TWO DIAGNOSTIC MODELS FOR PLC CONTROLLED

FLEXIBLE MANUFACTURING SYSTEMS

W. HU*, A. G. STARR*† and A. Y. T. LEUNG*

* Manchester School of Engineering, The University of Manchester, Manchester M13 9PL, UK

† To whom correspondence should be addressed

Abstract: The control of flexible manufacturing systems (FMS's) is generally characterised by logical and sequential functions under the auspices of a programmable logic controller (PLC). Operational faults associated with control processes are often confusing to maintenance personnel at workshop level. This has resulted in the development of automatic diagnosis techniques. In this paper two generic diagnostic models based on the logical function chart and sequential control process of the PLC are developed. With the two complementary models, the major operational faults of PLC controlled FMS's can be diagnosed. Application of the models to a typical FMS is presented.

Keywords: Discrete diagnosis, PLC, FMS, Logical diagnosis, Sequential diagnosis

1. INTRODUCTION

Programmable Logic Controllers (PLC's) are used by most Flexible Manufacturing Systems (FMS's) as their process controllers because they are adaptable, modular, user-friendly and acquired at low cost. For a sophisticated FMS, however, the PLC's capability in fault detection is limited because of its inflexible programming system [1]. The PLC is also a relatively simple device, and has no inherent architecture for fault diagnosis other than of its

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own functions and hardware. Therefore, it is necessary to develop effective methods or models to assist the maintenance personnel in diagnostics.

Like that of an ordinary FMS, the faults of a PLC controlled FMS usually include structural faults, operational faults, condition faults or abnormalities, and NC faults. Among these faults, operational faults occur most often (about 70%). These mainly appear through the I/O of the PLC in a FMS [2]. Here operational faults refer to those associated with PLC controlled actions [3]. Typically, when a fault occurs, about 80% of downtime is spent locating its source and only about 20% is spent on the repair [4]. Thus, the diagnosis of operational faults is a major problem for maintenance personnel at workshop level.

The operation of a FMS is a complex process with multiple operating conditions. At any time, several actuators may act simultaneously. When one action is out of synchronisation, not only the next action but also actions of other components will be affected [5]. Hence, in using the I/O display of the PLC to diagnose a fault, maintenance personnel are required to be very familiar with the transformation relationship between the operating process and the signals from the machine in order to locate the fault accurately. In other words, to diagnose operational faults, the use of simple and direct I/O display from the PLC is seriously insufficient.

Various fault diagnosis methods and models for manufacturing systems have been reported in recent years. Kuo modelled the fault diagnosis behaviour of a FMS using the Coloured Timed Petri Net (CTPN). The models depend on the measured data from the inspection machines and the sensor data from the devices [6]. Toguyeni proposed two reasoning mechanisms for the implementation of an on-line diagnostic system for FMS's, i.e., temporal reasoning and hypothetical reasoning. These mechanisms are based on a distributed processing of symptoms that enables the problems of real-time constraints to be solved [7]. Ye developed a hybrid intelligent system that integrated neural networks with a procedural decision-making

algorithm to hypothesis-test cycles of fault diagnosis in advanced manufacturing systems [8]. McFarlane proposed a generic methodology for self-diagnosis within a holonic manufacturing system, in which faults and problems are analysed as a standard function of the system [9]. Girault explored an approach for a model-based diagnosis of discrete event dynamic systems such as manufacturing plants. The principle of this approach is to use linear logic in order to elaborate adductive reasoning above a Petri net based deep model of the behaviour of the manufacturing system [10]. These methods, models or systems have been implemented in the laboratory and some of them have been applied to practical manufacturing systems. However, no diagnosis method, model or system has been reported to directly depend on the internal signals in the controller, in particular in a PLC controlled FMS. This should diagnose the fault by modelling both the PLC operation and the human way of thinking in the diagnostic process. Operational faults occur most often in a PLC controlled FMS and are the major cause of down time. Therefore, research on diagnosis models for PLC controlled FMS's is necessary.

