Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 61 (2017) 329 – 334

www.elsevier.com/locate/procedia

The 24th CIRP Conference on Life Cycle Engineering

Web-based component data for the commissioning of machine tools

Benedikt Klee*, Joerg Bauer, Hanqiu Jiang and Juergen Fleischer

wbk - Institute of Production Science, KIT, Kaiserstr. 12, 76131 Karlsruhe, Germany

* Corresponding author. Tel.: +49-721-608-44289; fax: +49-721-608-45005. *E-mail address:* Benedikt.Klee@kit.edu

Abstract

This article presents an approach of simplifying machine tool commissioning processes with web based component data. As commissioning and error compensation processes of machines often require extensive manual labor and repetitive tasks, they present great potential for further digitalization. Therefore, a systematic approach for generating and implementing a digitalization concept is applied. As a result, a commissioning device accessing web based component data is implemented. The device uses geometric errors of individual components in a machine tool and generates compensation values for the control of the machine's axes.

Peer-review under responsibility of the scientific committee of the 24th CIRP Conference on Life Cycle Engineering

Keywords: Machine tool; Reconfiguration; Identification; Error; Lifecycle

1. Introduction

Between the years 1992 and 2012, the cost of computing power has declined from over 200 USD to just 0.06 USD per Million transistors. In an even shorter period of time, between 1999 and 2012, the cost of internet bandwidth has fallen from 1245 USD to just 23 USD per 1,000 Mbps [1]. These are just two of many indices that reason why a fundamental shift in the use of information technology has taken place in business just as well as in daily life. Cornerstones of this shift are the use of the internet technologies and, in the recent years, the use of mobile devices such as smartphones. However, many companies from the field of heavy and industrial machinery as well as discrete manufacturers still feel unprepared for the changes of a further digitalization [2].

As a matter of fact, not every new technology has a suitable application every field of manufacturing technology. Therefore, a key question for companies in the manufacturing industry is how to create a substantial benefit from the multitude of technologies that have become available in recent years. To answer this question, a systematic approach can support designing and testing novel technologies in the field of manufacturing technology.

Looking at the manufacturing of complex machinery, commissioning processes can often be seen as particularly time-consuming with many possible sources of error. The commissioning is often hindered by the usage of different data media and inefficient manual processes, especially when components of different manufacturers are being used. This potential motivates the systematic approach for the generation and implementation of a use case in the field of machine tool commissioning presented in this paper.

1.1. Machine tool components for error compensation in commissioning processes

Geometric errors at the tool center point of a machine tool result from a sum of geometric errors within its kinematic chain. In the kinematic chain, the different components of the machine tool contribute to the error at the tool center point. Potential errors result from manufacturing tolerances of the components or their assembly. However, as avoiding errors leads to quickly rising costs with more precisely manufactured components, a compensation of errors becomes necessary [3].

Therefore, when commissioning a machine tool, geometric errors of components need to be taken into account. However, in the commissioning of machine tools paper-bound data sheets

Peer-review under responsibility of the scientific committee of the 24th CIRP Conference on Life Cycle Engineering
doi:10.1016/j.procir.2016.11.145

are still widely used to provide individual component data [4]. This leads to expensive manual labor and high error rates. It also indicates a high potential of improvements in the commissioning process and the lifecycle of machine tool components in general.

In [5], Bauer presented a highly integrated hydraulic feed axis for modular machine tools which, compared to conventional feed axes, can provide additional functionalities for error compensation. The hydrostatic guiding system integrated in the axis is able to individually control the orientation and position of the axis carriage with small compensational movements in five degrees of freedom. Therefore, geometric errors of the axis and other components within the kinematic chain of the machine tool can be compensated [5]. In [6], an algorithm to calculate the parameters for error compensation with this axis system was presented. When geometric errors of the individual components are available and additional errors resulting from assembly can be neglected[1], this calculation can be carried out prior to the commissioning of the assembled machine tool. Therefore, the calculation can supersede complex measurement and compensation of the assembled machine.

