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Modeling a Numerically Controlled Machine Tool for Integrated Supervision Design

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ABSTRACT

Implementing effective supervision of industrial systems is becoming increasingly difficult due to the increasing complexity of these systems. effective supervision requires sharp monitoring of the different states of the system and its parameters. in order to properly identify the states to monitor we use an analysis function it. For our approach, we will use a numerically controlled machine tool as a study system. In this paper, we propose to conduct a supervision by a methodology based on a functional analysis and a Bond graph modeling.

Keywords: *Supervision, CNC machine tools, Bond graph, SADT, FAST*.

1. INTRODUCTION

The global economy has imposed on industries very strict constraints to be competitive on the international market scale, for this they are forced to face these constraints by the installation of efficient and robust production chains, so having industrial systems are able to optimize production to ensure a high-level functional objective. Industrial systems differentiate themselves from conventional systems (management information systems) by the fact that they control physical installations (production units and chains, water distribution units, ...), and some of them provide functions of the protection of goods and processes.

Industrial Process Monitoring is a computer monitoring and control technique that involves monitoring the operating status of a process to keep it at its ideal operating point [1]. In recent years the supervision has marked a great development thanks to the evolution of the computer science whose aim is to optimize the functioning of the systems and to ensure safety.

Today, supervision is now a fundamental technique integrated within the company, which will help to integrate the production into the control-command, a grouping of a group of data from the workshop with offices, in a direct and healthy way [2]. Thus, each person of the company, whatever its level, can benefit from a direct access in real time to all the data necessary for its work.

In the industrial field, safety represents the guarantee of goods, people and the environment while ensuring the sustainability of the company.

Today and facing the sudden multiplication of industries (chemical, mechanical, electronic, ...) a breakdown or a malfunction can cause a danger see a disaster for machines even for people, for this reason the safety of functioning must to be taken into account and to guarantee this safety, it is necessary to supervise the processes so the supervision is a rather important requirement to ensure the safety of operation and subsequently the safety of the industrial installations [3].

In this study we will use as a support system a numerically controlled machine tool. First, we will make a functional analysis of this system based on the SADT method, the FAST diagram. Once the different functions of the system are well defined, we will use the Bond Graph model for the analysis of the system that will allow us to propose a strategy of supervision.

2. COMPUTER NUMERICAL CONTROLLED MACHINE TOOLS (CNC)

Tools machine is a piece of mechanical equipment intended to perform machining, it's manufacture mechanical parts by removing material from this part to give a desired shape and dimensions, or repetitive tasks with precision and appropriate power [4].

The control cabinet which receives the machining program is known as numerical control, this one underwent several developments, indeed, in 1950 are known in the form of ribbons perform, however in 1970 they become magnetic tape or data providing from computer.

Thanks to the use of CNC technology, machine tools can now manufacture complex shapes without dismantling parts. Indeed, the change of the machining tools is programmed according to the numerical definition of the part; these are in the form of digitally defined files (DDF) which represent computer files generated by a computer-aided design (CAD) and which replaces the technical file. These definitions have to be computed by computer-aided manufacturing (CAM) software, then software called "post processor" processes all these steps so that they are understandable by numerical control (NC) it is the programming of the NC.

In this manuscript we focus our work into modelling and real-time simulating the workpiece support of CNC machine

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tool using the Bond Graphs method in order to successfully establish an integrated supervision design model.

This machine consists of two parts:

- Control part for the programming of the machining and the display of the general instrumentation plan for the supervision.

- Operative part for machining workpieces

Our system is composed by an electric motor driven through a gearbox, screw / nut, a table-holder moving horizontally. The motor is powered by a voltage and the table is marked by its position Pos(t) [5].

following figure shows the components of the system.

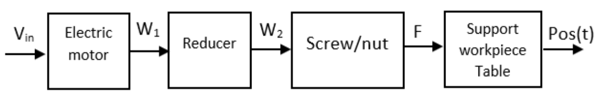

Fig. 1. Presentation of support workpiece table

With :

- V_{in} is the supply voltage of the system;
- W_1 is the motor rotation speed;
- W_2 is the motor rotation speed after reduction;
- F is the table moving force;
- Pos(t) is the table position.

PROBLEMATIC

In the industrial field, safety is the guarantee of goods, people and the environment while ensuring company sustainability.

Industries continue to develop and diversify (chemical, mechanical, electronic, ...) a breakdown or a malfunction can cause a danger for machines and even for people. In order to avoid critical situations, the safety of the industrial systems should be ensured and guaranteed. This can not be done without a powerful supervisory process.