The objective of the development of the models reported here is to address operational fault diagnosis of PLC controlled FMS's. They provide effective methods for maintenance personnel at workshop level to identify, classify, and correct operational faults occurring in production. Such models will also help to raise the efficiency and accuracy of diagnosis using PLC data. The models make full use of the powerful I/O capacity of the PLC and various control signals available. The following two diagnosis models are put forward to meet this need.

- A *logical diagnosis model* based on the PLC logical function chart (LFC). The fault is sought according to the logical transformation relationship between the signals from the PLC. This is inherent in the LFC, and identifies the faulty signal status.

- A *sequential diagnosis model* based on the PLC sequential control process (SCP). This method of diagnosis traces the execution of the sequential control commands and identifies the step in which the fault occurs, so as to locate the unit.

2. PLC CONTROL IN A FMS

A FMS is a complex manufacturing system. It is normally composed of a tool system, several automated production systems, a material transportation system, several load/unload stations, a computer control and management system, and an interface. All these components are interdependent, interrelated and interactive. They carry out different tasks respectively so as to complete the functions of the entire system. The layout of an existing FFS-1500-2 FMS in Zhengzhou Textile Machinery Plant is shown in Figure 1.

The control system, machine and process data contain the most important information because they are closely related to operational fault diagnosis. In a FMS, the PLC directly monitors and controls the logical and sequential operation of the entire system, which is usually modelled for the purpose of diagnosis. The hardware of PLC control is normally in two or three levels. For the FFS-1500-2 FMS, it is as shown in Figure 2.

The system level controller, i.e. the main computer, compiles the part programs into object code. It is also responsible for management, control, reports and tables, and recording historical data. The mid-level PLC distributes the data from the main computer to cell level controllers, and co-ordinates the operation of all PLC's at the cell level. The cell level controllers, in this case the PFZ1500 PLC, KBNG85 PLC and AGV PLC, perform the I/O functions of the entire system. A PLC typically executes the following algorithm [3,11]:

```
For (ever) {
        Read all PLC inputs;
        Evaluate the PLC program;
        Set all PLC outputs; }
```

The PLC controls the FMS operation according to its user program, which is embedded in the controller. The user program defines a series of operations in the FMS, including logical and sequential operations. When a fault occurs, the current status of all sensors or actuators is saved as an array of input or flag signals in the PLC memory. Therefore, the program is the basis of the diagnosis models for operational faults in a PLC controlled manufacturing system.

3. LOGICAL DIAGNOSIS MODEL

When diagnosing a PLC controlled FMS, maintenance personnel often focus on the LFC of the units that compose the machine, and trace the faulty output along it [4]. This method of diagnosis is based upon the concept of the machine as a transformer of power, information and material: the effect of a faulty unit is propagated with the LFC [12]. Therefore the LFC-based diagnosis model which we call a *logical diagnosis model* will be effective for locating FMS faults.

3.1   *Construction of the logical diagnosis model*

In the logical diagnosis model, all variables associated with the LFC are described in a binary form. These binary variables include all the signals in the PLC, such as input signals, output signals, flag signals, timer signals, counter signals, and data signals. The logical diagnosis model is constructed from these variables in accordance with the LFC. The detailed algorithm is as follows.

We assume that $S(x)$ is the state function of an operating state signal of the machine. $S(x) = 1$ means that the operation associated with $S(x)$ is on, while $S(x) = 0$ means that the operation associated with $S(x)$ is off. $\{s_k\}$ denotes the combination of several PLC signals connected by

