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A GEMMA-GRAFCET Generator for the Automation Software of Smart Manufacturing Systems

Software Specifications for the Filling and Encapsulating Machine Case Study

Contents

Introduction

This document contains the software specifications of the 'GEMMA layer' and the nested behaviour of each 'GEMMA state' of the filling and encapsulating machine used as case study in the article "*A GEMMA-GRAFCET Generator for the Automation Software of Smart Manufacturing Systems*".

Machine Description

An automatic machine for filling and encapsulating bottles is shown in Figure 1. The machine consists of three stations: (i) transport and feeding; (ii) dosing and filling; (iii) encapsulating. Two stepping slat conveyors allow the simultaneous operation of the three stations. Extension of pneumatic cylinders H and B respectively determines the incremental advance of the input and filling conveyors. The transport and feeding station is constituted by pneumatic cylinder A that is responsible for the feeding of the bottles from the input to the filling conveyor. The dosing and filling station is composed by a volumetric dispenser actuated from pneumatic cylinder C, and by an on/off valve (D) used to open and close the liquid supply. The encapsulating station has a pneumatic cylinder (G) to feed the cap that is recollected and released on the bottle through the movement of cylinder E. Vacuum pump F is used to grab and hold the cap. Eventually, magnetic limit switches are used to signal the position of the pneumatic cylinders and light barrier sensors to indicate the presence of a bottle on a station.

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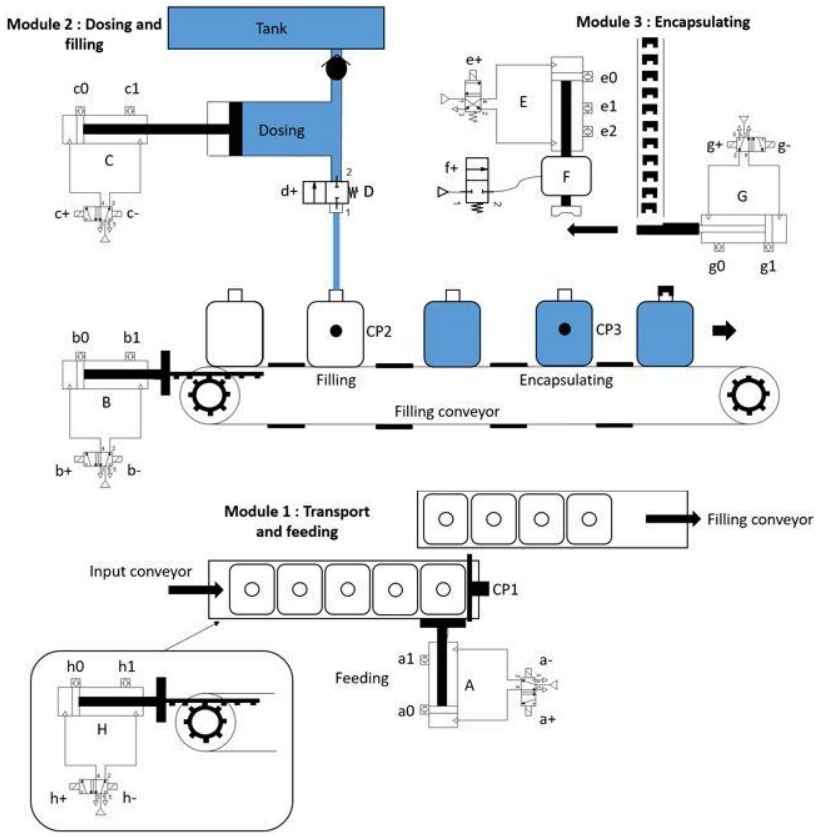

Figure 1: Schematics of the filling and encapsulating machine.