3. ANALYSIS METHODOLOGY OF MECHATRONIC SYSTEMS

We propose in this part an analysis and modeling methodology for our system based on the external and internal functional analysis method, using the methods of APTE and SADT and the Bond Graph method for supervision [6] [7].

In the first phase, we apply the external functional analysis method "APTE", it is necessary to determine: the needs to be satisfied, the main functions as well as the component functions in order to formulate finally an explanatory octopus' diagram.

In the second phase, a modeling and internal functional analysis will take place, we will apply the SADT method which is characterized by a top-down and modular analysis to facilitate the complexity of any process, after which we will deduce the FAST diagram. from the SADT method. Several steps are achieved in this phase; the first one is preparing SADT model to define the objectives and point of view for which the model will be created. Then we create the A-0 diagram which represents the main function to analyze in an actigram. Then from this diagram, we try to explode the less clear box to get more information to create "Ai" diagram with (3 <i <6). Secondly, we apply the same decomposition principle for the other diagrams to be able to represent all the diagrams of the SADT model. Finally, we will finish this step by developing the FAST diagram of our machine studied.

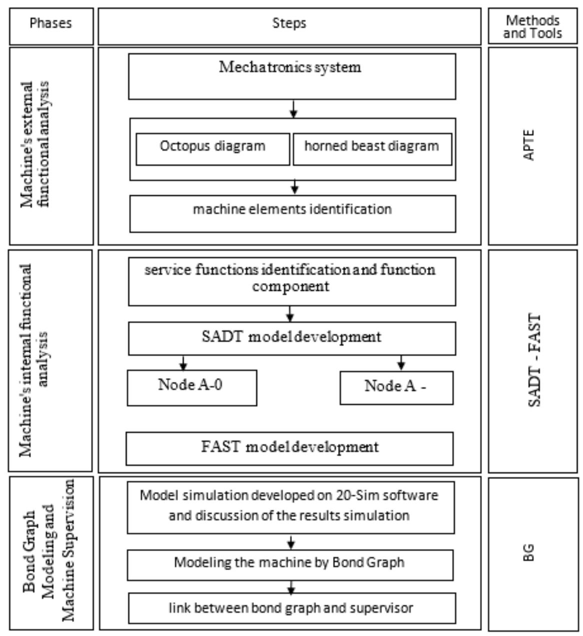

Fig. 2. General methodological mode

In the third phase, the Bond de Graph method will be applied to supervise the studied system as a multidisciplinary, efficient and accurate modeling method. We will use the 20-sim software for model simulation and generate the equations associated with each junction and finally study the relationship between Bond Graph tool and the monitoring.

4. CNC MACHINE ANALYSIS

A. CNC Machine presentation

CNC machines are partially or fully automated machines. The movement orders of the various organs are given by programming. In particular, the successive positions of the tool relative to the part are expressed in digital form. Figure 3 shows an example of CNC machine.

Fig. 3. example of CNC machine

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The control part (PC) consists of a computer. It allows to control the different movements of the machine, it can also inform operator on the machining progress. The operative part (OP) performs the machining, receives the commands from the control part and executes them. The operating principle is simply a succession of CAD file generation; it involves drawing the workpiece on a specific software and generating FAO files; this step includes information about the machine (type of machine), tool (nature, diameter, shape, ...), machining conditions (cutting speed, feedrate, number of passes and depth , ...), origin of the workpiece (starting point on the table).

The last step is machining; put the tool in place, immobilize the workpiece, carry out the machining cycle which includes the positioning on the workpiece origin and the realization of the machining [8].

B. SADT analysis

In this part we present the analysis of the MOCN by the SADT method. Figure 4 presents a functional analysis by the SADT method of a numerically controlled machine tool. The developed activity diagram or actigram has made it possible to create or generate data at the output (machined part, burrs, noises ...), to transform or modify or change state an input data (non-machined part), and to solicit the input data from control directives, relying on the potentialities of the mechanisms (electric motor, gearbox, screw-ecru, ...) [9].

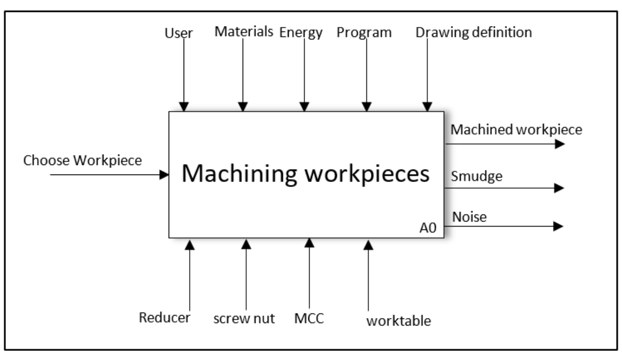

Fig. 4. Node A-0 of the MOCN SADT Model

The goal of the SADT model obtained is multiple: the SADT model will make it possible to formalize the state of the studied system, as shown by the two nodes presented, and to reveal the complexity of the system.

