parts, large and small.

These two types only differ in their height. The tall parts press on the Cg sensor, but the short ones do not.

For the short parts, the operation is as follows:

Upon pressing the Start button (BP), the spindle rotates and descends at high speed (GV) until it reaches Cm, then continues its movement at low speed (PV). It then ascends at high speed.

For the tall parts, the spindle always moves at low speed.

The descent stops at Cp, and then the spindle ascends.

MB: Spindle Start

DBGV: Spindle Descent High Speed

DBPV: Spindle Descent Low Speed

MBGV: Spindle Ascent High Speed

MBPV: Spindle Ascent Low Speed

Establish the level 2 Grafcet for this system.

BIBLIOGRAPHIE :

[1] Les Automatismes, La programmation; L. Lycée L.RASCOL 10, Rue de la République BP 218. 81012 ALBI CEDEX.

[2] Les Systèmes Automatisés de Production; A. MTIBAA., Université de Monastir, Ecole Nationale d'Ingénieurs de Monastir, Département de Génie Electrique, 2012.

[3] Support de cours Automatismes Industrielle; K. TLILI, Institut supérieur des étudess Technologiques de Sousse, Spécialité : Génie Electrique.

[4] Réalisation technologique du GRAFCET ; Daniel DUPONT, David DUBOIS., 2002.

[5] Le GRAFCET et sa mise en œuvre de cours Automatismes Industrielle; Université Luis Pasteur, Institut professionnel des Sciences et technologies.

[6] Comprendre, maîtriser et appliquer le Grafcet; M. BLANCHARD., Editions Cépaduès, Janvier 2000.

[7] Le GRAFCET, Conception-Implantation dans les automates programmables industriels ; S. Moreno, E. Peulot, Casteilla, 2009.

[8] Développement des grafcets. Des machines simples aux cellules flexibles, du cahier des charges à la programmation, B. REEB, C. Chèze, 2ème édition, Technosup, ELLIPSES, 2011.

[9] Norme internationale CEI 60848, Langage de spécification Grafcet pour diagrammes fonctionnels en séquence, AFNOR, Octobre 2013.

[10] Le Grafcet : conception - Implantation dans les API ; S.Moreno, E. Peulot., Editions Casteilla, 1996.

[11] Support de cours, Les automates programmables industriels ; L. LALAOUI., Université Mohamed Boudiaf de Msila, Département d 'électronique faculté de technologie, 2017.

[12] Automatismes Logiques, Modélisation et commande ; H. HAMDI., Volume 1, Structure et principe de fonctionnement, les éditions de l'université Constantine.