GEMMA Layer

The GRAFCET model of the GEMMA guideline is shown in Figure 2. A *Step* defines a state that does not contain a nested behaviour. The use of a *macro-step* indicates that its outgoing transitions can only fire when the exit step of the nested behaviour is active. Whereas, the outgoing transitions of an *enclosing step* can fire independently from the active step of the nested behaviour. The *initial step* indicates from which state the system starts to operate once initialized. *Reset transitions* are used since in GRAFCET the nested behaviour must be initialized each time the super-ordinate state is entered. A number is placed on each transition to indicate its priority; i.e. the order in which conditions are evaluated within the code. Finally, negation operator can be placed on the priority number. This operator changes the behaviour of the composite state with respect to the one illustrated in the representation – when the 'negated' transition is evaluated. The following states are implemented:

- *F1 Normal Production*: batch production in which one bottle is manufacture per cycle. Apart for the transitions to the emergency stop mode, the F1 mode must be exited only when the current production cycle is over;
- *F2 Starting Procedure*: each station can start producing only when a product is signalled from the corresponding light barrier sensor. This mode is exited once a bottle is placed on

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each station, and entered when the operator presses the ''start'' push button (PB) and the machine is in the ''automatic'' production mode;

- *F3 Finishing Procedure*: machine stops its stations progressively once products are processed. Bottles are no more entered to the system: i.e. station 1 and input conveyor stop working. This mode is exited when the filling conveyor is empty and entered when the operator presses the ''empty machine'' PB;
- *F4 Disordered Producing Test*: the operator can select the station to test and one production cycle is performed only for that station. The interrupter of the ''station test'' production mode must be active in order to enter this mode;
- *F5 Ordered Producing Test*: test of one functionality at a time following the control logic of the normal production mode. A ''step'' PB is pressed in order to advance the production cycle of one step. The interrupter of the ''semi-automatic'' production mode must be active in order to enter the mode;
- *D1 Emergency Stop*: all the movements are stopped. Emergency stop is entered either by the pushing of the normally closed (NC) ''emergency'' interrupter or by the miss of a product at the beginning of the new production cycle. This mode is exited when the emergency interrupter is deactivated and all the actuators are in their resting position;
- *D3 Production with Failures*: when the encapsulating station fails, production is continued and the capping is manually implemented. A ''manual capping'' interrupter is used in order to enter and exit the mode;
- *A1 Stopped at Initial State*: system rest condition in which all the actuators are energized but in their retracted position;
- *A2 End of Cycle Request*: machine terminates the current production cycle and moves to the mode A1. All the actuators must be in their resting position before exiting the mode. In order to enter the state, NC ''stop'' PB is pressed or “Manual Capping” is deactivated;
- *A5 Preparation for Restarting after a Failure*: after the emergency stop, a check and cleaning is performed from the operator. The ''operator check'' PB is pressed for exiting the mode and the alarm condition is reset;
- *A6 Restarting*: manual control of the different actuators. This mode is entered either when the ''manual'' production mode is selected or after the recovery from a failure. Restarting is exited when all the actuators are in their resting position and the ''manual movement check'' PB is pressed. The operator must press the button once the correct functioning of all the actuators has been verified.

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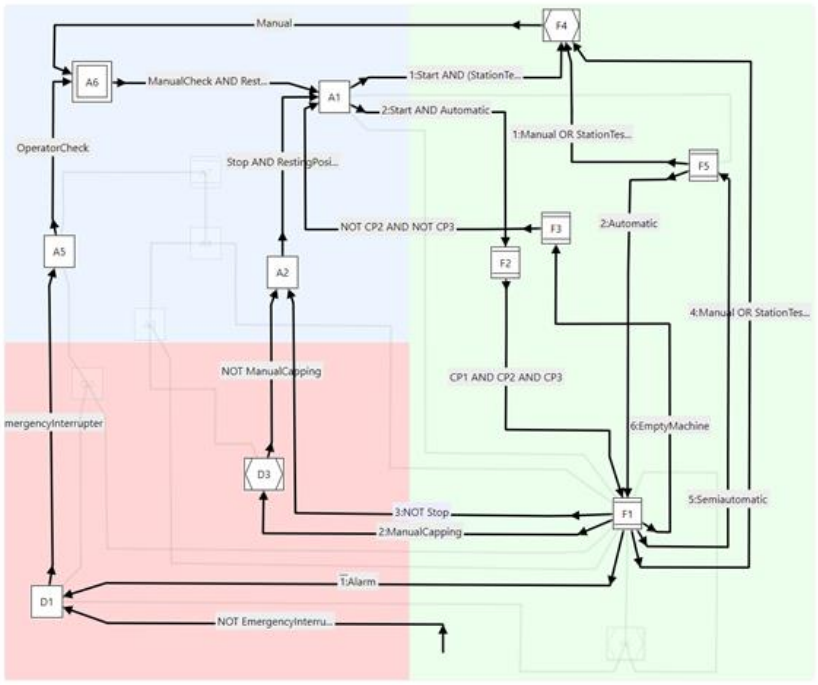