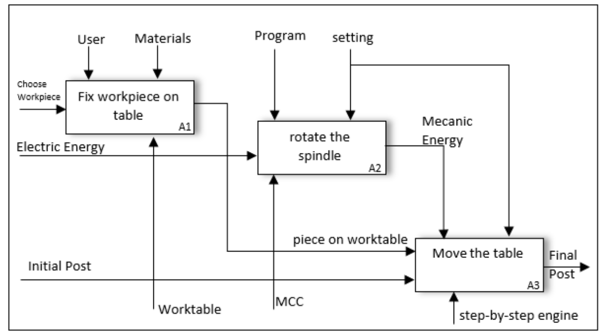

Fig. 5. Node A-0 of the MOCN SADT Model

The principle of a descending decomposition is at the root of most structured methods. An approach often followed in the context of the realization of an information system leads to the realization of four models (existing, ideal, feasible and future) whose focus is on the specification of "What? And on the information, the objects he exchanges, could exchange, can exchange or exchange.

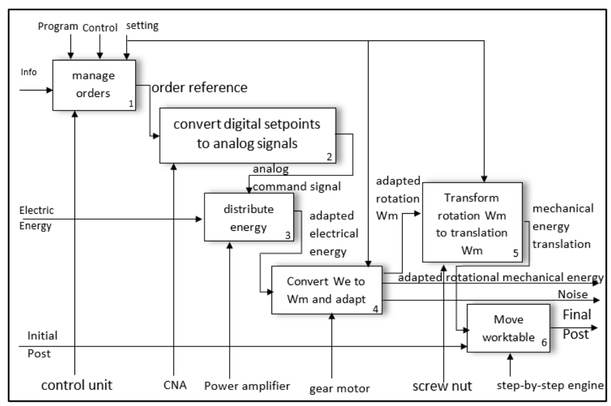

Fig. 6. Node A-3 of the MOCN SADT Model

The figure above represents and explains the interactions between the various functions of displacement of the workpiece table of a numerically controlled machine tool starting from the management of the orders of order until being able to move the workpiece table to perform the correct machining of the loaded part.

C. Fast Analysis

After having presented the SADT diagrams relating to our machine, we propose in this part a functional analysis by FAST method presented in figure 7, this method makes it possible to translate each function of service into technical function (component) then materially into constructive solution by interrogative logic as shows next figure:

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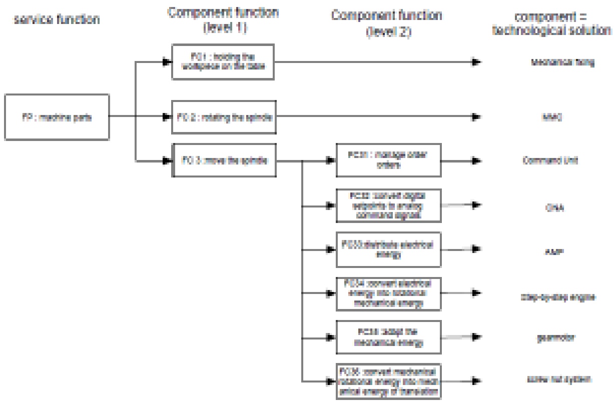

Fig. 7. FAST Model of MOCN

All these methods of functional analysis gave us an explanatory modeling of the studied system which will facilitate the validation of the proposed model of analysis and supervision.

D. Bond Graph Analysis

The bond graph tool is a graphical method for multidisciplinary modeling of dynamic systems. Its main interest is to make the link between different components of a system of very varied natures, and often governed by nonlinear equations and sometimes difficult to model. This tool highlights the relationships between flows and efforts of systems combining mechanical, electrical, thermodynamic, thermal, energy, etc. It is therefore very suitable for mechatronic systems [10] [11].

In our study, we will model and simulate the workpiece part of a numerically controlled machine using the BG method to arrive at a model for the integrated supervision design [12] [13]. This machine consists of two parts:
- Control part for the programming of the machining and the display of the general instrumentation plan for the supervision.
- Operative part for machining parts.

An electric motor drives via a reduction unit, screw / nut a horizontal workpiece table. The motor is powered by a voltage and the table is marked by its position.

