Robotics and Computer-Integrated Manufacturing 34 (2015) 70–78

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Machine tool capability profiles for representing machine tool health

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ARTICLE INFO

Article history:
Received 5 January 2013
Received in revised form
10 March 2014
Accepted 12 November 2014
Available online 4 December 2014

Keywords:
CNC
Machine tools
Resource information modelling
STEP-NC
Machine tool testing standards

ABSTRACT

Control charts at present are used to provide statistical representation of machine tool health. These charts are based on machine tool testing standards, for example ISO 230, ASME B5.54 and VDI 3441, and can be utilised to decide a particular resource's level of utilisation during manufacturing execution. Although these standards provide an indication of machine tool accuracy, they do not provide any mechanism to exchange and use health information within these control charts to identify whether a particular machine is performing to the desired level of capability and whether that machine is healthy. It is only after control charts are manually interpreted, that machine tool selection decisions can be made. This paper reports research that exploits and extends an ISO 14649 (STEP-NC) Part 201 and Part 200 series (Machine Tool Data Model) for representing machine tool health data. This provides a new approach for representing statistical machine tool accuracy information while maintaining the compliancy within prevalent machine tool testing standards. A data model for representing machine tool health based on capability profiles has been proposed. A case study of machine tool showing the interpretation of a control chart with proposed data model has been utilised to represent machine tool health through capability profiles.

1. Introduction

Machine tool selection for the manufacturing of high value products such as aero-engine turbine blades and structural components requires accurate and up-to-date knowledge regarding machine tool health. The manufacturers of such high value components must monitor their manufacturing resources, specifically machine tools, in respect of accuracy and positioning errors to be able to avoid any unaffordable non-conformance during manufacture. Currently, turbine blades are manufactured in batches on dedicated machine tools. Every batch pertains to different blade geometry, and this influences resource selection, the way in which machine tools are selected, configured and optimised depending up on the blade geometry to be machined. Machine tool selection is time-consuming, knowledge intensive and a real-time information based activity, which exerts tremendous responsibility on manufacturing engineers to utilise and maintain instantaneous knowledge regarding machine tool capability for making informed decisions [1,2]. This implies the first step in making informed machine tool selection is generating information regarding machine tool capability.

The subsequent aspect in making this informed decision is identifying which information needs to be analysed for selecting an appropriate machine tool. A typical turbine blade manufacturing facility may consist of several in-house machine tools or a discrete supply-chain manufacturing network. Thus, for selecting an appropriate machine tool, a decision maker needs to evaluate a large amount of capability information regarding available machine tools. The state-of-the art machine tool testing and verification standards provide valuable guidelines for making such decisions. They provide plenty of machine tool verification techniques required to express the health of the machine tool along with informative attributes for representing machine tool health with statistical control charts. However, they do not provide any guidelines on the structure of these informative attributes to store, use and exchange this machine tool health information digitally within the supply chain to help make informed decisions [3]. Thus, currently there is a lack of a standard format or procedure to the store this capability information, which is complicating the machine tool selection process.

Today, refurbishment of turbine blades demands re-machining facilities within the supply chain as it is estimated that around 25 million blades will need to be refurbished over the next decade [4]. Machining of such legacy components does not only requires a machine tool with known capability data, but also a resource selection and accuracy estimation tool with a provision of recognising machine tool health information constructs associated with control charts. In order to develop this decision making application,

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http://dx.doi.org/10.1016/j.rcim.2014.11.002
0736-5845/

a data model is needed to structure health information constructs provided in prevalent machine tool testing standards, so that this data can be stored, accessed and exchanged throughout the supply chain. In addition to the above merits, the machine tool health data model can be utilised for maintenance and quality control applications throughout machine tool's operational life span.

In this paper, the STEP-NC [5,6] compliant methodology for representing machine tool information [7] is extended to represent machine tool health. Information requirements to represent machine tool health are derived from the established machine tool testing standards. A data model for generating machine tool verification profiles is proposed, which consolidates various machine tool testing and verification approaches commercially available on the market. This data model enables representation of machine tool health parameters in a STEP compliant format [8]. A case study is presented to highlight the advantages of implementing the proposed data model. Further avenues for enhancing the applicability of the proposed information model are discussed along with possible options for extending the current research.