However, a modular architecture of machine tools implies further challenges for the commissioning and error compensation process. As different machine tools can be configured with modular machine tools, different kinematic chains with different modular components have to be commissioned. When components are supplied by different vendors, gathering individual component data also becomes increasingly complex.

The case of modular machine tools, as presented in [8], therefore provides a suitable base for a further digitalization of the commissioning process. Fig. 1 shows a configuration of a modular machine tool with the respective components and highly integrated feed axis [5].

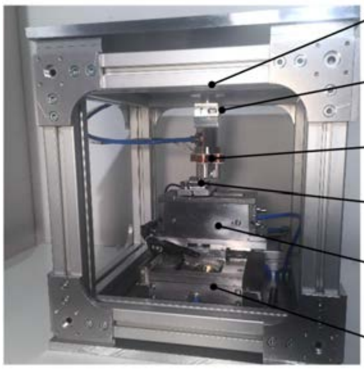

Fig. 1. Modular machine tool with hydraulic feed axes for grinding operations cf. [5]

In the context of digitalized commissioning processes, Dosch et al. [4] showed the benefits of RFID transponders for ball screw drives in machine tools. In this work, RFID transponders containing individual component data were physically attached to the ball screws. The availability of machine readable data was then used to automatize previously manual processes [4].

RFID transponders therefore present an inexpensive way to digitalize the exchange of component data and automatize the commissioning process of machine tools. Furthermore, it restricts the access to the component data to the physical possessors of the component.

Compared to storage devices that are physically attached to a component, a web based data storage can offer a number of potential advantages and disadvantages. Examples for advantages are the simplicity of scaling data storage and accessing information without physical access to the component, whereas data security issues and questions regarding permanence of information show potential disadvantages.

Therefore, the subject of this paper is the evaluation and application of web based data storage for the process of machine tool commissioning.

1.2. Development of use cases for the digitalization of manufacturing processes

In the field of digitalization in manufacturing, Anderl et. al [9] present a concept of selecting suitable fields of application and generating beneficial use cases. A core aspect of this approach is the use of a toolbox for the creation of use cases in the context of a digitalization in the manufacturing industry.

The toolbox can be used for the generation of business models and technological concepts in a wide spectrum of applications. It consists of two sections focusing on new products and improvements in production processes. Each section consists of six application levels with five development stages. The application levels represent different technologies and potential fields of application for a further digitalization. The development stages of each application level represent different stages towards a higher degree of digitalization. As these stages potentially stand for a different benefit and cost, a creative process for creating valuable concepts is necessary.

In a creative process, the application levels are related to products and production processes. Suitable application levels are chosen and analyzed regarding their development stages [9].

2. Approach

2.1. Systematic generation of a technological concept for the commissioning of modular machine tools

The subject of this work is to systematically develop a beneficial application of state-of-the-art technologies for the commissioning of a modular machine tool. Therefore, the first step is to generate and evaluate a concept for an application.

[1] As shown by Grimske [7], mechanical interfaces for modular machine tools can reach sufficient geometric accuracy. It is therefore assumed that the assembly of the machine tool does not result in geometric errors relevant for the compensation process.

To develop a concept, the toolbox presented by Anderl et al. [9] is used. As described in the previous paragraph, it consists of two sections for products and production. In order to develop the use case for the commissioning of a modular machine tool, relevant levels of the two sections are applied to the commissioning process. Therefore, the status quo of the commissioning process is assessed in these levels in a first step (red frame in Fig. 2, 3, 4). Then, possible steps towards a further digitalization of these levels are evaluated and chosen for the prototype to be implemented (red dashed frame in Fig. 2, 3, 4).

The application levels targeted in the approach for the commissioning of modular machine tools are “Functionalities for data storage and information exchange”, “Communication and Connectivity” as well as “Man-machine interfaces”. The relevance and application of these levels for the context of machine commissioning is described in the following.

