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PROJECT OF CONTROL OF THE OPEN CNC IN AGILE MANUFACTURING SYSTEM

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Abstract. Competition in the market is getting more and more globalized and the fast technological changes force manufacturers to search for new ways to stimulate the productive system to the market requirements. Several proposals have been put forward in an attempt to solve the problem of the control of productive systems distributed whenever it is necessary to include a new process in the system. To reach this goal, it is necessary to develop a new model which includes agile manufacturing. The purpose of this article is to project the control of agile productive systems with Computerized Numerical Control (CNC) of Open Architecture. The organization, people and the combination of machines with traditional CNC, dedicated workstations, CNC of Open Architecture, form the Productive System. The introduction of the philosophy of Open Architecture in the control of the operation of machines has given rise to a new phase of controllers. The new CNC generation of Open Architecture keeps the CNC technology (control of position and rotation) and adds to it the technology of computers (programming has become easier, configuration, net communication), and it has structures that enable changes in the hardware configuration and changes in the software for all the levels of control. Through the Open CNC Architecture we have increased the flexibility of the machine-tool and it also makes it possible to develop a new way to treat the control at the management level of production in the plant. In this essay the control has been developed by the integration of superior levels through the Norm ANSI ISA S95 and implemented through the Norm IEC 61499.

Keywords: *Open CNC Architecture, Agile Manufacturing, Reconfigurable Manufacturing System.*

1. Introduction.

The industrial automation was developed through flow-shop production lines and with the increase in competition, the cycle of life of products was reduced with the required costs to their differential position in the market. Thus, production by lots became higher. Currently new products are launched in the market at short intervals. For this to happen, many changes occur in the manufacturing system, as the alteration in the schedulling, changes in processes and, in some cases, it is necessary to change the hardware and the software of the machine-tool to implement the new process. In this case, the following problems may occur: the CNC control of the present machine is not prepared for updating or part of the machine is not compatible with the new component because it is a propriety system. This way, the user remains dependent on the technology of the machine manufacturer. For the industry to keep on being competitive, it will have to be in charge of a new type of manufacturing system that can answer quickly to the changes in the plant. With this in mind, in the 90's several proposals of open architecture controllers were put forward, such as OSACA (Open System Architecture for Controls within Automation System), OSEC (Open System Environment for Controller), OMAC (Open Modular Architecture Controls). The advantage of the machine-tool that can be reconfigurated is to enable the industry to adjust the production to the fluctuation of the market requirements and to adapt functions to new products. As per Koren, the paradigm of reconfigurated manufacture will become as important as mass production and Lean Manufacturing, because the introduction of new products in the market has been increasing a lot and the quick configuration of a manufacturing system motivates the new lines of products.

2. Manufacturing System and Computerized Numerical Control (CNC) of Open Architecture

In this item we describe the environment of Agile Manufacture, giving emphasis to the flexibility of resources. We demonstrate the functional hierarchy of the Norm ANSI ISA S95 that aims at the operational management of manufacture and the characteristics of CNC Open Architecture to work in open systems.

2.1 Agile Manufacturing.

The essay has, as its basis, the agile manufacture that aims at the integration of the organization, people and technology to obtain cooperation and innovation in the supply of customized products to clients (Kidd, 1994). As for the importance of people the process of agile manufacture, this agility increases the control and job descriptions, workers become faster, they have more knowledge, are better informed and have a bigger condition to make decisions

(Sahin, 2000). The reasons to adopt the technology as a lever to agility are: to reduce time-to-market, improve skills and flexibility of people, improve the resource flexibility and facilitate the continued changes in processes (Levini, 1996).

