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Reduced commissioning time of components in machine tools through electronic data transmission

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Abstract

This article presents an approach to increase data availability over the life cycle of machine tool components. This includes the consideration of type-specific and instance-specific data of a machine component throughout its entire life cycle. Currently, the provision of the component data for the physical component is only realized by paper-bound data sheets. This leads to growing costs of the component through its commissioning. The presented approach proposes to store data on a RFID transponder attached to the component. In the article, a procedure to generate the optimum amount of data for instance-specific data is presented. This data are measured on a test bench, processed to generate the values and finally linked with the component over the whole life cycle. This enables increasing efficiency of the component by reducing the commissioning time during its life cycle.

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Keywords: Ball screw; Compensation; Lifecycle

1. Introduction

In recent years, revolutionary changes in industry have emerged. This is indicated by the growing trend towards information technology networking on the shop floor as well as by the implementation of internet-based data exchange in production engineering. This is based upon cyber-physical systems which enable the connection of physical objects with the digital world [1, 2]. The connection of the physical system to the internet is realized by a symbiosis of an embedded computing device and the system itself. The representation of a technical system/object in the cyberspace is called Internet of Things. This innovation in production engineering is referred to as Fourth Industrial Revolution [3]. The computerization of production technology is known as the Industry 4.0 project in the high-tech strategy of the German federal government. These changes enable a data availability in real-time everywhere [3].

In many areas of production engineering, the integrated information technology has not prevailed yet. Paper documents are still the predominant communication medium, particularly in the field of machine tools and its components. A large amount of information is exchanged exclusively on paper. This information can contain, for example operating parameters of motors or mechanical parameters of ball screws.

These data can be differentiated in type-specific and instance-specific data. In this context, type-specific data means that the data have the same parameters for a product series of components. Instance-specific data are the properties of each individual instance. These data are mostly created during production and tested at the end of the production by the manufacturer and are delivered together with the components on paper.

During the commissioning of the component by the machine tool manufacturer, a technician has to read the data sheet and enter the relevant data into the machine tool control. In the industrial environment the paper is not suitable because it take a lot of time for the technician to find the required information and to enter them into the machine tool control. Moreover manual labor is prone to errors and the troubleshooting effort is large. In addition, the time-consuming transfer of the information keeps qualified

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employees from pursuing their actual work which requires higher skills.

Hence, the approach of continuous networking of all involved instances of production can provide substantial improvements by providing all relevant data to every step of the life cycle of components. In this article, the data flow through the life cycle of a machine tool component and the problem definition as well as an approach of increasing the availability of its data is presented.

1.1. Life cycle of a machine component

A machine tool can be divided into subsystems that include frame, feed axis, main spindle, machine control and peripheral units [4]. The feed axis is subdivided into non-electrified components and electrical drive components. In the following, the life cycle and subsequent data flow of typical mechanical parts of the non-electrified components of a feed axis such as ball screws, guides and bearings will be presented.

The life cycle of a machine tool component starts with the development at the component manufacturer's site. At this stage, the properties and the general behavior of the component for its later use are defined. The type-specific data of the component is determined by using CAx-development tools. Moreover, in this area the development relevant data are stored in databases with Excel-based interfaces. The production of the components is planned based on the data, which are specified in the development. Machine tool components are produced in several steps, based on semi-finished products. With every machining and assembly step, the level of detail of the components rises. The mechanical dimensions, which were defined in the development, are transferred to instance-specific dimensions of the components during production. For example, the specific balls within the nut of ball screws are selected. Finally, the manufactured machine tool components are validated for their required properties in a test run at the components' manufacturer. The data measured at this stage of production are instance-specific data. The evaluation and documentation of the data usually takes place in specific programs and is passed on in paper form.