The first application level regarding data storage and information exchange is targeted because of the importance of data availability in the commissioning process. Considering the different development stages of the application level, the status quo and potential future development stages are evaluated. The red framed development stage in Fig.2. represents the status quo of the commissioning process, where compensation data is transferred manually. The use of directly attached data, either for the possibility of an individual identification, or with a rewritable data store for further functionalities (red dashed frame in Fig. 2), can potentially improve the commissioning process. However, the storage is usually limited in terms of its scalability and access to the data.

Fig. 2. Data storage and information exchange in the commissioning use case cf. [9]

Therefore, a second application level of the toolbox is applied. Instead of storing the data of individual components on data storages that are attached to the components, most of the data can also be stored externally. If the component provides an individual identification which links to an external storage, the cost of data storage at the component can be kept considerably lower. An internet based cloud solution presents an external storage that is easily scalable to different sizes of data sets and is accessible to all the participants in the value chain. Through encryption of the component data, this access can be restricted to certain participants in the value chain or phases within the lifecycle of the component.

Fig. 3. shows the utilization of the respective application level “Communication and Connectivity” for the use case. From no commissioning-relevant interface in the status quo (red frame), the product can be extended with a simple interface connecting to an external, web-based storage (red dashed frame).

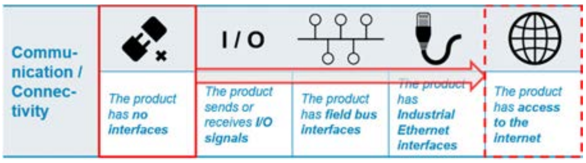

Fig. 3. Communication and connectivity in the commissioning use case cf. [9]

When it comes to digitalizing commissioning processes with a high percentage of manual labor, the topic of man-machine interfaces also needs to be addressed. In the status quo of machine tool commissioning processes, local user-interfaces are widely used to enter individual component data and process it for the machine control (red frame in Fig. 4). Considering the high mobility of the modular machine tool components in the use case, a mobile user interface to guide the commissioning process of the different modular machine tools is chosen (red dashed frame in Fig. 4.).

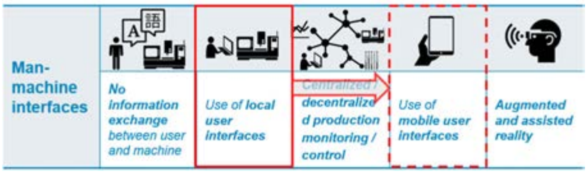

Fig. 4. Man-machine interfaces in the commissioning use case cf. [9]

2.2. Prototypical development of a commissioning concept

Different development stages in the application levels of the toolbox described in the previous paragraph lead to varying use cases with individual advantages and disadvantages. This can lead to a multitude of variations for potentially beneficial use cases. However, they have not yet proven their benefit or suitability in a practical context. After an expert evaluation and selection of a use case, a prototypical development for further evaluation is necessary.

In order to accelerate the development of a functioning prototype, a modular hardware-structure and software-environment is chosen. With modular building blocks for prototype development, the focus can be shifted towards the implementation of core functionalities. The implementation of functional details which are non-specific for the use case (e.g. electrical wiring, software connection of sensors and actuators) can be achieved with hardware and software modules and is therefore not directly relevant for the implementation of the use case.

For developing the hardware structure of the use case, a modular architecture of microcontroller building blocks is used. The chosen architecture [10] provides hardware building blocks and dedicated programming interfaces for a variety of functionalities, such as network integration or the connection of sensors and actuators. The main functionalities needed in the use case (connection to the internet, wireless reading of identification tags, data storage and processing) can be established using this architecture. It also supports the programming language used for the calculation of compensation values for the axis.

The chosen Python programming environment provides libraries for quickly establishing functionalities like data retrieval from the internet, handling of data containers or the implementation of user interfaces. The aim of combining modular hardware with a high percentage of preprogrammed libraries is to minimize tasks which are non-specific for the use case's prototyping process. Instead, the tasks specific for the use case, the calculation of compensation values from multiple machine tool components, is focused.

The use of generative processes can further accelerate the development and evaluation of prototypes and products. Therefore, mechanical components, such as the device's casing, are 3D-printed.