Figure 2: GEMMA state-chart diagram of the filling and encapsulating machine.

Nested Behaviour

GRAFCET is used to model the nested behaviour of each 'GEMMA state'. Next, the states that have a nested behaviour are represented; i.e. macro-steps and enclosing steps.

F2 Starting Procedure

Starting procedure mode (F2) is necessary before the implementation of normal production (F1) since machine starts its execution empty. The three stations start working progressively once a bottle is available. Machine initialization terminates when a bottle is placed in front of each station; i.e. sensors CP1, CP2 and CP3 are active. The GRAFCET diagram (Fig. 3) starts with the advance of the input and filling conveyors (step 1), the retraction of the corresponding actuators (step 2), and with the verification of the different conditions (step 3). The following possibilities can occur:

- $\overline{CP1}$: cycle is restarted without the execution of any station since a bottle has not arrived yet to station 1;
- $CP1 * \overline{CP2}$: product is available only to station 1, therefore this is the only implemented functionality before the restarting of the cycle. Cylinder A is extended for feeding the bottle from the input to the filling conveyor, and then retracted;
- $CP1 * CP2 * \overline{CP3}$: product is available to station 1 and 2, and these two stations are executed before the restarting of the cycle. For station 2, cylinder C is extended and valve D opened for supplying the liquid to the bottle. Eventually, cylinder C is retracted and valve D closed in order to fill the dispenser.

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- $CP1 * CP2 * CP3$: the complete interface variable is set to true since the initialization sequence has been completed.

Magnetic limit switches signal when the actuators fulfil the commanded operation, with the only exception of valve D that is controlled without a feedback mechanism.