2.2 Norm ANSI ISA S95.

The Norm ANSI ISA S95 aims at the operational management of manufacture and, thus, has a functional hierarchy, which is well defined (Figure 1), starting at level 0 and going up to level 4, as per description. Level 0 defines the real physical process. Level 1 defines the activities involved in the monitoring and manipulation of physical processes, operating typically inside time windows of seconds or even smaller time measurements. Level 2 defines the activities of monitoring and local control of physical processes, operating inside time windows of minutes, seconds or its divisions. Level 2 typically operates equipment inside a center of work, according to the hierarchy proposed by the norm. Level 3 defines the activities that perform the progress of process to generate the final products. It includes activities of maintenance of registers and coordination of processes. Level 3 operates typically inside time windows of days, shifts, hours, minutes and seconds, operating over areas in centers of work. Level 4 defines the activities of the business, which are necessary to generate the organization of the manufacture. Among the activities described with the manufacturing are the establishment of the main agenda of the plant, determination of inventory levels and the certainty that materials are liberated correctly for the production. Pieces of information from level 3 are critical to the activities of level 4. Level 4 operates typically in a time window of months, weeks and days, acting over the business as a whole or over parts of it. At level 4 or higher levels there are other activities which are related to the business, but which are not part of the purpose of this norm.

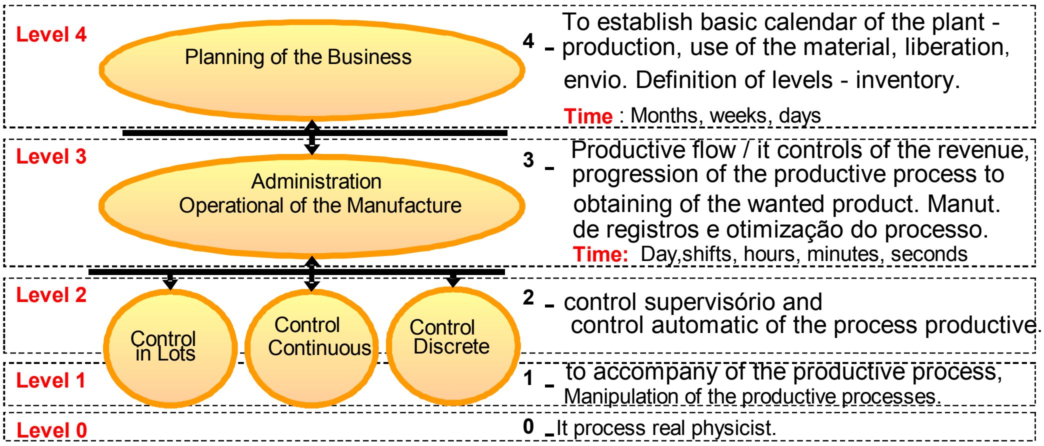


Fig.1 - ANSI ISA S95

2.3 CNC de Arquitetura Aberta.

The CNC of Open Architecture, assists the specifications of the Agile Manufacture, because the requirements allow the integration of modules of programs independent applications, control algorithms, sensor and plates of computers developed by several manufacturers (PRITSCHOW et al., 1993). An Open System has the capacity to program and to work with the software in several different platforms. The controllers of open architecture possess flexible structures in software and in hardware, allowing changes in the basic configuration of the hardware and alteration in the software in all the control levels. (Wright et al., 1996)

Criterion to specify a control of open architecture (Pritschow,G. 2001) :

- **Portability**: application modules can be used on different platforms without any changes, while maintaining their capabilities.
- **Extendibility**: a varying number of application modules can run on a platform without any conflicts.
- **Interoperability**: Application modules work together in a consistent manner and can interchange data in a defined way.
- **Scalability**: Depending on the requirements of the user, functionality of the application modules and performance and size of the hardware can be adapted.

The IEEE defines an open system as follows: "An open system provides capabilities that enable properly implemented applications to run on a variety of platforms from multiple vendors, interoperate with other system applications and present a consistent style of interaction with the user"(IEEE, 1998). A vendor-neutral open control system can only be realized if the control functionaly is subdivided in functional units and if well defined interfaces between these units are specified. Therefore these units are identified as the key for an open system architecture. (Pritschow, 2001) The Proprietary System is "black-box" system and Open System combining modules requires of standard Application Programming Interfaces (APIs).

3. Reconfigurable Machine-Tool.

The reconfigurable machine-tool has a Open CNC and, to better understand it, we will expose below how to assemble this machine in a modular way, so that we can have a flexible configuration. The new assembled module may have a new function. To build a new module one has to combine the base, engine head, fuses and tools and connect the interfaces of the components to the controller. This way we can see this set as a unique block and we will call it a module. The set of modules forms the machine-tool with the required functions. Up to the present moment, only the physical part of the machine has beel built.