3. Results

Following the approach outlined in the previous paragraph, a technical realization of the use case for a web based commissioning process of a modular machine tool was developed. The prototype consists of a modular hardware structure which provides the hardware functionalities necessary for the commissioning process and a user interface guiding through the commissioning workflow. Fig. 5. shows the workflow of the commissioning process.

The developed commissioning process, hardware and software are described in the following.

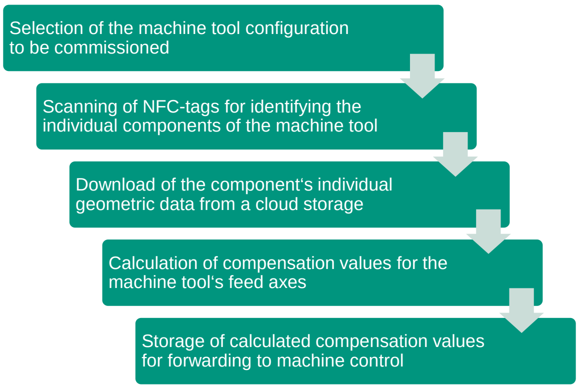

Fig. 5. Commissioning process for geometric compensation of modular machine tools

In a first step of the commissioning process for the modular machine tool, the user selects the machine tool configuration to be commissioned. The list is displayed on a touch screen user interface of a mobile commissioning device. According to the chosen configuration, the components needed for the machine tool and their kinematic relations are chosen by the software.

In a next step, the user is guided through the scanning process of the individual components. Each component is equipped with an identification tag with Near Field Communication technology (NFC). A NFC-Read/Write-Device is implemented in the commissioning device and placed next to the tags by the user. The individual tags link to data containers in a cloud service. Depending on the implemented strategy for data security, encryption passwords for the data container can be stored on the individual tags as well. Therefore, a physical possession of the component enables accessibility of the component data.

The encrypted data containers in the cloud storage supply the individual components' geometric errors. Depending on the type of component, the geometric deviations are either static or, in the case of feed axes, variable. For feed axes, the geometric data is dependent on the axis' position in its feed direction and therefore multidimensional.

After scanning all individual tags of the components which are needed for the machine tool configuration, the data containers are wirelessly downloaded from a cloud service and unpacked in the device's internal storage.

In order to calculate error compensation values for the control of the machine tool, the individual geometric data of all components is then combined using an iterative algorithm. Since the kinematic relations in the assembled machine tool are known from the selected configuration, an algorithm to calculate compensation values for different tool center point positions can be used. The algorithm used in the compensation process extends the algorithm presented in [6] to the use with multiple modular components in the kinematic chain of a machine tool. By virtually building the kinematic chain of the components and their individual geometric errors, a resulting error at the tool center point is calculated. Then, by iteratively altering the linear travel positions of all linear axes and the gap widths of the hydraulic guidance shown in [5], compensation values for the axis control are calculated. An exemplary machine tool configuration with the relevant components can be seen in the introducing paragraph (see Fig. 1.). The algorithm is executed on the central processing unit of the commissioning device and uses the chosen machine tool configuration and downloaded individual geometric errors as inputs.

The resulting compensation values for the axes and active guidance systems are then locally stored on the device. In a further step, they can be forwarded to the control of the machine's axes.

Fig. 6. shows the assembled mobile device with touchscreen user interface, NFC-Reader and wireless internet access.

Fig. 6. Mobile commissioning device with touchscreen interface, NFC-Reader and internet access

As the computing time of the error compensation is crucial for the commissioning process with a handheld device, an evaluation of the computing time was carried out. With a central processing unit with ARM Cortex A8 1 GHz Core, an exemplary calculation of compensation values for 3375 tool center point positions could be achieved in 50 sec. The number of tool center point positions being calculated results from a 3-dimensional axis-setup with 15 positions in each dimension. However, as the computing time exponentially rises with a larger number of tool center point positions per axis, the computing power of the embedded device is not sufficient for a calculation of a mesh smaller than 15 positions per axis.