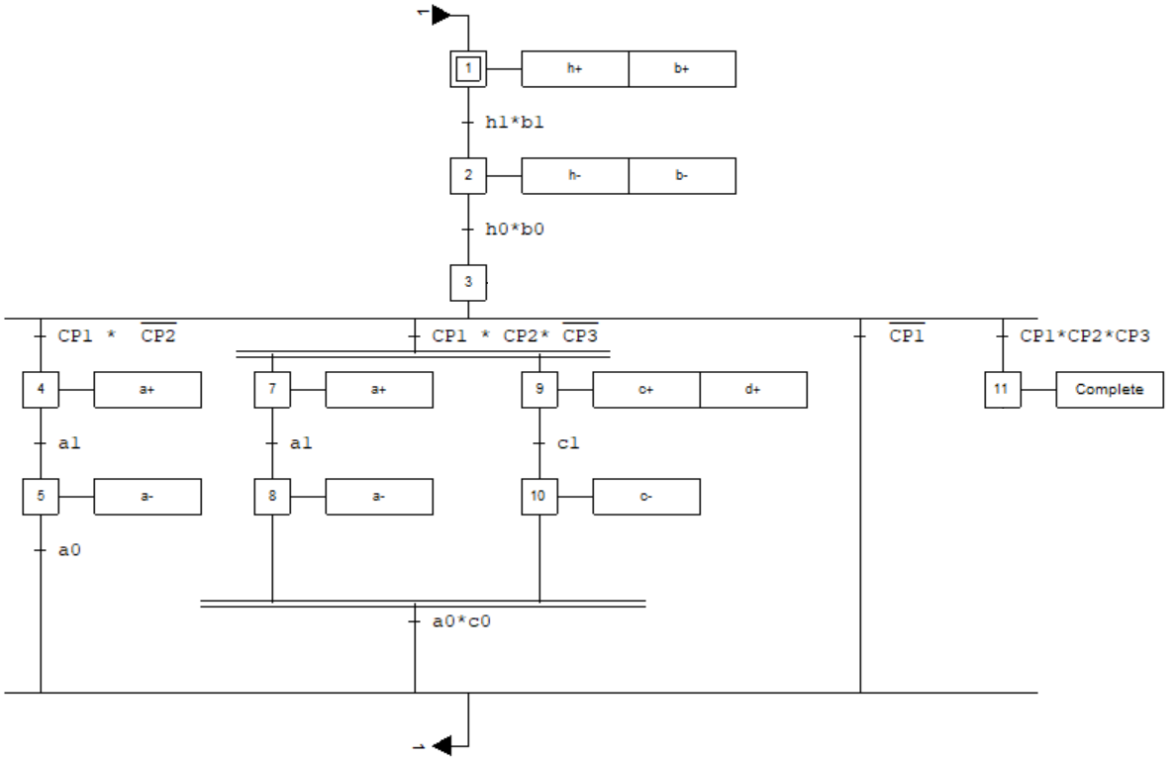

Figure 3: Nested behaviour of the starting procedure F2 mode.

F1 Normal Production

When normal production is accessed from F5, the two conveyors must be advanced of one step before the production cycle can start. Whereas, when normal production is accessed from F2 mode, GRAFCET starts from step 5 since conveyors have already advanced one step before exiting the F2 mode. In step 5, an alarm condition is verified by checking that a bottle is placed in front of each station. Then, the functionality of the three stations is simultaneously implemented. The functionality of station 1 and 2 was explained in the F2 Starting Procedure section. Next, the functionality of station 3 is illustrated. Cylinder G is first extended in order to supply the cap to cylinder E. Then, cylinder E is ejected until the position of the cap. Limit switch e1 signals the reaching of the grabbing position and vacuum pump F is activated for holding the cap. Then, cylinder E and F are retracted. Eventually, cap must be placed on the bottle. Cylinder E is extended until e2 limit switch becomes active, and then vacuum pump is deactivated. Cap falls on the bottle neck and cylinder E is retracted.

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Once the three stations have performed their operation, a flag variable “Complete” is activated in order to indicate that production cycle has been completed. This variable is used since F1 mode has some transitions that must be implemented only after the termination of the current production cycle. If the F1 state is not exited, a new production cycle is started.