3.1 Modules of the hardware in the system

In the figure below, figure 2, the following parts are shows: a base of displacement in the direction Z, b) a base of displacement in the direction XZ, c) the engine, encoder and tool, d) module of displacement XYZ with base of displacement XY, a head engine of displacement in the direction Y, motor spindle, encoders, axe motor, tool holder and so on. e) Module YZ, base of displacement Z, a head engine with displacement in the direction Y, motor of the spindle, encoders, motor axe, tool holder and so on. f) Module Y: one head engine with displacement in the direction Y, motor of the spindle, encoders, motor, tool holder and so on.

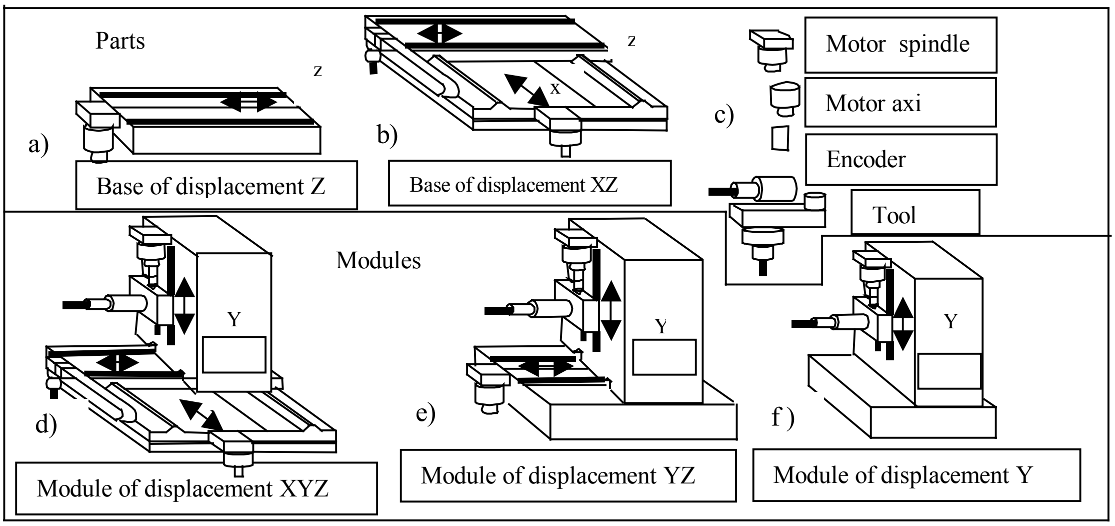


fig.2 - Quadro de Componentes

This way it is possible to select the parts we want to use to make a module. There is a bank of semi-ready modules to be used in case of need. The machine as a whole is formed of various modules as shown in Figure 3.

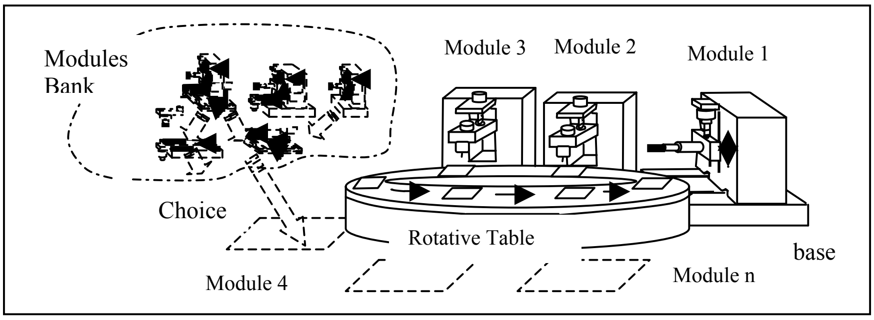


fig.3 Reconfigurable Machine

3.2 Technique to choose physical parts that make part of the hardware of the machine

In this topic we describe how to choose the parts that make the machine-tool. The technique to choose the parts of the module will be based on the analysis of three areas: Process Sheet, Bank of Modules and Production Management.