The next step of the life cycle of the machine tool component is the integration into a machine tool and the commissioning of the control. First, the component is mostly subjected to an incoming inspection. Thereby, the manufacturer checks the compliance of measurement data with the required tolerances. This is done by manual inspection of the documents. The next step is the assembly of the machine tool. It takes place by site assembly, clock-bound or flow assembly [5]. The final step of the production of the machine tool is the commissioning of the machine tool control and the compensation of component errors. In doing so, the required parameters are stored in the machine tool control, e.g. the length of the feed axis or the pitch of the ball screw unit. To ensure high positioning accuracy of the feed axis, the pitch error of the ball screw is compensated [6, 7]. The pitch error indicates the difference between the actual distance of the spindle nut and the travel distance calculated on the basis of rotation. This is particularly important in the case of indirect measurement of the feed axis position. In order to achieve this, the accuracy of the positioning is detected by measurements and the corresponding correction values are stored in the machine control. This could be done by direct measurement of the positioning error with a laser tracker at the end of manufacturing. Another compensation procedure is the generation of correction values based on the pitch error. This error is measured by the components manufacturer and sent to the machine tool manufacturer on a data sheet supplied on paper. In both cases, the data is submitted manually to the control. The commissioning, testing and configuration of the systems at the machine tool control desk uses a considerable portion of the total production time of each machine tool [8].

The final commissioning of the control takes place at the operator's site and last settings depending on the placement situation are adjusted.

The maintenance of the components has to be executed in the given intervals from the manufacturer. In case of failure the components has to be replaced. Wear parts such as the ball screw have to be replaced several times throughout the lifetime of a machine tool [9]. The re-commissioning of these components requires the re-entering of instance-specific data such as the pitch error. Figure 1 illustrates the life cycle of a component and occurring data flows.

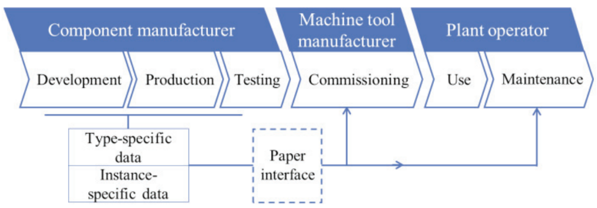

Fig. 1: Life cycle of a machine component

1.2. Problem definition

As described in the previous section, the commissioning of machine tool components requires the input of various data in the machine tool control. The type-specific data are mostly entered with predefined templates into the control, whereas instance-specific data have to be entered separately in the control for each machine tool. This instance-specific data are usually required for compensating component specific errors, for example, the pitch errors of the ball screw. These data are supplied on a paper-bound data sheet from the component manufacturer. The values are usually transmitted with a grid distance of 100 mm and are entered manually into the controller. To achieve higher accuracy in error compensation, a smaller grid distance must be selected. The upper diagram in figure 2 shows the positioning with compensation with a grid distance of 100 mm and the lower diagram with a grid distance of 5 mm. The difference between the two position curves is up to 2 µm. However, to achieve high accuracy for a ball screw with a length of 1000 mm, 200 values have to be entered into the controller. In case of manual input, the high number of inputs to the machine control leads to inefficient commissioning.