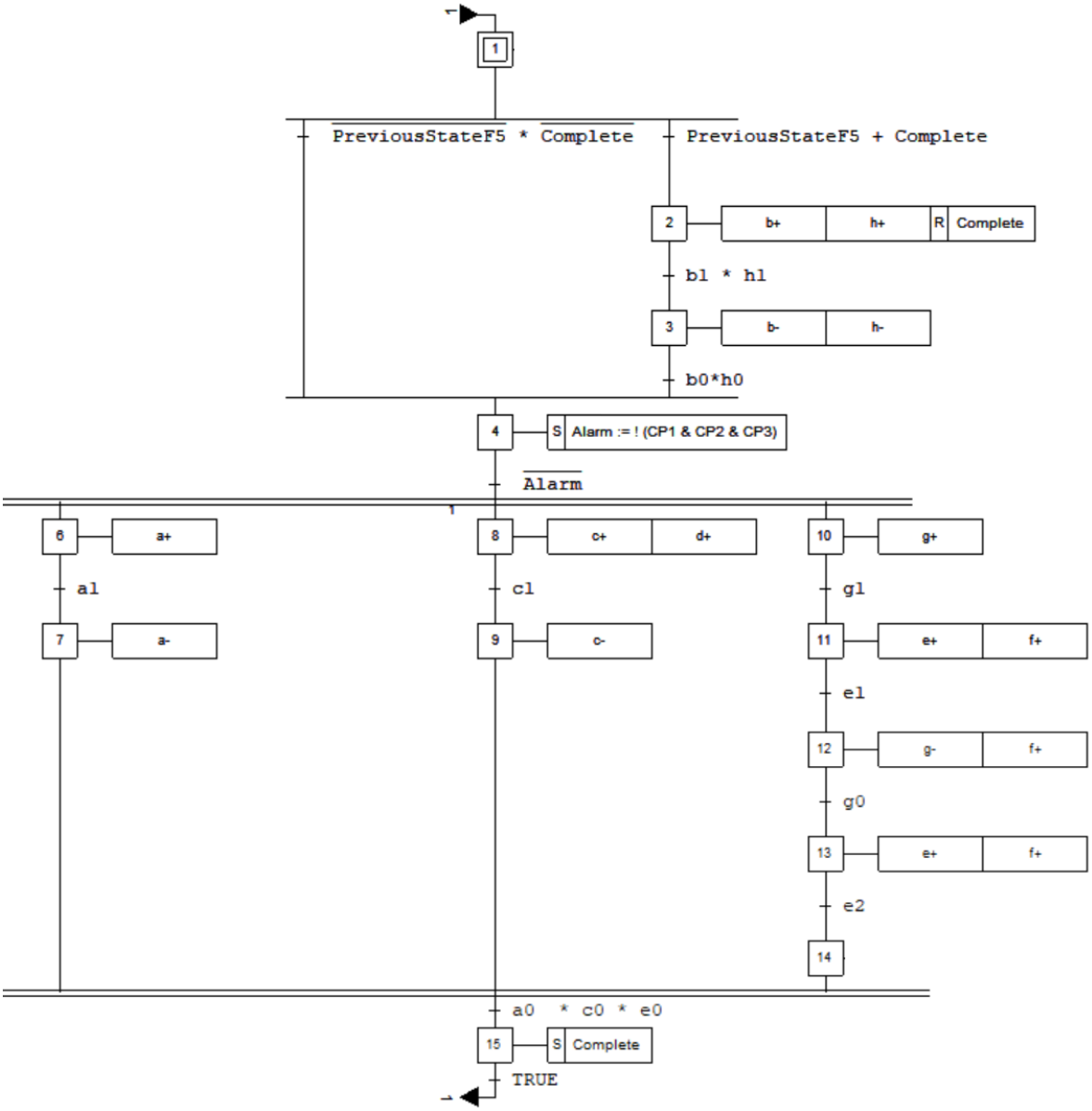

Figure 4: Nested behaviour of the normal production F1 mode.

F3 Finishing Procedure

Whithin finishing procedure, input conveyor and station 1 are deactivated and machine must empty by processing all the bottles placed on the filling conveyor. The first operation is the advance of one step of the filling conveyor. Then, the different alternatives are evaluated:

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- $CP2 * CP3$: a bottle is available both for Station 2 and 3. The two stations perform their functionlity before a new cycle begins;
- $\overline{CP2} * CP3$: station 2 has processed all the bottles on the filling conveyor, while station 3 not. Therefore, only station 3 is executed;
- $\overline{CP2} * \overline{CP3}$: machine has been emptied and the F3 start can be exited. A "Complete" flag is used to signal the completation of the operations