2. The state of the current technology and standards

2.1. Machine tool health elements

The machine tool's capability can represent an instance of machine tool's health, and this can be represented with information regarding geometric errors, positional accuracy, repeatability, etc. There are two broad approaches [9] namely “error avoidance” and “error compensation”, which can be utilised to maintain machine tool's health throughout its operational life cycle. The prior is deployed mainly by machine tool manufacturers, at the stage of assembly, whereas later is adopted during operational life span. Since the primary objective of the proposed data model is to develop a consistent data model for representing machine tool capability throughout its working life span, mainly information required for compensating the above errors are considered within the scope of this work. Fig. 1 summarises different aspects for machine tool health information covered in prevalent standards.

2.2. Machine tool testing and verification standards

A wide range of machine tool testing standards have emerged as a result of establishing machine tool acceptance criterion on the global market. A machine tool's geometric accuracy and repeatability are now considered as core descriptors of a machine tool's health, and thus defines the machine's expected level of performance [10]. Consequently, most prevalent machine tool testing standards depict; (i) elements of machine tools errors, (ii) methods and test procedures for identifying these errors, (iii) a methodology to evaluate machine tool positional accuracy and repeatability and (iv) guidelines for representing health parameters. In addition to the above health parameters, standards describe various methods of testing machine tool performance and detailed guidelines on presenting the corresponding health check results. Adhering to the fact that the current scope of ISO 230 series standards underpins VDI/DQG 3441 and ASME B5:54 standards, prior has been discussed with relevant details. Although a number of standards and guidelines now exist outlining how to evaluate machine tool positional accuracy and repeatability, they differ in their analysis procedures and in key parameter definition.

2.3. Enabling technologies

A range of machine tool testing technologies are available on the market to verify a machine tool's health. These technologies can be classified according to their capability to identify machine tool errors, and can be divided into two main categories, namely (i) individual error identification and (ii) combined error identification [9]. Individual error identification methods isolate single geometrical errors described in Fig. 1, Generally, successive tests are then used to quantify each geometrical error in turn although it may be possible to run tests simultaneously. Tests for combined error effects determine the combined effect of multiple geometrical errors which gives a good indication of the overall health of a machine tool. Simultaneous error parameter determination involves initially carrying out tests, then applying sophisticated best fitting algorithms to determine the value of each geometrical error responsible for the combined errors. Individual error identification methods involving successive tests are likely to be too slow for rapid verification although systems allowing simultaneous tests to be carried out may be of relevance. Tests for combined error effects are typically used for verification purposes. Simultaneous error parameter determination is an emerging state of the art method that may be appropriate for both calibration and verification. Although they possess diverse approaches in identifying machine tool health parameters, errors are represented according to the guidelines described in standards.

Although standards clearly specify “how to evaluate machine tool's health”, “what machine tool health parameters should be reported on the test report” and provide guidelines on how to represent machine tool health by using charts/graphs, they do not provide any guidelines on the structure of the information to construct these graphs or charts. Thus, technology providers have adapted proprietary information modelling methodologies, resulting in non-interoperable machine tool health information in a variety of formats. Additionally, this information is available in the form of charts/graphs for human interpretation and underlying information beneath these graphs loses its context. Consequently, human intervention or additional software is required to understand and compare this underlying information to select feasible resources from the supply chain pool.

3. Machine tool health representaion in the supply chain

3.1. Accessing manufacturing resource information for decision making

In addition to the product information, a typical interaction between supply chain owners and manufacturers (suppliers) consist for exchanging and utilising information regarding manufacturing resource [17,18]. This resource information provides a foundation to the majority of manufacturing decisions executed on a variety of levels in the supply chain. For example, CNC controllers attached with the machine tools requires this information in the controller's native format [19,20]. Computer Aided Process Planning applications (CAPP, CAM) require this information in the form of postprocessors to generate resource dependent tool paths [21,22]. Maintenance logs also utilise it for scheduling periodic tasks [23]. Manufacturing engineers employ this information for process planning and resource allocation [24]. Metrology engineers require it for associating axes errors in order to represent the health of the machine tool [25]. Similarly, contract managers and costing engineers utilise it for selecting the optimum resource in the supply chain to manufacture high-value products [26], whereas suppliers compile this information for acquiring manufacturing contracts [27]. In addition to this, not only manufacturers require this information to reconfigure their manufacturing systems for incorporating sustainable manufacturing strategies [28], but also machine tool builders exploit it for accomplishing life cycle assessment (LCA) in order to monitor performance of their in-service manufacturing resource [29]. The stake of the resource