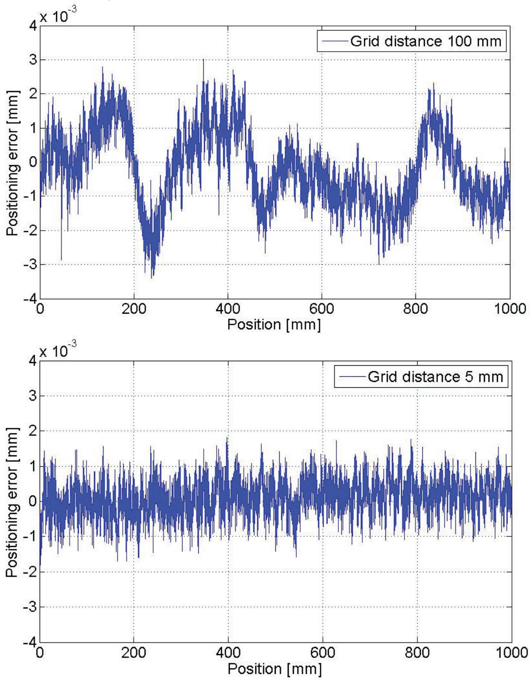

Fig. 2: Positioning error at feed axis position

The data for the non-electrified components of the feed axis such as guides, bearings and the ball screw are currently supplied by the component manufacturer to the machine manufacturer on paper. In most cases, these data sheets are created by the manufacturers exclusively for the delivery with the component. This also includes the data exchange between different electronic data-processing systems, for example, between the measurement data evaluation and the development database. Therefore, the component data storage is subject to multiple media breaks. It also occurs quite frequently, that data are lost due to the changing transmission medium. This may happen, for example, at the conversion of measurement data from the test bench to a data sheet. The quantity and quality of information is reduced drastically during this procedure.

A continuous availability of data throughout the life cycle has not been realized yet, which essentially results in longer commissioning times. The loss of data, which has to be procured from other stages of the components production process, conflicts with the principles of resource efficiency resulting in higher life cycle costs for individual components as well as entire machine tools.

2. Approach

This article presents an approach for increasing the type- and instance-specific data availability of mechanical components throughout their life cycle. In order to increase the efficiency of the component during its life cycle, the component data needs to be linked with the component over its entire life cycle as soon as it is available [10]. Therefore, the availability of the necessary component data has to be ensured and the life cycle cost can be reduced. The resource efficiency can be increased by upgrading a purely mechanical component with an electronic data interface in order to ensure the continuous exchange of data throughout the entire life cycle. The electronic interface allows the linking of type-specific data and instance-specific data with the specific machine tool component. This data can be used during the commissioning of the machine tool as well as to improve the controller settings in use. Figure 3 illustrates the life cycle of a machine tool component extended with an electronic interface and the occurring data flows. This extension leads to the networked machine tool component.

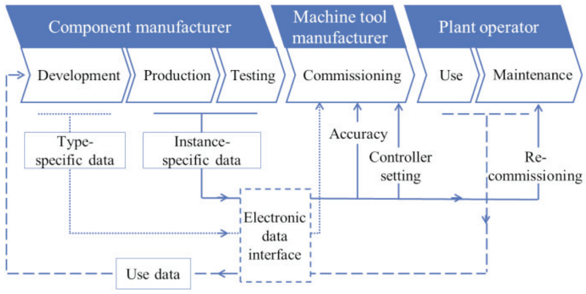

Fig. 3: Data flows over the life cycle of a networked machine component

A machine tool component with an electronic data interface can be realized by the following procedure: First, the components and its life cycles are extensively analyzed. The objective is to identify the data which sufficiently describes the ball screw and are required for the commissioning at the machine tool control. A communication path is chosen based on the requirements of the position on the component and the data amount. The next step is the development of measurement strategies which enable the transfer of the optimum amount of data. For this purpose, the spindle pitch error is fully analyzed and afterwards the exact number of data to be transmitted is determined.

In this article, the approach is demonstrated by the example of a ball screw. The ball screw is an accuracy determining part in a machine tool and therefore one of the important components. In addition, this component is replaced several times over the life cycle of a machine tool. The commissioning with the networked machine component decreases the time needed for each ball screw replacement and therefore the efficiency is increased over the entire machine tool and its life cycle.

3. Networked machine component

3.1. Component data

With an analysis of the data flows of the ball screw from the component manufacturer to the machine tool manufacturer and finally to the machine operator, the necessary data can be identified. To map all kinds of data, three data types are differentiated. Those are the type-specific data defined by development and the instance-specific data determined by production and testing. In addition, there are component information determined by development and use. Ball screws can be characterized by different type-specific values. These include length, maximum possible travel path, diameter and pitch. The ball screw can also be described in detail by several other parameters. Figure 4 gives an overview of the typical component data.