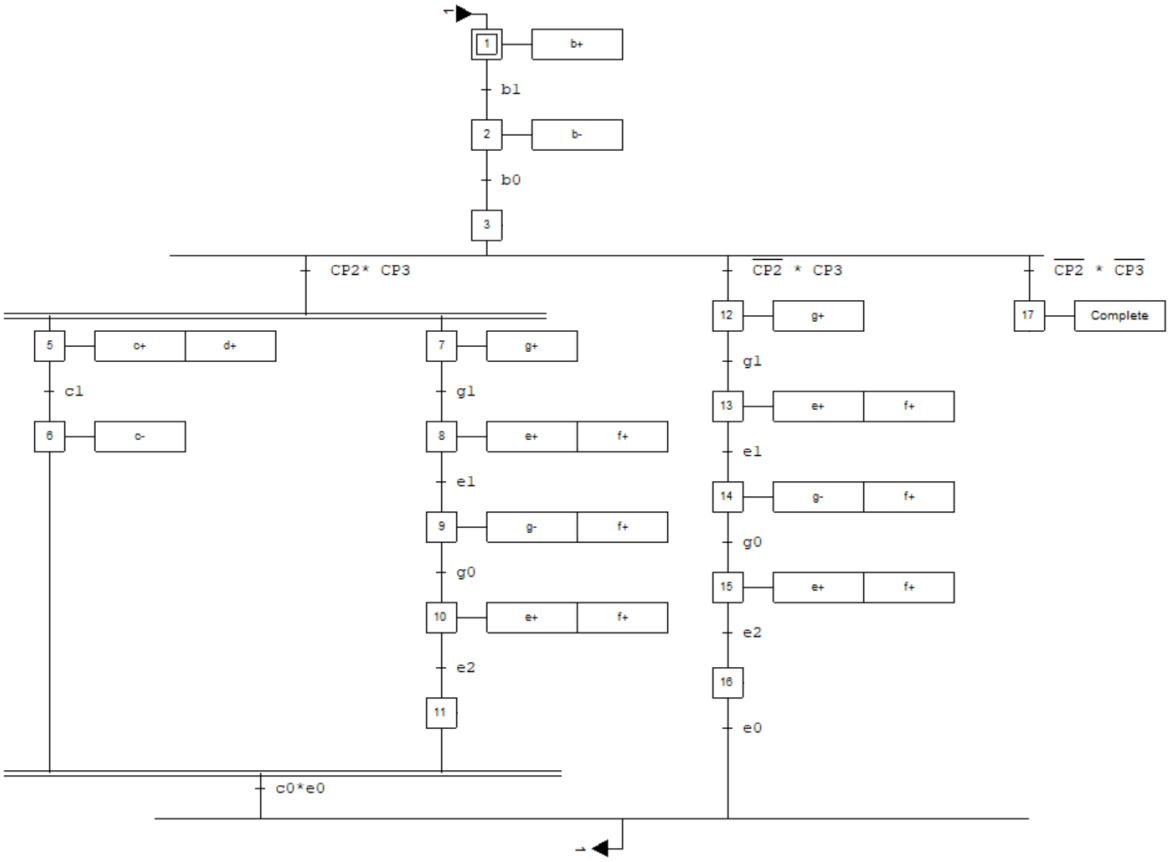

Figure 5: Nested behaviour of the finishing procedure F3 mode.

F4 Disordered Production Test

This mode is entered from A1, F1 and F5 modes. These modes are exited once the current production cycle is over. Therefore, the first operation is going to be the advance of the two slat conveyors. Then, machine enters an idle state waiting for the decision of the operating personell that is going to select which station to test. A boolean variable signals the station to test and a "start cycle" (SC) variable triggers the test of the selected station.

