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Towards the control of product quality from the process deviation monitoring: Overview and investigation in automotive sector

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Abstract: Key performances of industrial systems can be characterised by performances both related to the system itself but also the product/service it is delivering. It can be particularised in the manufacturing domain, by the performances related to the part manufactured (e.g. dimensional deviation, surface roughness) and to the machining centre (e.g. productivity, availability). The mastering of these two types of performances is nowadays mostly considerate separately, in the sense that current approaches lead to control product or machine performances mainly in an isolated way. Only few approaches try to take them into account jointly to permit to control performances of one thanks to the control of performances of the other and this all along the time. Thus a challenge in manufacturing is to be able to control part deviations from the mastering of the machining centre degradation. In that way, this paper is first proposing a review on current approaches able to support these two performance considerations and then to investigate scientifically, in the frame of automotive sector, a specific approach able to control part performances directly from machining centre performances.

Keywords: machining centre performance, product performance, maintenance decision making, health monitoring, part quality

1. INTRODUCTION

In the field of industrial systems, continuous control of system performances is a necessary requirement to face economic issue, particularly to ensure enterprise survival. These performances can be related both to the production system itself through its features and operating conditions and the product/service it is delivering (Liu 2013). This dual consideration of performance leads, in the manufacturing domain and in automotive industry (context of this R&D work), to focus both on the quality of machined part (e.g. dimensional variation, surface roughness) and on the effectiveness/efficiency of machining centre (e.g. productivity, availability) which is manufacturing these parts. The relationships between these two types of performances is not so simple to be mastered due to a lot of influencing variables occurring along the system operation and the system life cycle. For example, as the machine gets old, some deviations of machine characteristics are appearing implying to reconsider machining parameters in order to preserve quality of machined part constant. Moreover, product quality deviation is often resulting from combined degradations of several system components (Cocheteux et al. 2010). Indeed, health state of each component (individual view) could be seen not critical for the component itself but combination of these degradations can lead to deviation of the product parameter. In automotive sector, machining centre plays a central role in the production systems and are the target of the proposed study. Hence, as an anticipating strategy, controlling the quality of machined part from the machining centre degradation is a real challenge (Lu et al. 2016) in automotive sector.

Indeed at this time, the mastering of these both types of performances is not really done in synergy. It is mainly supported by sectorial approaches treating one type of performance (with an isolated view) but rarely the two together (with an integrated view). In fact, product quality control is generally performed by statistical approaches, e.g. statistical process control (SPC) or statistical quality control (SQC) techniques, and developed a posteriori i.e. after the part machining. Hence, when insufficient part quality is detected, a consequent number of machined parts is wasted and production time is lost in order to reconfigure machining centre parameters. It is resulting an important direct (non-conformed part) and indirect (production breakdown) costs.

In addition, to sustain the machining centre performances in an operating domain as close as possible to the nominal one, several maintenance plans have to be deployed. Even if these plans are solving the degradation or failure that may occur (machine point of view), a lot of maintenance actions are not optimal with regard to the impact they have directly on the product features.

To face the integration of these two types of performances, considered usually as isolated, few approaches are proposed. For example, (Colledani & Tolio 2009) search to estimate machine performance through SPC techniques, but do not tackle the limit caused by sampling inspections. (Bhuiyan et al. 2014) demonstrate a relationship between acoustic emission and surface roughness, then vibration emission and tool wear, during machining. (Jain & Lad 2015) consider the relation between wear of the cutting tool and the machined

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surface roughness. Nevertheless, most of the resulting models proposed are component-oriented with difficulties to obtain performance at the machine level, i.e. considering the interaction of several components. Moreover, they are usually specific to an application case (Lee et al. 2014), (Lu 2008).

Thus, current integrated approaches underline limitations in terms of (a) the consideration of the performance at the system level and not only at component one, and (b) the maintenance plan optimization to keep acceptable product performances from maintenance action on a component and to enhance machine availability before non-quality occurred. These limitations are really a weak point in car manufacturing where lacks in product quality have important impacts not only on productivity and profit but also in safety for the final customer.

