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Indirect predictive monitoring in flexible manufacturing systems

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Abstract

In this paper, a new method of monitoring of failures in flexible manufacturing systems (FMS) is developed. The main objective is to manage progressive failures in order to avoid breakdown state for FMS. To achieve these requirements an indirect predictive monitoring approach is proposed. The main ideas of this approach are first to follow the state evolution of the resources indirectly by the perturbations on the manufactured products. The parameter used is the production flow for which a drift rate indicator is defined for each of the family. Detection and diagnostic methods based on the on-line exploitation of the drift rates are presented in this paper. Another idea developed is the necessity to integrate different approaches of monitoring to obtain a global management of failures. For this purpose a functional framework of integrated monitoring in the control command of an FMS is proposed.

Keywords: Flexible manufacturing systems (FMS); Predictive maintenance; Indirect predictive monitoring; Production flow; Failures; Drift rate; Detection; Diagnosis

1. Introduction

The actual evolution of flexible manufacturing systems tends towards just in time by production control strategies enabling the elimination of excesses, rejects and variations. However, the occurrence of failures during the exploitation stage can deeply modify the FMS performances [1] or its availability. Since 10 years the L.A.I.L is interested in developing methods to manage the failures of FMS processes. The work developed in the field of monitoring of FMS is a part of a global project to develop methodologies to assist the design of FMS control/command: it is CASPAIM project [2].

Traditionally, two types of failures are considered in dependability: *cataleptic* and *progressive* failures. Cataleptic failures are failures that cannot be detected by process inspections achieved by maintenance operators; they are sudden and complete. According to their impact, they induce immediately a breakdown state of the faulty components or system. At the opposite, progressive failures characterise degradations occurring in a process. Consequently, they are partial. Their evolution can be followed and recovery actions [3–5] can be performed before the breakdown state is reached.

FMS are a type of discrete event systems (DES). Also, many authors have developed monitoring methods to manage complete failures [6,7]. Indeed, complete failures are characterised by the occurrence or the non-occurrence of events that can be handled by traditional tools used to model DES. Some authors propose approaches based on petri nets [8–10]. The formalism of causal temporal signatures (CTS) has been developed at L.A.I.L. It is based on the exploitation of a temporal graph [11]. In spite of some good results given by these different methods, it is important to notice that some of the failures might be treated earlier because they are progressive failures. Hereafter, these approaches are grouped under the name of *curative monitoring*. To integrate progressive failures, a new approach has been developed at L.A.I.L. The monitoring of progressive failures enables to predict the evolution of the failures. It is an approach suitable to apply a predictive maintenance policy. Consequently, hereafter, it will be called *predictive monitoring*.

Traditionally, the methods used to manage progressive failures are based on a continuous acquisition of signals sent by the surveyed process. This type of acquisition requires a specific instrumentation of the process. Indeed, sensors specialised in the monitoring and the acquisition of some types of signals are placed in the process.

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Generally, there are: noise sensors, thermal sensors, vibration sensors, etc. This approach of monitoring is called predictive monitoring because it is part of a predictive maintenance policy. It is generally suitable to continuous process because they naturally generate continuous signals. This approach can also be applied for the monitoring of some parts of a single machine tool: in this context it is a *resource approach*. However, since DES do not generate continuous signals but events, this approach cannot be applied systematically to FMS. One could think that it would be possible to survey each resource of a FMS by a resource approach. Two reasons can be invoked against such an approach:

- The resources used in FMS are generally not instrumented to implement it, so the cost can be important;
- In an FMS, the interactions between resources caused by the parts flows can induce failures that cannot be identified by a resource approach.

For these reasons a *system approach* of predictive monitoring suitable to FMS is required. Such an approach is proposed in this paper. It is an indirect approach with regard to the traditional one renamed *direct predictive monitoring* (It is the new name used to define the traditional predictive monitoring).

The paper is divided into three main sections.

The problem of monitoring in FMS is presented in Section 2. The control/command context is first described and the monitoring function is developed. The definition and structuring of monitoring for FMS regardless of CASPAIM project are also recalled.

The *indirect predictive monitoring* approach is developed in Section 3. The basic idea is that the resource failures of the FMS have consequences on the parts produced, in this case parts quality or quantity. A theory based on the perturbation of parts flows with regard to the planned flows is developed in Section 3. To confirm the applicability of indirect predictive monitoring, a valuation part is given in Section 4.

2. The problem of monitoring in FMS

The objective of this part is to explain the function of monitoring in the control/command of an FMS. First, monitoring is defined with regard to the other function of the control/command. Second, it is shown how monitoring works from an internal point of view.

2.1. Context definition

In the organisation of a production system according to CASPAIM project, the control/command has five main functions: maintenance, planning/scheduling, supervision, co-ordination control and monitoring (Fig. 1).

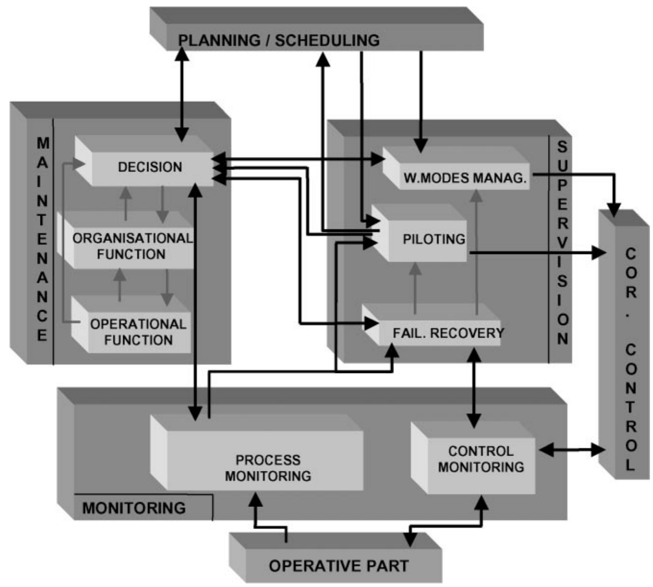

Fig. 1. Organisation of control/command according to CASPAIM.

- *Maintenance* [12]. The goal of Maintenance is to perform the maintenance policy defined for the system. In FMS context, three maintenance policies can be applied: curative maintenance, systematic maintenance and predictive maintenance. Curative maintenance consists of the reparation or the changing of breakdown components. Systematic maintenance consists of regular inspections and maintenance actions according to dependability parameters such as MTBF. Predictive maintenance consists of an anticipation of breakdown states by following the state evolution of the resources and by repairing or replacing some components when required.

  To establish the production plan, planning/scheduling must know the available resources on the considered period of production. This information is given by maintenance according to the requirements of the systematic maintenance, taking into account the failed resources.In this approach the maintenance module is structured in three sub-modules: the decision module, the organisational module and the operational module. The decision module is the heart of the maintenance function. It interacts with planning/scheduling and supervision to give them data required for self-decisions. The organisational module manages maintenance aspects such as component supply. It establishes the maintenance plan for a period and transmits it to the operational module for execution.
- *Planning/scheduling* [1]. It is an off line task. It defines and distributes the objectives of manufacturing (production ratios, quality, and delay) on a production