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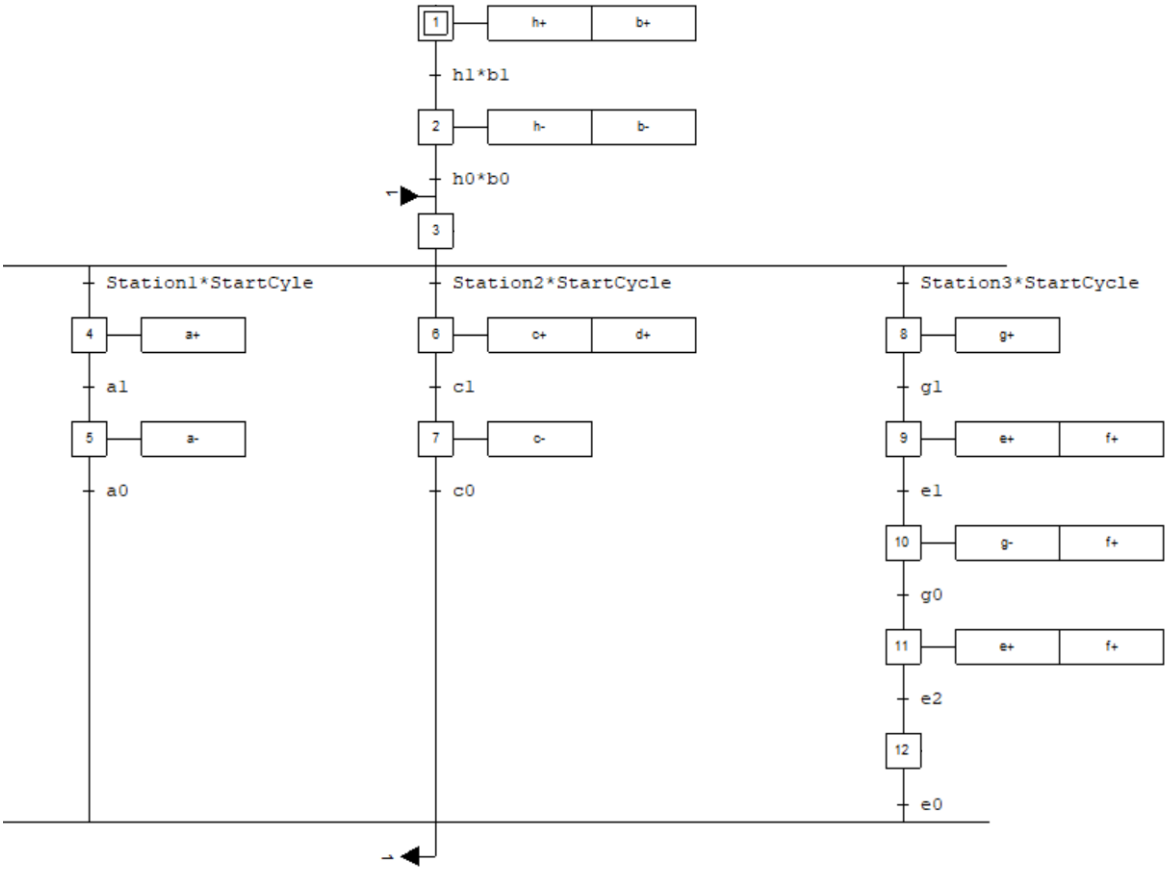

Figure 6: Nested behaviour of the disordered producing test F4 mode.

F5 Ordered Production Test

Here the operator has the possibility to monitor step by step the functioning of the machine. The simultaneous behaviour of the nominal production is processed sequentially, and the production cycle progresses when a “Step Button” is pressed. Since this mode must be exited once the cycle has been terminated, a “Complete” flag variable is momentarily set in the final step.

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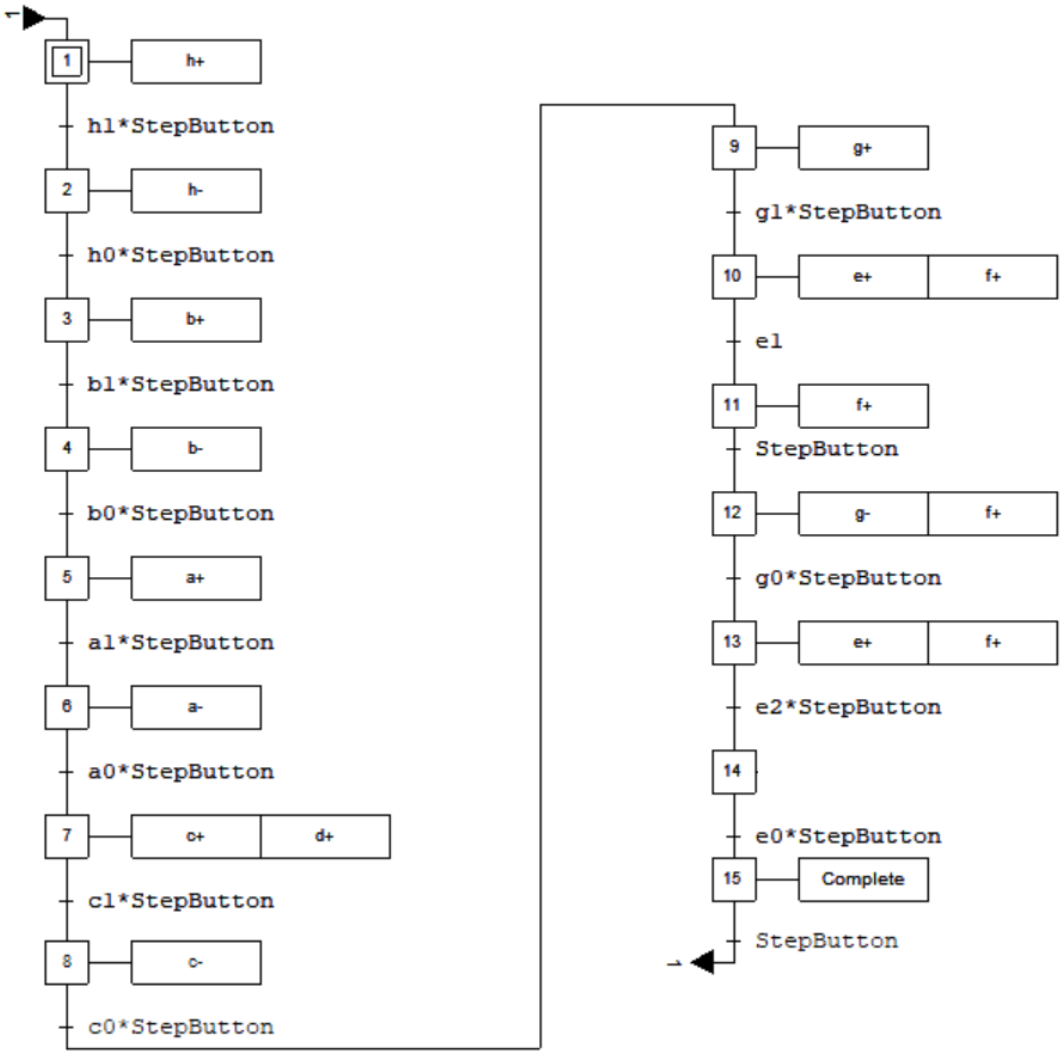