- Process Sheet – it holds information that refer to the parts that will be worked (for example: material, dimensions, tolerances, finishings and specific information about the part) .
- Bank of Modules – information stored in the computer memory, such as quantity, technical characteristics of the physical equipment available in the Stock (such as fuses, axes, motors, bases, tables, etc)
- Management Production - pieces of information coming from level 3 of S95, which are considered critical to keep the flow of production working (for example: decide which process is behind schedule), resulting in the choice of the process.

Procedure to choose the parts of the module.

There are four steps to choose the module:

Step 1 – via analysing the critical conditions from Production Management, level 3 of ISA S95. After the analysis of the critical conditions, select the respective process sheets.

Step 2 – a technician generates a list of physical tools and sequence of operations to perform the tasks described in the process sheets.

Step 3 – with the help of the list generated in step 2, search the database to have a second list with all the physical parts that have to do with the required characteristic. In this second list there may be more than one component to be allocated in the same place.

Step 4 – in this phase, in case there is more than one component to the same place, an analysis will be performed in order to decide, via cost , (method designation) which component will be chosen.

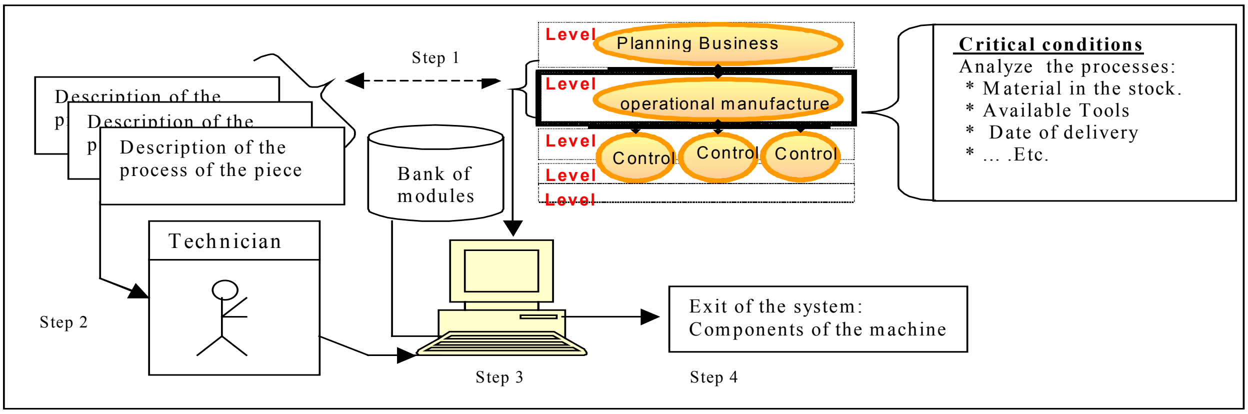


Fig.4 illustration selects only the physical part

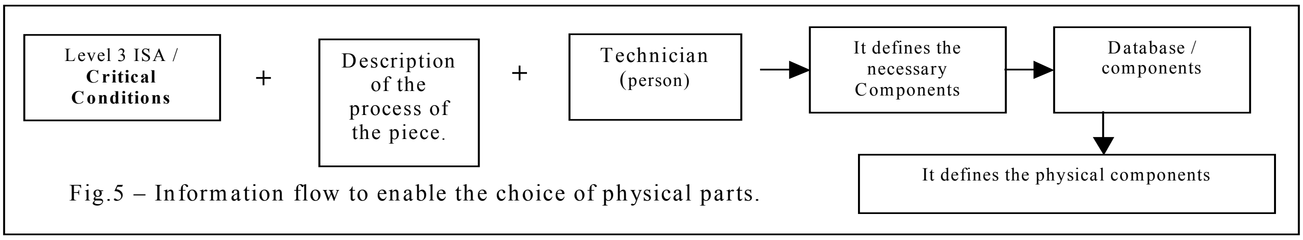


Fig.5 – Information flow to enable the choice of physical parts.

4. Technique to create the software of the machine

In this item we have the library Unit Function (UF) belonging to the database. The Open Module Architecture Controller (OMAC) to Application Program Interface and Norm IEC 61499 for implementation are shown. What can be noticed is that there is not a method that projects the control. In this essay we will use the Norm IEC 61499 and in the Model System to Discreet Event PFS/MFG to develop the project of control of machine-tool.