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a logical "AND" which is written as "·" in model expressions, and $\varphi(\{s_k\})$ is the state of $\{s_k\}$. Then we have

$$\{s_k\} = s_1 \cdot s_2 \cdots\cdots s_k \tag{1}$$

In practice, the logical expression of $S(x)$ is given by a signal decomposition according to the LFC. Therefore, if we define $\varphi_{ji}(\{s_{ki}\})$ as the i-th term of $S(x)$ at the j-th level, then the result of the decomposition of $S(x)$ at the first level is

$$S(x) = \varphi_{11}(\{s_{k1}\}) + \varphi_{12}(\{s_{k2}\}) + \cdots = \sum_i \varphi_{1i}(\{s_{ki}\}) \tag{2}$$

where $\varphi_{1i}(\{s_{ki}\})$ is a factor that makes $S(x)=1$. It may be a PLC signal or the combination of several signals connected by logical "AND". Except for the terms expressed by input signals or flag signals that cannot or need not be decomposed, other terms usually can be decomposed further according to the LFC. The decomposition of these terms is also the decomposition of $S(x)$ at the second level, i.e.

$$\varphi_{1i}(\{s_{ki}\}) = \varphi_{21}(\{s_{k1}\}) + \varphi_{22}(\{s_{k2}\}) + \cdots = \sum_i \varphi_{2i}(\{s_{ki}\}) \tag{3}$$

The decomposition can proceed level by level in the same form till the n-th level is reached where all the terms are expressed by input signals or non-decomposable flag signals, i.e.

$$\varphi_{(n-1)i}(\{s_{ki}\}) = \varphi_{n1}(\{s_{k1}\}) + \varphi_{n2}(\{s_{k2}\}) + \cdots = \sum_i \varphi_{ni}(\{s_{ki}\}) \tag{4}$$

So far, substituting the decomposition expression at every level into that at its higher level, we have

$$
\begin{aligned}
\varphi_{ni}(\{s_{ki}\}) &\Rightarrow \varphi_{(n-1)i}(\{s_{ki}\}) \\
\varphi_{(n-1)i}(\{s_{ki}\}) &\Rightarrow \varphi_{(n-2)i}(\{s_{ki}\}) \\
&\vdots \\
\varphi_{2i}(\{s_{ki}\}) &\Rightarrow \varphi_{1i}(\{s_{ki}\}) \\
\varphi_{1i}(\{s_{ki}\}) &\Rightarrow S(x)
\end{aligned}
\tag{5}
$$

In the end we get a non-decomposable and minimised logical expression of $S(x)$, i.e.

$$S(x) = \varphi_1(\{s_{ki}\}) + \varphi_2(\{s_{ki}\}) + \cdots = \sum_i \varphi_i(\{s_{ki}\}) \tag{6}$$

where $\varphi_i(\{s_{ki}\})$ is also a factor that makes $S(x) = 1$ and is composed of input signals or non-decomposable flag signals, $\varphi(\{s_{ki}\})$.

Now, let $F(x)$ be the fault state function of the machine. $F(x) = 1$ means that a fault has occurred, while $F(x) = 0$ means that there is no fault. If $F(x)$ equals $S(x)$, all the fault terms that make $S(x) = 1$ can be determined, which are expressed as $f_1(\{s_{k1}\})$, $f_2(\{s_{k2}\})$, …, respectively. These terms are finally used to construct a logical fault state expression of the machine, that is

$$F(x) = f_1(\{s_{k1}\}) + f_2(\{s_{k2}\}) + \cdots = \sum_i f_i(\{s_{ki}\}) \tag{7}$$

If $F(x)$ equals the inverse state of $S(x)$, the first step will be to extract the logical expression of the inverse of $S(x)$. Each term of the expression is a combined pattern of causes of the machine fault, i.e.

$$\overline{S(x)} = \overline{\sum_i \varphi_i(\{s_{ki}\})} = f_1(\{s_{k1}\}) + f_2(\{s_{k2}\}) + \cdots = \sum_i f_i(\{s_{ki}\}) \tag{8}$$

Thus, the logical expression at the faulty state of the machine is obtained as follows.

$$F(x) = \overline{S(x)} = \sum_i f_i(\{s_{ki}\}) \tag{9}$$

3.2   *Example*

The FFS-1500-2 FMS uses a SIEMENS U Series PLC. The SIEMENS U Series PLC has signals as shown below:

E   inputs

A   outputs

M   flags

T   timers

C   counters

D   data

Each item in the logical expressions above is a single signal or the combination of several signals via a logical "AND". In a LFC, the logical relationships between signals are expressed as in Figure 3.