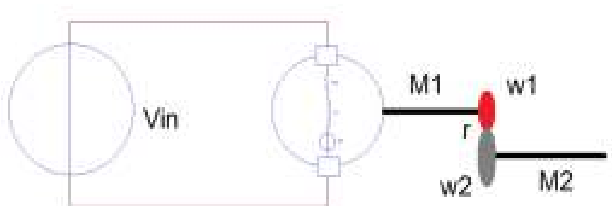

Fig. 8. DC electric motor coupled to a reducer

The following figure illustrates the bond graph model of CNC machine tool made with the 20-sim software:

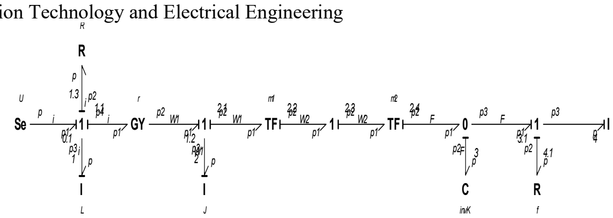

Fig. 9. Bond Graph model

This bond graph model makes it possible to analytically set all the equations of the system without reducing the causal path according to the rules of the junction elements and the rules of allocation of the causalities.

E. Supervision with Bond Graph tool

In recent years, research on diagnosis has mobilized a large community of researchers in different fields. Indeed, monitoring algorithms are based on principle of redundancy of information sources.

Redundancy is obtained by comparing real data from the process and theoretical data provided by a type of model (prior knowledge), comparing real data (transmitted by the sensors) and theoretical data (provided by a prior knowledge on the system) makes possible to verify that the information obtained at a given moment remains in accordance with normal operating standards (or within the fixed limits of tolerance) [14]. This step necessarily implements data from all modes of operation. Supervising the system requires several steps, an alarm detection phase and an alarm confirmation phase and the localization of the fault.

BG's analytical redundancy relationship generation for diagnostics consists in eliminating unknown variables in an observable subsystem [15]. On a bond graph model, the observability can be verified using the structural properties. The known variables K are those of the detectors and the sources and the unknown variables X are those of the power links in the elements C, I and R. L The elimination of unknown variables is systematic on a bond graph model thanks to its causal properties and the path of the causal paths.

In what follows, the approach developed consists in algorithmically and systematically generating the Analytical Redundancy Relationships, the corresponding residues and the failure signature matrix.

In a representation by BG, the relation relating to the definition of an analytic redundancy relation is :

$$f = (De, Df, Se, Sf, MSe, MSf, \theta m) = 0$$

With θm, all the measured or estimated parameters of the system.

In what follows, we present a method to algorithmically and systematically generate the RRAs, the corresponding residues and the failure signature matrix. The following algorithm generates RRAs systematically from a bond graph model [16] [17]. Here are, in order, the steps to follow:

1- put the BG model into preferential derivative causality (by reversing the causality of the detectors if possible).

2- Write the equations of the model obtained.

3- for any junction equation 0 and 1 containing at least one detector:

- eliminate unknown variables by traversing the causal paths on the bond graph.

- for any detector whose causality is reversed, an analytic redundancy relationship is deducted.

for any detector whose causality can not be reversed, an analytic redundancy relation is deduced by equating its output with the output of another detector of the same nature (hardware redundancy).

4- An analytic redundancy relationship is obtained from each controller by comparing its measured output with the output predicted by its control algorithm.

5- repeat steps 3 and 4. If the analytic redundancy relationships obtained are strictly different from those already obtained then we keep them, otherwise continue until all the equations of the junctions and those of the regulators are explored.

5 CONCLUSIONS

In this paper, we presented Bond Graph modeling as a new integrated approach to mechatronic systems supervision. Indeed, the classification criterion of monitoring methods distinguishes between two approaches types: methods with or without model. Our contribution relates to model-based methods using the Bond Graph tool.

Bond Graph tool, by its structural and causal properties on the one hand and by its multidisciplinary character for the realization of models in a generic way on the other hand, is thus introduced in mechatronics for analysis and monitoring of processes.

As perspectives of this research work, we plan to use functional analysis methods for study of numerically controlled machine tool as it allows to highlight the potential failures that a mechatronic system may encounter. Another perspective concerns the computer tool used to facilitate future use of our methodology in an industrial context, it is necessary to use a tool which facilitates supervision by a simple placement of sensor and thus to locate more simply source of the failure.

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Mohamed Fathi karoui obtained his engineering diploma in instrumentation and industrial maintenance at the INSAT of tunis in 2002, the master in production and logistics at the University of Lille in 2003 and the doctaurat in automatic and industrial computer science of the university from Grenoble in 2011. he is currently teaching researcher at the national school of engineering of Carthage and member of the Research Laboratory Smart Electricity & ICT, SEICT, LR18ES44 of ENICarthage.

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