4.1 Library Unit Function

This function belongs to the open system that enables the generation of new functions. Thus, when a new function is generated, it is enclosed in functional units (UF) and it is stored in the library of UF's. This operation can be developed off line. The meaning of Unit Function (UF) is a block of program that performs a certain task.

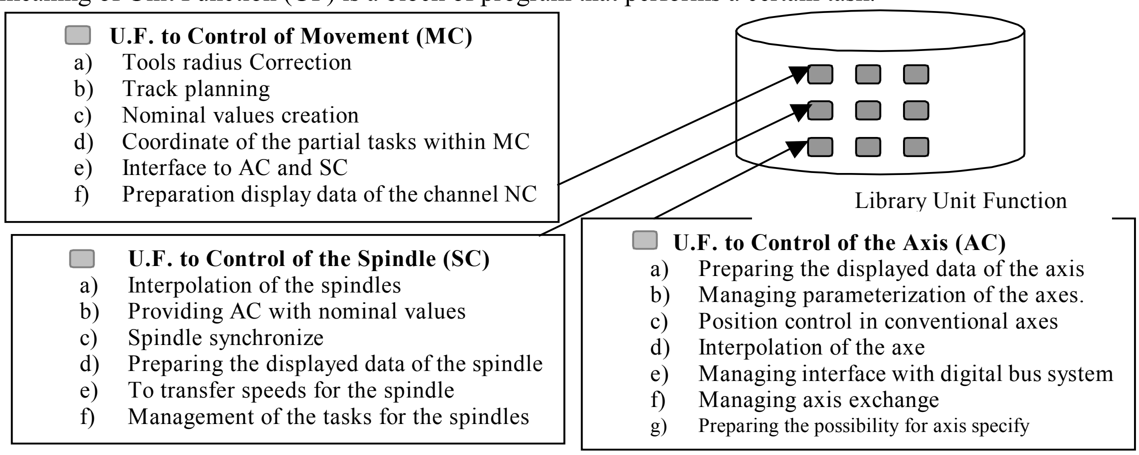


Fig. 6 Example

Library Unit Function

4.2 Open Module Architecture Controller- Application Program Interface (OMAC-API).

The OMAC-API, figure 7, describes the basic services for the integration of components and to analyze the dynamic operation it uses a Machine of Finite State (FSM). The conexion API is the middle of two interfaces: one interface to control the operation and another to connect with other modules.

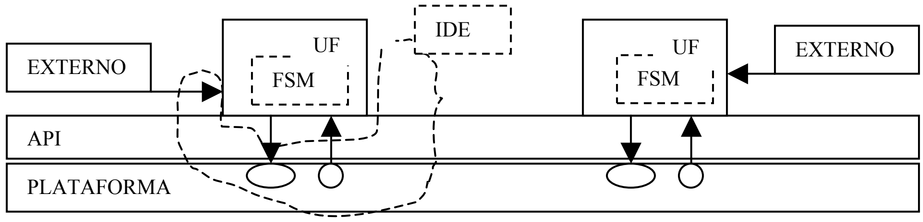
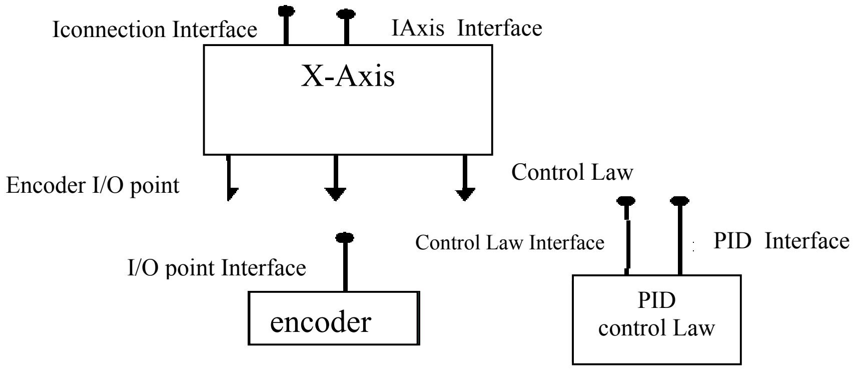


Fig.7
OMAC API

The figure 8 is one example where one wants to integrate a UF of the X-Axis to the encoder and PID Control Law. To set the parameters in the UF it has a global name for a general purpose. When we call the parameters by its global name it is possible to access the reference system with a local name to fill the type of parameters and conexion address.