4. Discussion

As outlined in the previous paragraph, the computing power of the used hardware is sufficient for a mesh of up to 15 tool center point positions per axis. As the needed computing power exponentially increases with more positions per axis, a denser mesh size is not practicable with the used hardware. With fewer tool center point positions calculated, the accuracy of the geometric compensation can decrease. To estimate the adequacy of a mesh size for compensated tool center point positions, exemplary geometric deviations of components need to be evaluated. Geometric errors of axes vary depending on their feed position and therefore have varying influence on the tool center point position. Therefore, they are key for the estimation of adequate mesh sizes.

Fig. 7. shows exemplary non-compensated geometric errors of a hydraulic feed unit as used in the modular configuration.

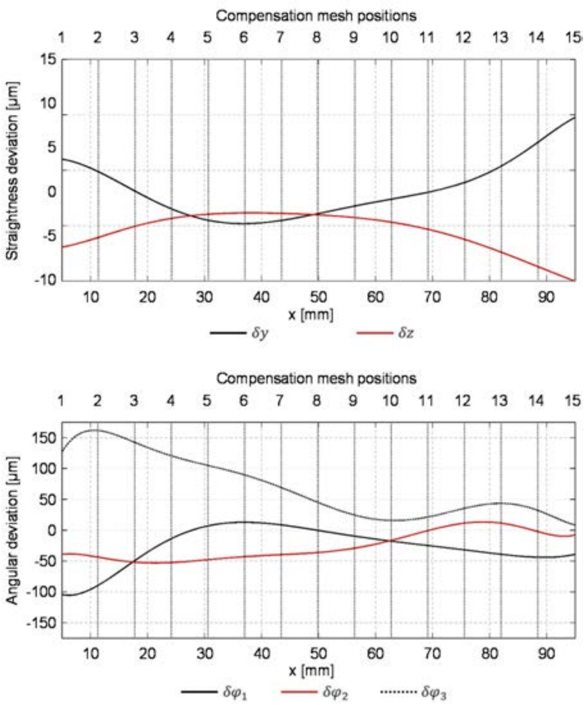

Fig. 7. Non-compensated linear and angular errors of hydraulic feed unit with exemplary linear mesh for compensation cf. [5]

In the upper graph, δy and δz represent the linear deviations normal to the feed direction x, whereas $\delta\varphi_1$, $\delta\varphi_2$ and $\delta\varphi_3$ in the lower graph show the angular deviations of the feed unit at given feed positions x . These deviations result from manufacturing tolerances of the feed unit and are, in combination with errors of other components, target of the compensation.

The shape of geometric errors show a continuous development of errors in linear feed direction. The errors do not indicate discontinuities or changes with high gradients over the linear travel of the axis. When applying a mesh size of 15 positions per axis to approximate resulting errors at the tool center point, no critical changes remain between compensation positions. Hence, a mesh of 15 compensated positions per axis can be assumed to be adequate for compensating major geometric errors of the axes. As the computing power of mobile devices also continues to grow, the application is feasible.

Furthermore, the approach to developing a use case and functional prototype for the digitalization of manufacturing processes and products proved to be relevant for commissioning processes of machine tools. By connecting technologies such as component identification with NFC-tags, component data storage with cloud services and user-guidance with handheld devices, a use case for further digitalizing manual processes in the commissioning of machine tools was implemented. Given the developed device, a high quality of provided geometric data and an absence of additional errors resulting from assembly, the commissioning process of a modular machine tool can be significantly simplified.

By using a systematic approach for use case generation and fast prototypical development, the feasibility and first evaluation of the use case were quickly achieved.

However, the use of internet technologies and cloud services in a manufacturing context also poses potential threats to data security. Hence, a sufficient encryption of the component data stored in the internet is necessary for practical application and acceptance.