Figure 4 is a LFC describing the start conditions of the NC (Numerical Control) system in a FFS-1500-2 FMS which is installed at Zhengzhou Textile Machinery Plant in China. In Figure 1, M132.4 is the flag signal indicating the start condition of the NC system. If we define $\overline{Xm.n}$ as the inverse state of Xm.n, according to the logical diagnosis model, M132.4 can be decomposed as follows.

$$M134.2 = M132.0 \cdot M132.3 \cdot N1 \cdot \overline{M21.2} \cdot \overline{M22.2} \cdot \overline{M23..2} \cdot \overline{M129.3} \cdot E7.1 \cdot E7.3 \cdot E7.5$$

$$M132.0 = A9.6 \cdot A18.4 \cdot E19.0 \cdot \overline{E23.1} \cdot \overline{M144.1} \cdot E20.6$$

$$N1 = E30.5 + N2$$

$$N2 = M133.2 \cdot E30.2$$

where "+" denotes logical "OR". After being simplified,

$$S(x) = M132.4 = A9.6 \cdot A18.4 \cdot E19.0 \cdot \overline{E23.1} \cdot \overline{M144.1} \cdot E20.6 \cdot M132.3 \cdot$$
$$(E30.5 + M133.2 \cdot E30.2) \cdot \overline{M21.2} \cdot \overline{M22.2} \cdot \overline{M23.2} \cdot \overline{M129.3} \cdot E7.1 \cdot E7.3 \cdot E7.5$$

The first possible fault is that the NC start conditions are not satisfied, in which case the state function $S(x)$ = M132.4 = 0. From the above expression, the logical expression at a faulty state, i.e. $F(x)$, can be obtained as

$$F(x) = \overline{A9.6} + \overline{A18.4} + \overline{E19.0} + E23.1 + M144.1 + \overline{E20.6} + \overline{M132.3} + \overline{E30.5} \cdot \overline{M133.2} +$$
$$\overline{E30.5} \cdot \overline{E32.2} + M21.2 + M22.2 + M23.2 + M129.3 + \overline{E7.1} + \overline{E7.3} + \overline{E7.5}$$

The components related to the terms that make $F(x)$ = 1, are the potential fault locations.

3.3 *Diagnostic procedure using the logical model*

In the logical diagnosis model each term of the logical expression at a fault state represents a possible combined signal pattern of causes. The next step is to analyse all the possible

combined patterns, until an input signal, or a non-decomposable flag signal, is found which causes the fault. Consequently the fault is located. The detailed diagnostic procedure is as follows:

- Compare the faulty state of $S(x)$ with the current state of signals in PLC: if they are the same, then it is concluded that a fault has occurred;

- Establish a logical equation about the faulty state, i.e.

$$F(x) = \sum_i f_i(\{s_{ki}\}) = 1 \tag{10}$$

- Substitute the actual state values of signals in the PLC into the above equation and calculate if any term $f_i(\{s_{ki}\}) = 1$;

- Acquire the combined pattern corresponding to the term $f_i(\{s_{ki}\}) = 1$. The pattern shows the exact cause of the fault.

For comprehensive coverage of fault states we must make sure that the combined patterns in the logical expression cover all the possible fault causes, and are independent to each other.

4. SEQUENTIAL DIAGNOSIS MODEL

The LFC-based logical diagnosis model is a static model and cannot describe the dynamic change of the operating state of a FMS. However, many processes in a FMS, such as gear and tool exchange, are controlled sequentially. In other words, some actions must be done after some others have taken place. If the first action doesn't finish, then the second will not start. There are many logical relationships defining chains and prohibition [13]. The sequential control is performed by a series of sequential commands. These sequential commands lead to a dynamic change of the machine operating state. For the diagnosis of a sequentially controlled FMS, the LFC-based logical diagnosis model is obviously not suitable. Thus a SCP-based diagnosis model which we call a *sequential diagnosis model*, is introduced. The

principle of this model is identical to the sequence of state changes induced by the input commands, so it is effective for locating the faults of sequentially controlled machines.