Global Name	Component	Local Name
“X-AXIS-ENCODER”	“X-AXIS”	“ENCODER”
“X-POSITION-CONTROL_LAW”	“X-AXIS”	“POSITION_CONTROL_LAW”
…	…	…

Local Name	Type	Connected
“ENCODER”	IIOScaledPoint	Y
“POSITION_CONTROL_LAW”	IcontrolLaw	Y
…	…	…

Fig. 8 - Exemple

4.3 Norm IEC 61499

As the UF’s are distributed all over the system of the machine, we will use the Norm IEC 61499 to its implementation. In the IEC 61499 the applications can be distributed among one or more devices. As shown in Figure 9, one application consists of one or more blocks of function, interconnected via event conexions and data conexions. The block of the function may be distributed among devices. In figure 10 the interface of the event (UNIT_EVENT) is shown and the data interface (XIN) connected to the functional block

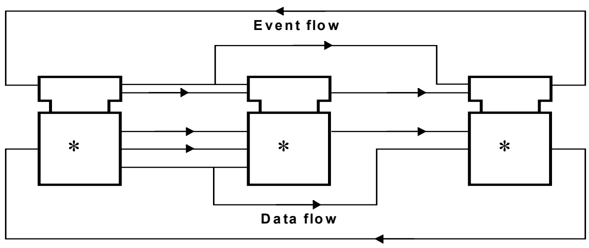


Fig.9 – A distributable application

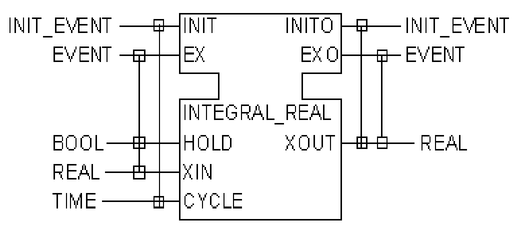
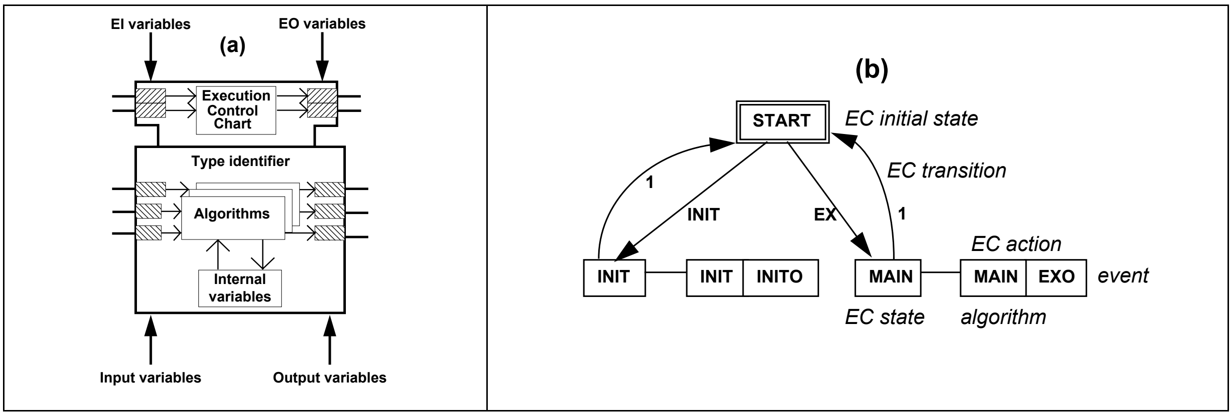


Fig.10 – Function Bloc –FB

Event-driven state machine control of execution: As shown in Figure 11, in IEC 61499 *basic function block types* are defined by declaring: (1) their external interfaces as shown in Figure 10; (2) their *Execution Control Chart (ECC);* and (3) the *algorithms* whose execution may be invoked by the ECC. The ECC may be considered a specialized version of the Sequential Function Chart (SFC) defined in IEC 61131-3, where *EC (event connections) transition* conditions may be expressed as combinations of event inputs and other Boolean conditions. One or more *EC actions* associated with an *EC state* specify the *algorithm(s)* to be executed upon entering the EC state and the *output event(s)* to be issued upon completion of algorithm execution. The algorithms themselves may be expressed in the programming languages defined in IEC 61131-3 or other languages, utilizing the values of input, output and internal variables to produce new values of internal and output variables.