Ball screw data		
Type-specific data	Instance-specific data	Information
▪ Nominal diameter ▪ Ball screw lengh ▪ Ball screw pitch ▪ Max. travel path ▪ Static load rating ▪ Dynamic load rating ▪ Stiffness	▪ Pitch error ▪ Friction torque curve ▪ Max. acceleration ▪ Max. jerk	▪ Part number ▪ Drawing number ▪ Date of manufacture ▪ Date of last service
Data determined by development	Data determined by production and testing	Data determined by development and use

Fig. 4: Data of a ball screw

The type-specific data is defined during development and does not change for a series of different instances. The instance-specific data shows the real values and properties of one specific instance of a ball screw. The pitch error of a ball screw is a particularly characteristic feature for this data type.

3.2. Communication unit

The next step is the identification of a suitable communication unit to realize the networked machine component. A ball screw is a component which is exposed to difficult conditions while in use. This places high demand on the communication unit which is placed onto the ball screw.

The ball screw heats up to 80 °C during operation and is exposed to lubricants. Therefore, the communication unit needs to be robust against mechanical loads, resistant to oil and grease and insensitive to temperature fluctuations. Another important point for the realization of the electronic interface is a suitable installation location for the communication unit. The structure of a ball screw consists of a threaded shaft, nut and balls in between. In most applications, the screw shaft rotates and the nut is rigidly connected to the movable component, e.g. the carriage. The scheme of a ball screw is presented in figure 5. The thread extends over the entire shaft. The bearing seats and the flange for force transmission are located at each end. In production, as well in the machine tool, the ends of the shaft are used for clamping. Therefore, the screw shaft is unsuitable for integrating a communication unit. Basically, the nut of the ball screw is accessible during installation and operation. In most installation cases, the nut is connected to the machine table and thus not rotating. For that reason, a possible place to install the communication unit is the nut.

In industrial applications, the use of RFID transponders has proven to be successful for transmitting small amounts of data, mostly for identifying purposes. RFID based communication fulfills the requirements for the networked machine component. However, the storage space on this communication unit is usually limited. In case of the ball screw nut, a RFID transponder with a diameter of 10 mm can be mounted. With this transponder, a data amount of 2,000 bytes of user data can be stored. This is enough memory for the storage of the ball screw data. Figure 5 shows the position of the RFID on the ball screw. To be protected against mechanical exposure, the RFID transponder is glued into a borehole at the nut.