The sequentially controlled machine usually consists of a number of functional units, and each command activates a specified unit. Therefore, if we trace the executions of the sequence of commands, and identify the step in the control sequence where a fault occurs, we can locate the faulty unit.

In general, faults of the sequentially controlled FMS or its processes are classified into three categories: control signal fault, sensor signal fault and actuating mechanism fault [14]. For the first two, we assume "stuck-at-1" and "stuck-at-0" faults, and for the latter, we assume seizures and mechanical open faults. Here we do not deal with faults of the PLC itself.

4.1   *Construction of the sequential diagnosis model*

The sequential control of a PLC controlled FMS is usually performed by a sequencer. Sequential control consists of a series of action steps. Each step contains a number of control commands and conditions on which the next step can be started. The initial conditions are used to trigger the first step, which depends on the specific situations about design and application.

A SCP-based sequential diagnosis model consists of a certain number of machine states and state changes in time sequence. It describes the sequential changes of the machine operating states. The action in a step is not only related to the control commands in this step, but also related to the conditions in the previous step. The current step can only be started under the condition that the previous step has finished and the current control commands have been received. Whether a step is finished or not is decided according to its step conditions. So, the sequential diagnosis model can be constructed as follows.

We assume that $C(t)$ is the combined state of all the step conditions in the t-th step. Since each condition is normally a PLC signal, marked by $c_1(t)$, $c_2(t)$, …, thus

$$C(t) = c_1(t) \cdot c_2(t) \cdots = \prod_j c_j(t) \tag{11}$$

$C(t) = 1$ indicates the step conditions are satisfied and the next step can be started. $C(t) = 0$ indicates the conditions are not satisfied and the action sequence cannot be carried out. Similarly, the step conditions of the previous step are expressed by

$$C(t-1) = c_1(t-1) \cdot c_2(t-1) \cdots = \prod_j c_j(t-1) \tag{12}$$

Now we can let $I(t)$ be the combined state of all the control commands in the t-th step. Every control command is also a PLC signal, marked by $i_1(t)$, $i_2(t)$, …, thus

$$I(t) = i_1(t) \cdot i_2(t) \cdots = \prod_j i_j(t) \tag{13}$$

$I(t) = 1$ indicates the commands are received while $I(t) = 0$ indicates not received.

As mentioned above, we know that a fault at the t-th step is either because the control commands are not received, or because the commands are received but the previous action has not finished. So, if we let $F(t)$ be the state of the step, $F(t) = 1$ indicates that the step is faulty. In the case where a fault exists, it is possible that

$$F(t) = C(t-1) \cdot \overline{I(t)} \tag{14}$$

When $F(t) = 1$, $C(t-1) = 1$ and $I(t) = 0$ the previous step has finished and current step started, but the control commands have not been received. From the expression

$$\overline{I(t)} = \overline{\prod_j i_j(t)} = \overline{i_1(t)} + \overline{i_2(t)} + \cdots = \sum_j \overline{i_j(t)} = 1 \tag{15}$$

the exact command that is not received can be found. It is also possible that

$$F(t) = I(t) \cdot \overline{C(t)} \tag{16}$$

When $F(t) = 1$, $I(t) = 1$ and $C(t) = 0$ the current control commands have been received, but the action has not finished. Like the first case, the following expression determines the exact condition which is not satisfied, allowing fault location:

$$\overline{C(t)} = \overline{\prod_j c_j(t)} = \overline{c_1(t)} + \overline{c_2(t)} + \cdots = \sum_j \overline{c_j(t)} = 1 \tag{17}$$

4.2   *Example*

The SIEMENS U Series PLC uses the programming language STEP 5. A PLC program coded with STEP 5 is divided into the following blocks:

OB   organisation block

PB   program block

SB   step block

FB   function block

DB   data block

The LFC in the logical diagnosis model is usually programmed in the PB, while the sequential control is carried out in the SB. Each SB contains a machine operation command. Several SB's form a control sequence by linking together in a specified order. The operation of the tool-head exchange in the FFS-100-2 FMS is shown here as an example to explain the sequential diagnosis model. The tool-head can be attached to the spindle so as to change the feed direction of tools. The tool-head is exchanged frequently, and various faults may occur in the process.