Figure 7: Nested behaviour of the ordered producing test F5 mode.

D3 Production with Failure

A failure occurred to the encapsulating station and this operation is performed manually. Within this mode, the same behaviour of the normal production is implemented with the only exception that the functionality of station 3 is not executed.

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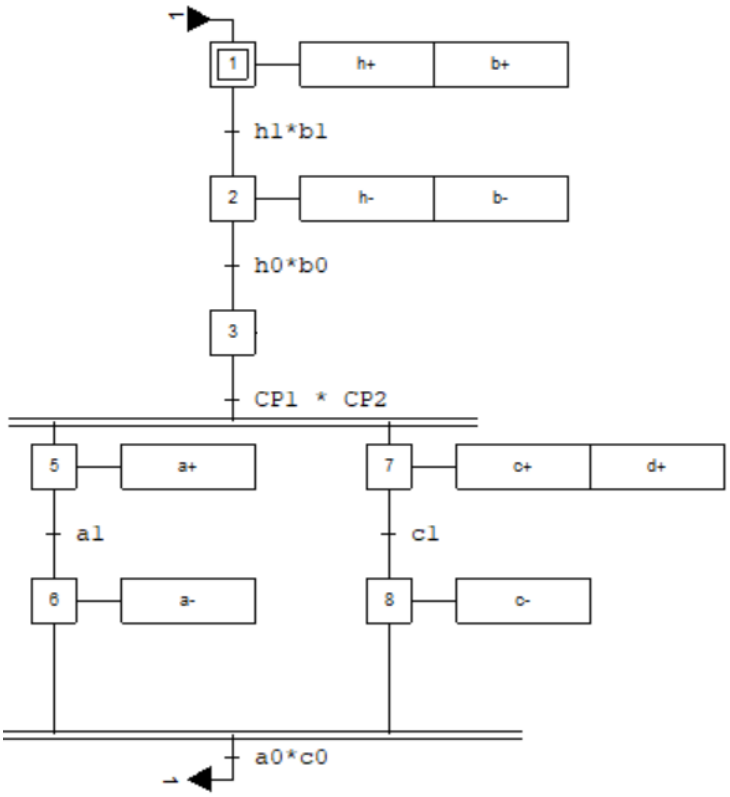

Figure 8: Nested behaviour of the production with failure D3 mode.