(a) A basic function block type; (b) An Execution Control Chart (ECC)

Figure11–Event-driven-execution-control

5. Modelling of the control

Once the physical parts and their respective programs are defined, it is necessary one can model the control to reach his objectives. The model used will be PFS/MFG adapted to the norm IEC 61499. In this work the used method is PFS/MFG. The Production Flow Scheme (PFS) and Mark Flow Graph (MFG) are shown and a few examples are given.

5.1 Methodology – PFS/MFG adapted to the Norm IEC 61499

The Production Flow Scheme (PFS) (Miyagi, 1996) is used to describe graphically, in general terms, the processes related to the production of items (parts, information, etc), establishing the sequence of the steps in the activity. The PFS consists of : activity elements, distributing elements and arcs of flow, which connect sequencially one to the other. Adapted to the Norm IEC 61499 (Cavalheiro, 2004), it can be described like this:

- Activity Element ([Activity]) : algorithm of the functional block
- Arc (**→**) : flow of data among functional blocks
- Distributing element (**O**) – communication among Functional Blocks

[activity1]→O→[activity2]→O→[activity3]

Fig.12 - Example PFS

Mark Flow Graph (MFG) (Hasegawa, l980, Miyagi et al 1984, Santos Filho, Miyagi 1995) is a net interpreted and derived from the Petri Net to the modelling and control of systems. The MFG is composed basically by the following structural elements: the transitions that indicate the occurrence of events, the boxes that represent the pre and post conditions, the arcs oriented that establish a causal relationship between events and conditions, the doors that enable or impede the occurrence of events and the marks that indicate the maintenance of a condition.

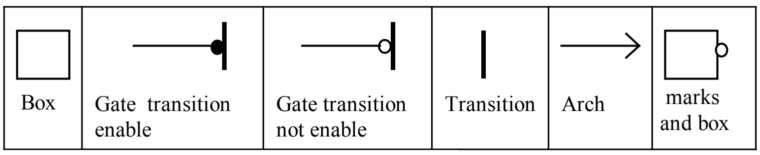


Fig.13 – Element MFG

Examples of control model using the PFS/MFG Methodology it is possible to build models of program that enable the machine-tool to perform a function as required. In Figure 14, below, some models of PFS/MFG are shown