The tool-head exchange sequence programmed in the SB is described in Table 1, which includes a series of actions, from removing the old tool head to fitting a new one.

Now let us consider the first two steps, SB117 and SB118, and assume SB118 is the current step. The start condition of SB118 is that SB117 is finished. The programs of these two steps are shown as STEP 5 code in table 2.

From SB117 we know that the start conditions of the current action (SB118) are:

$$C(t-1) = \text{M143.0} \cdot \text{M143.1} \cdot \text{M160.1} \cdot \text{M165.0} = 1$$

This identifies that:

- the internal cooling oil is stopped (M143.0=1);

- the spindle blower is turned off (M143.1=1);

- step running is enabled (M160.1=1);

- automatic operation of tool-head magazine is enabled (M165.0=1).

From SB118 we can see that the control command of this step is:

$$I(t) = \text{M227.4}$$

The start conditions of the next step (SB119) are:

$$C(t) = \text{M159.0} \cdot \overline{\text{M158.4}} \cdot \text{M165.2} \cdot \text{M134.5} \cdot \text{E18.4} \cdot \overline{\text{E18.5}} \cdot \overline{\text{E38.2}} = 1$$

This identifies that:

- the middle variables are cleared (M159.0=1);

- Z-axis is at its reference position (M158.4=0);

- the tool-head magazine has moved to its right position (MM165.2=1);

- the spindle has been oriented (M134.5=1);

- the protection door for tool exchange manipulator is open (E18.4=1 and E18.5=0);

- the C-axis has returned to its reference position (E38.2=0).

These conditions are also used to determine whether SB118 is finished.

If $C(t\text{-}1)=1$ and $I(t)=0$, then the control command of step 2 is received. When $I(t)=1$ and $C(t)=0$, the current step is not finished. From the expression below we know that the components associated with the terms that make C(t)=1, are the potential fault locations:

$$\overline{C(t)} = \overline{\text{M159.0}} + \text{M158.4} + \overline{\text{M165.2}} + \overline{\text{M134.5}} + \overline{\text{E18.4}} + \text{E18.5} + \text{E38.2} = 1$$

4.3 *Diagnostic procedure using the sequential model*

Under normal operating conditions, the PLC controls the FMS according to a predefined sequence of actions. At the same time, each step in the control sequence is monitored by the watch dog timer in the PLC. If the machine is normal, it will operate sequentially according to the preset sequence. The occurrence of a fault may be indicated by excessive time spent at a control status during an action.

When a sequential control fault is detected, diagnosis is carried out using the sequential diagnosis model. At first the current values of all the signals in the PLC will be read. The start conditions of every step are analysed according to these values, in conjunction with the control sequence. By doing so, the step where a fault has occurred can be determined. Each control command and fault step condition is checked, until the exact fault is located.

5. CONCLUSIONS

The logical diagnosis model describes the propagation of the effects of faults through a machine system and its components. The algorithm, in which causes of the fault are identified with the LFC, models the human approach to the diagnostic process. The LFC is a static model and cannot represent the dynamic change of the machine operating state. However, the sequential diagnosis model can describe such a series of state changes, and can be used to identify the step in the operating sequence where the fault occurs and the precise cause.

The logical diagnosis model and the sequential diagnosis model are complementary. First a faulty step in the control sequence is identified using the sequential diagnosis model. Commands issued in each step activate units of the machine. Further diagnostic procedures can be performed using the logical diagnosis model, which corresponds to the unit.

The logical diagnosis model and sequential diagnosis model have been successfully used in an existing automatic diagnosis system which the author developed for a FFS-1500-2 FMS at

Zhengzhou Textile Machinery Plant in China. The system has been running for over a year at the time of writing. The results show that the direct benefits lie in the following areas.