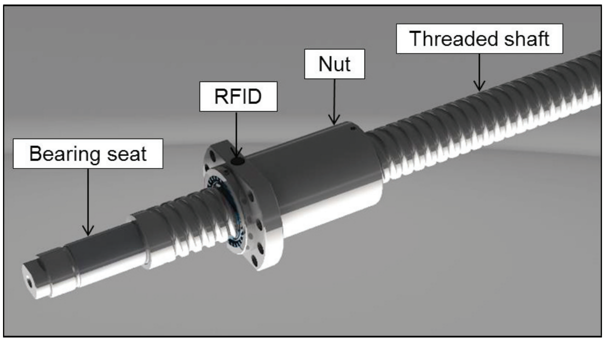

Fig. 5: RFID position on ball screw

3.3. Measuring of instance-specific data

The instance-specific data are measurement data and data determined in production. Currently, the individual measured data and characteristic properties are gained at several test benches and joined to one data set. In case of the pitch error, the measurements are performed on a test bench. Here, the nuts of the ball screws are connected to a carriage and its position is measured with a highly precise linear encoder. The rotation of the spindle is recorded by a rotary encoder at the unloaded end of the spindle [11]. Finally, the pitch error is calculated by subtracting the position calculated by the rotation of the ball screw and the measured nut position. Entering the pitch error into the machine control occurs with compensation values at defined grid distance. The error is compensated in the control with linear approximations between those points. In the following, the procedure for determining the optimum grid distance is represented. The procedure includes an analysis of the data regarding the necessary grid distance between the points. A grid distance of 100 mm is defined as required by the state of the art [12]. The curves are shown in the upper part of figure 6. Here, the curves for the pitch error profile are presented for a grid distance of 100 mm and 5 mm. The actual pitch error measurement is shown in green. The diagram below depicts the difference between the respective curves. It depicts the maximum error of 3 µm for a 100 mm supporting point distance in relation to the measurement. The curves clearly demonstrate that the higher the number of grid points, the smaller the error is.

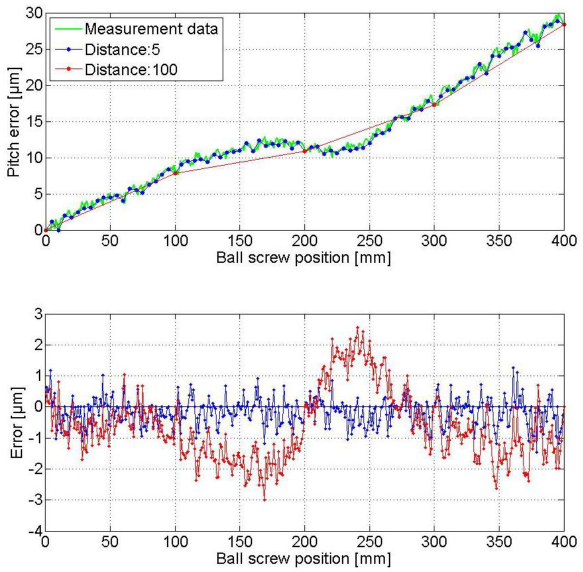

Fig. 6: Pitch error and relative error

Criteria for a precise mathematical description are defined to evaluate the different grid distances. This enables a target assessment. In general, it refers to the maximum error between the measurement curve and the curves of the respective supporting point density x_{max} in formula (1). Additionally, the mean square error x_{ms} in formula (2) and the medium error x_{arithm} in formula (3) constitute a significant parameter to evaluate the error between the supporting points and the measurement curve.

$$x_{\max} = \frac{d}{dx}\left(f_0 \frac{x_1 - x}{x_1 - x_0} + f_1 \frac{x - x_0}{x_1 - x_0} \right) \tag{1}$$

$$x_{ms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}} \tag{2}$$

$$x_{arithm} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{x_1 + x_2 + \cdots + x_n}{n} \tag{3}$$

The values of the different grid distances are now calculated for the analysis. Starting with the value of 100 mm, the grid distance is reduced and the three values are calculated for each distance. The resulting curves are depicted in figure 7.

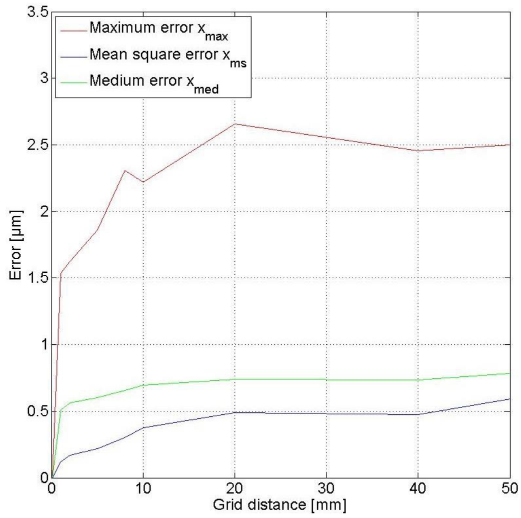

Fig. 7: Error relative to grid distance

The course of the curves shows that the error increases significantly up to a grid distance of 10 mm and then remain nearly constant. For transmission of data with an optimal grid distance a threshold of each error curve can be defined. The optimal grid distance allows the compensation of the pitch error by using a minimum amount of memory space of the RFID transponder.