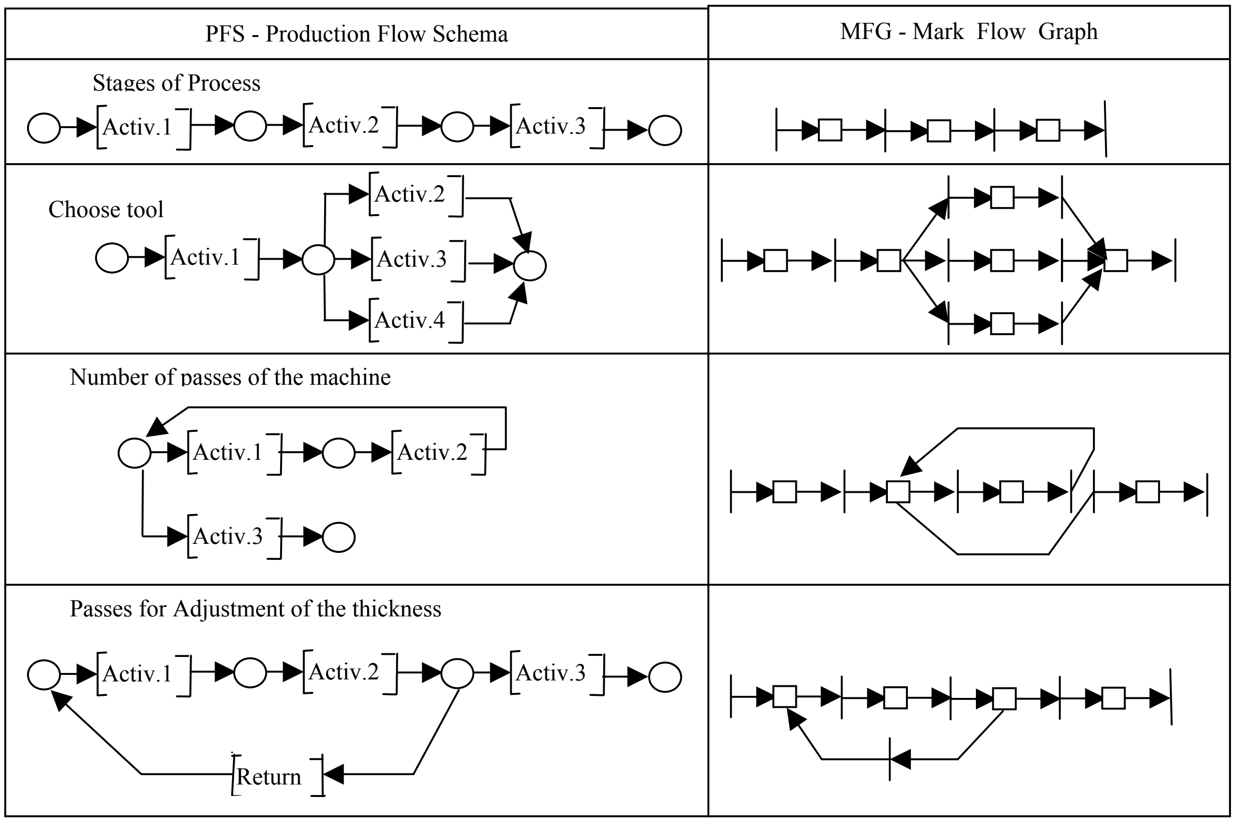


Fig. 14 – Exemples of model PFS/MFG

5.2 Interpretation of PFS/MFG according to the Norm IEC 61499

In the process Event-Driven-execution-control the interface of event is used (Event In, Event Out). The Data Flow passes by the Variable In and Variable Out and application consists of one or more function block instances, interconnected by event connections and data connections. The model MFG is carried in the algorithm of control.

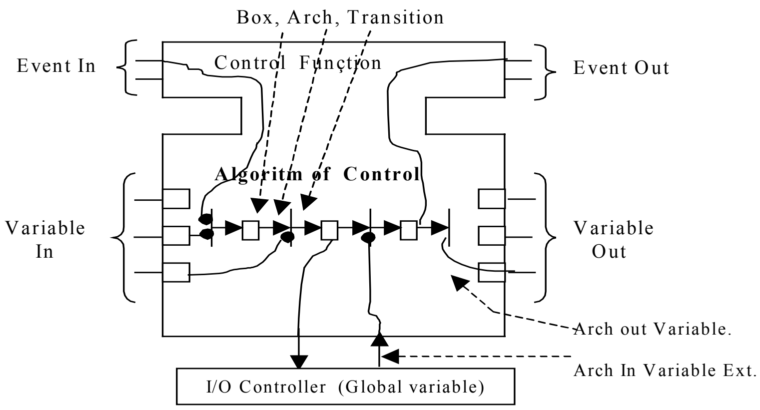


Fig. 15 - MFG applied to FB

Figure 15 shows how an algorithm of control using MFG is implemented to the Function Block. This way, we show that via the PFS one organizes the sequence of activities of the process and via the MFG the dynamic behavior of the system is also shown. The model MFG is adapted to the Norm IEC 61499

6. Conclusion

In this essay the project of control of the Agile Productive System has been developed based on Open CNC Architecture to offer a bigger flexibility, the Norm ANSI ISA S95 for the integration of the higher levels and the modelling of the control through the method PFS/MFG adapted to the Norm IEC 61499 for implementation. The contribution is made clear in the new way of treating the model of control in the level 3 of the norm ANSI ISA S95. This new way appeared due to the increase of flexibility offered by the Open CNC Architecture. The project is not complete; we still have to specify the interfaces of control with the user, control of the Kernel, logical control of the system and a way to validate the project. All these further steps will be the objects of future essays.

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