- An approximate 80% increase in the efficiency and accuracy of diagnosing a fault has led to a reduction in down time.

- The requirement on technical maintenance personnel is greatly reduced. Operators are able to handle most problems with the help of the automatic diagnosis system. The cost of training maintenance personnel has been reduced.

- The machine availability has been improved, hence the efficiency of the FMS has been enhanced.

The diagnosis models were developed for a SIEMENS U Series PLC-controlled FMS. They can also be applied directly to other manufacturing systems controlled by the same series PLC. The control mechanisms of PLC's (logical and sequential) are generically similar even if they have different programming languages and methods. The models are theoretically suitable for other PLC controlled manufacturing systems. The models have been integrated into a distributed fault diagnosis system for 21 automated production lines in a large diesel engine manufacturing factory in China.

The modelling of a complex manufacturing system is always labour intensive. Fault diagnosis is not usually carried out in real time. In addition, the signals from the PLC are limited and there is no diagnostic knowledge available for more accurate diagnosis. The future work should tackle the following problems:

- The design and implementation of a new generation of knowledge-based diagnosis tools that can continuously acquire data from the PLC, identify possible faults, search for their causes and suggest corrective actions.

- The establishment of an automatic modelling mechanism that can automatically reproduce the functional and operational logic embedded in the control logic of a PLC.

- The definition of an embedded diagnosis system approach which will integrate the models in the manufacturing system controllers (CNC/PLC), so that faults can be diagnosed in real time.

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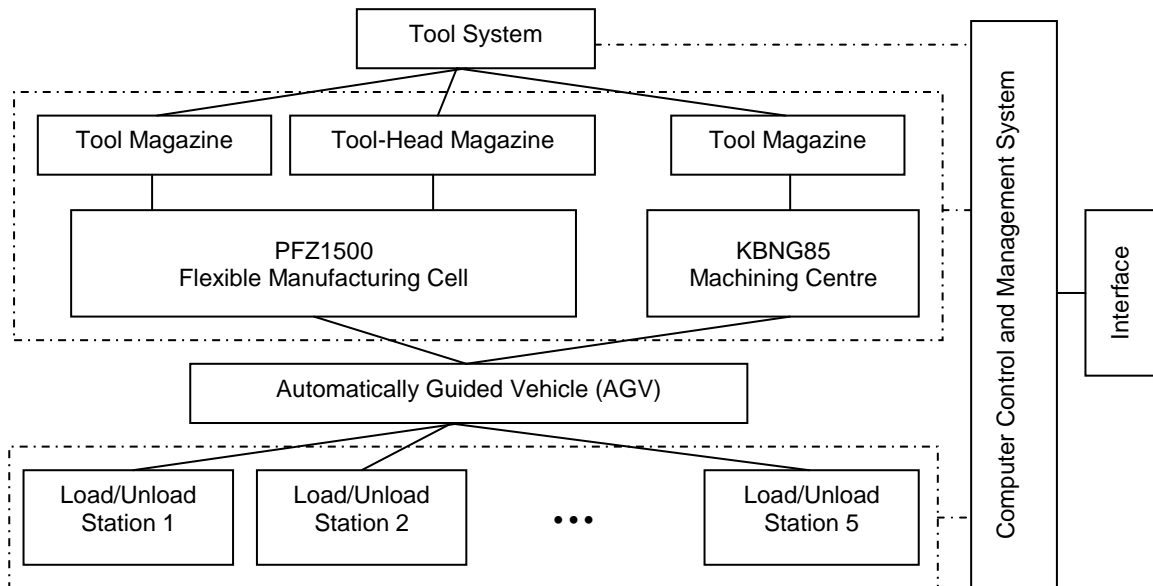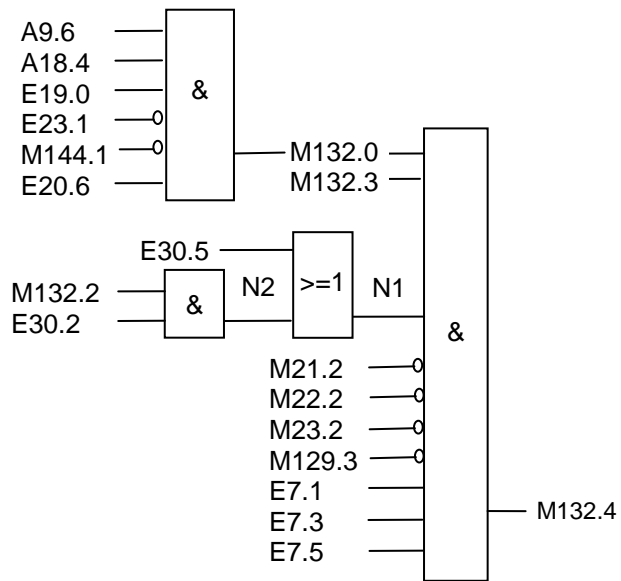
Figure 1 FFS-1500-2 FMS
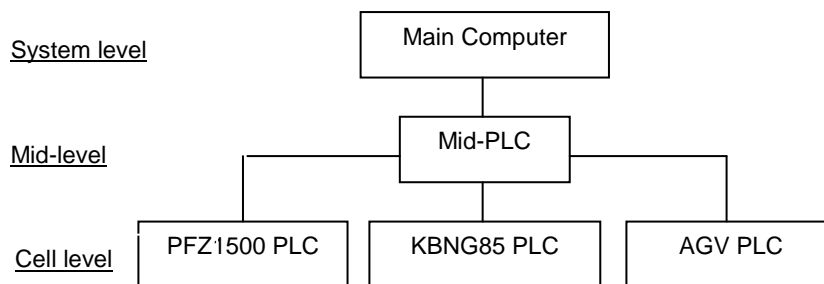
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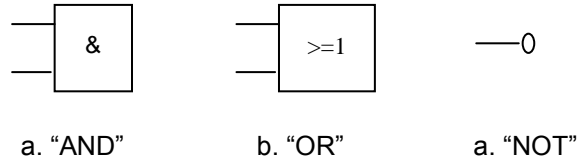
Figure 3. Logical Relationship between Signals