The developed concept also indicates that an individual identification linked to an external cloud based storage can also be used in later stages of the lifecycle. To extend the use of cloud based component data, a standardization of data formats and communication standards needs to be targeted. As shown by Schleipen et al. [11], the use of open standards and software protocols, such as AutomationML or OPC UA, can build a base for a higher interoperability of data and information in the manufacturing context. Just as the used technologies for web based storage of component data, these standards and protocols are easily scalable and adaptable to different use cases. Therefore, they lay a foundation for the use of web based component data in later phases of the component's lifecycle, e.g. when maintenance related data can be used.

5. Summary and Outlook

In this paper, a concept for a further digitalization of machine tool commissioning processes with web based component data was presented. The concept was derived following a systematic approach for use case development in the field of digitalization. The implemented concept shows a handheld commissioning device to support the compensation of errors in the commissioning of a modular machine tool.

Therefore, the device uses web based data of the individual components of the machine tool. The components are identified with NFC-tags which link to an external cloud based storage containing geometric data. In order to calculate compensation values from the individual components of the machine tool, an algorithm for error compensation is used.

By using web based component data in combination with a commissioning device for error compensation, the commissioning process can be simplified.

In order to be able to completely avoid compensation processes after assembly, further work will have to focus on establishing processes to assure the quality of provided geometric data.

The benefits of web based component data are not limited on the exchange of geometric data for error compensation. Therefore, potential benefits of web based component data in further lifecycle phases of machines and machine components need to be addressed as well.

Acknowledgements

This paper is based on investigations of the priority program SPP1476: Small machine tools for small work pieces which has been kindly supported by the German Research Foundation (DFG).

References

[1] Hagel J III, Brown J S, Samoylova T, Frost M: The burdens of the past. Report 4 of the 2013 Shift Index series. Deloitte University Press; Available online: http://dupress.com/articles/the-burdens-of-the-past/ ; 2013.

[2] McKinsey & Company: Industry 4.0 - How to navigate digitization of the manufacturing sector; McKinsey Digital; 2015.

[3] Ramesh R, Mannan M A, Poo A N: Error compensation in machine tools - a review. In: International Journal of Machine Tools and Manufacture 40 (9), S. 1235–1256. DOI: 10.1016/S0890-6955(00)00009-2. 2000.

[4] Dosch S, Spohrer A, Fleischer J: Reduced Commissioning Time of Components in Machine Tools Through Electronic Data Transmission. Procedia CIRP 29, Elsevier B.V.; p. 311-316. 2015.

[5] Bauer J: Hochintegriertes hydraulisches Vorschubsystem für die Bearbeitung kleiner Werkstücke mit hohen Fertigungsanforderungen. Aachen: Shaker ISBN 978-3-8440-4665-6; 2016.

[6] Klee B, Bauer J, Graule D, Brenner D, Fleischer: Compensation of geometric errors using a highly integrated hydraulicfeed axis. WGP Congress 2015 - Progress in Production Engineering, Trans Tech Publications, S. 395-402; 2015.

[7] Grimske S.: Multifunktionale Schnittstellen für kleine modulare Werkzeugmaschinen. Dissertation. Helmut-Schmidt-Universität, Hamburg. 2014.

[8] Wulfsberg, J: SPP 1476 - Small Machine Tools for Small Workpieces; Institute of Production Engineering (LaFT), Helmut Schmidt University, Hamburg; 2016.

[9] Anderl R, Picard A, Wang, Y, Fleischer J, Dosch S, Klee B, Bauer J: Guideline Industrie 4.0 – Guiding Principles for the implementation of Industrie 4.0 in small and medium sized businesses. ISBN: 978-3-8163-0687-0. VDMA Verlag GmbH, Frankfurt am Main; 2016.

[10] Tinkerforge GmbH: Dokumentation. Available online: http://www.tinkerforge.com/de/doc/index.html; 2016.

[11] Schleipen M, Lüder A, Sauer O, Flatt H, Jasperneite J: Requirements and concept for Plug-and-Work - Adaptivity in the context of Industry 4.0. at – Automatisierungstechnik; 63(10); p.801.820; De Gruyter; Oldenburg; 2015.