Consequently, the research question addressed in the paper is the following:

Is it possible to develop a formalized and efficient approach to control the performances (and their deviations) of the machined part directly from the control of machining centre performances (and its degradations)?

The main result expected by using such approach is to be able to obtain a required product quality as output by controlling the machine performances. It should allow to drastically reduce, or even delete, a posteriori quality control. This research question requires, in the frame of manufacturing domain and more precisely the automotive sector, to review respectively control of machine performances and control of product performances, then to formulate some issues related to a joint mastering of these two types of performances, enabling finally, to construct an integrated approach answering to these issues.

In that way, the paper is structured as follow. Section 2 propose a first overview of isolated approaches related, first, to mastering of machine performances and, second, to mastering of product quality performances. It allows to explore, in section 3, integrated approaches that support these two types of performances jointly. From these overviews, issues are then identified regarding applications in automotive manufacturing sector. These issues are reused in section 4, for investigating the main items of an integrated approach that could further lead to ensure by means of the control of machine performances, the control of product quality. This section is referring to a specific industrial application which is the initial working situation, i.e. GROB machining centre of cylinder block production line, at Renault Cléon factory (France). Finally, section 5 proposes a conclusion and further perspectives.

2. OVERVIEW ON MACHINE PERFORMANCES AND PRODUCT PERFORMANCES

Manufacturing system performance, mainly in automotive sector, is characterized by several factors. For example, (Chao et al. 2007) expressed that these performances are composed mainly with reliability, productivity, scalability, convertibility, quality and cost factors. In additional view, (Jayaram et al. 1999) identified human resource management as key factor impacting cost, quality, flexibility and time performance. These orientations are synthetized by (Liu 2013) on three main performance axis: time performance, quality performance and efficiency performance. Time and efficiency considerations are really focused on machine performances while quality item is more related to product performance.

2.1 Machine performances

Performances of machining centre is seen most of the time as availability and productivity (Tobon-Mejia et al. 2012). In addition to these type of performances based on conventional view, emergent performances related to sustainability such as energy and resource consumption are proposed by (Li et al. 2012). The providing of these performances from raw data monitoring is based on a chain of activities, mainly synthetized by (Baglee & Jantunen 2014) in terms of a sequential process: sensing and data acquisition, data processing and feature extraction, elaboration of indicators, then performances, performances prognostics and finally aided decision-making from the performances tracked.

At the first step, data monitoring on machining centre is based on monitoring of representative data of critical components e.g. bearing, gear, shaft, pump, alternator (Lee et al. 2014). Many investigations consider also the tool as “a component” of the machine (Tobon-Mejia et al. 2012). Monitored data of these components are mainly related to vibration signals (Goyal & Pabla 2015), acoustic signals (Caesarendra et al. 2015), (Papacharalampopoulos et al. 2013), temperature and cutting forces (Lauro et al. 2014), (Sikdar & Chen, 2002), defining items on status of the component itself but also on the health of the machine taking into account contextual parameters, such as the load (Li, 2002), the features of machined product, etc.

In order to extract interesting features which can be in further step interpreted regarding the performance state or the health of the machining centre, input signals have to be processed. Nevertheless, they have to be most of the time pre-processed by means of filtering techniques (Teti et al. 2010) in order to remove non-interesting “information” such as noise, artefact. Relevant features can then be extracted supported by signal processing techniques conditioned by the type of data collected in relation to its value, waveform and multidimensionality (Jardine et al. 2006). In order to improve the robustness of this step, signal processing methods may be coupled (Lei et al. 2008).

Once relevant features are extracted, data interpretation process allow the assessment of machine indicators. Two methods are generally identified: model-based methods and feature-based methods (Goyal & Pabla 2015). Current methods of performance assessment are even more precise and able to detect small deviations from nominal conditions (Singh & Zhao 2015). Then, assessment of future state of performance go further by its anticipation which permit to prevent deviation leading to loss of performance outside the authorized operating limits. Generally component oriented, these processing are widely developed in link to specific component and/or usage, limiting their use on other industrial domains. Nevertheless, generic methodologies are investigated to face that issue. For example, (Lee et al. 2014) present a facilitated approach to help determining the proper algorithm, based on prediction