Figure 4. LFC of NC Start Conditions

Table 1. Operation sequence of tool-head exchange

Step	SB	Action description
1	SB117	Tool-head magazine moves to the position of the old tool-head
2	SB118	Z-axis returns to the reference
3	SB119	Y-axis moves to the position to exchange tool-head
4	SB121	Z-axis moves to the position to exchange tool-head
5	SB122	Adapter looses and the old tool-head is put into tool-head magazine
6	SB123	Z-axis returns to the reference
7	SB124	Tool-head magazine moves to the position of new tool-head
8	SB125	Z-axis descends to the position to pick the new tool-head
9	SB126	Adapter clamps the new tool-head
10	SB131	Z-axis returns to the reference
11	SB132	Y-axis returns to the machining position
12	SB133	Tool-head magazine returns to the reference

Table 2: Step programs

SB117:			SB118:		
0000	:=	M254.0	0000	:UN	M159.0
0001	:R	M159.0	0001	:R	M149.1
0002	:L	DW22	0002	:U	M227.4
0003	:T	DW10	0003	:S	M149.1
0004	:A	DB100	0004	:S	M159.0
0005	:O	D68.1	0005	:U	M227.4
0006	:O	D68.2	0006	:UN	E10.6
0007	:O	D68.3	0007	:S	M158.4
0008	:O	D68.4	0008	:U	M159.0
0009	:O	D68.5	0009	:UN	M158.4
000A	:O	D68.6	000A	:U	M165.2
000B	:S	M165.0	000B	:U	M134.5
000C	:A	DB170	000C	:U	E18.4
000D	:L	DW21	000D	:UN	E18.5
000E	:L	KB63	000E	:UN	E38.2
000F	:!=F		000F	BE	
0010	:U	M254.0			
0011	:=	M143.0			
0012	:U	M143.1			
0013	:U	M160.1			
0014	:U	M165.0			
0015	:BE				