3.4. Implementation in machine control

The data of the ball screw obtained on the test bench may be stored in the RFID transponder, enabling the data transfer of a ball screw in future applications in the machine tool. The values for the compensation stored on the data medium may be integrated into the control of the machine. Then, the correction values are used to compensate the position values during operation.

The presented approach reduces the commissioning time of machine tool significantly. This is due to the automatic implementation of necessary commissioning data and compensation data in the machine control. For the highly accurate compensation of errors, data can be transferred in a small grid distance. For this purpose, the transmission time remains the same regardless of the data quantity. An overview over the life cycle and the time savings is provided in figure 8. The savings are effective at initial commissioning and each further commissioning.

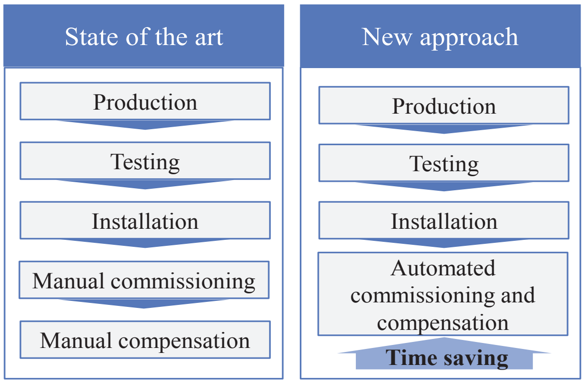

Fig. 8: Comparison between the state of the art and the new approach

3.5. Outlook

In the future, an integrated test bench will be developed to measure the pitch error curve as well as the neutral friction torque curve. The neutral friction torque significantly influences the control characteristic of the machine tool. The test bench has a flexible structure to allow quick refitting or adapting to different lengths and diameters of the ball screws. In the future, the integrated approach will show a significant increase in efficiency in measuring and processing the data.

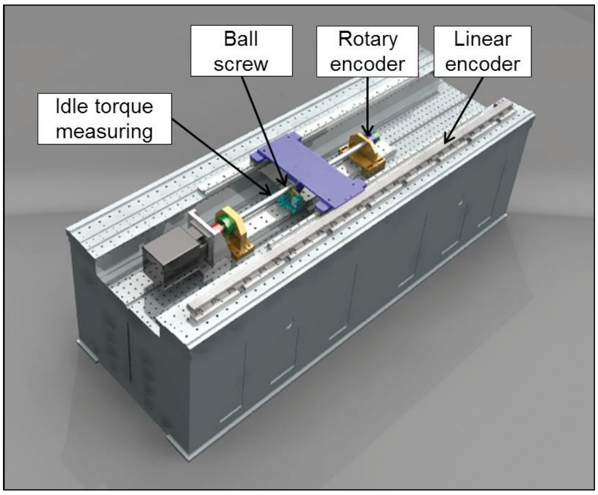

Fig. 9: CAD model of test bench

For this purpose, the test bench offers the possibility to capture the idling torque of the nut. This is achieved by connecting a measuring carriage that picks up the friction torque fluctuations with a highly sensitive piezo element. Figure 9 shows the test bench for measuring the ball screw specific values. In the future, the approach may be applied on guides and bearings. These components have also type-specific and instance-specific data and are therefore suitable to link the data to the component over their entire life cycle.

4. Conclusion

In this paper, an approach to increase the availability of type-specific and instance-specific data of a machine component has been presented. Currently, the provision of the component data with the physical component is only realized by paper-bound data sheets. This leads to growing costs of the component during its commissioning. The presented approach proposes to store data on a RFID transponder attached to the component. Therefore, the data accompanies the component for a subsequent use during its life cycle. This allows increasing efficiency of the component by a reduced commissioning time during its life cycle.

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