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Improvement of defect detectability in machine tools using sensor-based condition monitoring applications

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Abstract

The aim of this paper is to present a reliable methodology for condition monitoring of components of high performance centerless grinding machines. This enables the detection and localization of the defects on the ball screw. The fault detection is realized using a self-implemented classification algorithm and other pattern recognition algorithms. The diagnosis is based on acceleration and AE measurement data performed on an axis test rig using various damaged ball screws at different operating parameters. Moreover, the structure of the pattern recognition process will be introduced, this includes the signal pre-processing, the selection of the most suitable features for this specific application using MATLAB®. Finally, the evaluation of the developed solution will be showed. The actions allowing improving the accuracy of measurement data and the effectiveness of the processing algorithms, based on MATLAB® applications, are described throughout the paper. Satisfactory classification results will be obtained and discussed.

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Keywords: Condition monitoring; Measurement uncertainty; Acoustic emission; Vibration; Grinding

1. Introduction

Due to the very high customer specific quality and availability requirements regarding machine tools and to reduce the machine breakdown time caused by wear and tear damage, the use of condition monitoring (CM) approaches is increased over the last decades. Description, issues and possible solutions to deal with sensor-based CM and diagnostics applications can be widely found in literature, such as [1].

In this context, the metrological characteristics of the systems called to provide the needed data allow evaluating the quality of the results of the further analysis and to remove possible causes of errors in the diagnosis process [2]. Several innovative approaches in manufacturing systems and management raise the interest in considering the contribution the metrology offers in facing engineering issues, and to handle with its methodologies and basics [3]. Furthermore, the application of CM methods is a suitable example, where experts are called to manage with a huge amount of data, justifying the adoption of optimized solutions, which take into account, among others: (1) the application of CM and data mining techniques [4, 5], (2) the exploitation of data coming from disparate sources, sensors and other equipment [6-8] and (3) the most appropriate methods of data processing, to perform meaningful and coherent analysis [9, 10]. In this framework, the key-factor lies in the possibility of being able to provide meaningful indications, by synthetizing the information coming from a big data environment, also for addressing the issues connected to the industrial reality, which often would rather reduce the quantity of data needed for the analysis. Nevertheless, recent advances in technologies such as Internet of Things, Machine to Machine communications and Cloud computing technologies create the opportunity to transfer models and techniques form the research lab to industry [11].

When the analysis is devoted to the study of complex and technologically-advanced machining tools, the failures are caused in many cases by mechanical components, such as the mean spindle and the feed drives (especially the ball screws).

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Normally the breakdown of these mechanical components is induced through wear [12]. In general, the CM systems for production machines available on the market focus on different parts of the machine (e.g. feed drives or mean spindle). All these systems pursue the strategy of fault detection in early stage to avoid machine breakdown caused by component failure. These systems can be divided into mobile systems, which can be used manually to measure signals (e.g. vibration) on the components and systems and into upgradable systems, which can be integrated in already installed machines. Furthermore, there are CM solution integrated in some of the new production machines. Due to high requirements regarding the diagnostic accuracy, which can be not granted by using mobile CM systems, because of the uncertainty of the measurement, the most common CM solutions for machine tools are permanently installed ones [13]. Therefore, in case of not-embedded sensors, in order to have reliable results, reliable measurements on the one hand and reliable algorithms, on the other hand have to be guaranteed.

The aspect of interest to guarantee the reliability of the algorithms are resolution and selectivity, i.e. their ability to classify the defects and to select the most suitable features for the analysis. Regarding the measurements, their reliability is guaranteed by means of preventive solutions involving rigorous methods and operating procedures, able to avoid or minimize errors from the beginning. In this sense, the steps of the procedure for CM applications have to be all optimized, data acquisition included.

The aim of the paper is to highlight the main aspects to be taken into account in order to get a reliable methodology for a sensor-based CM application, with a specific focus on the components of high performance centerless grinding machines. The methodology does not necessarily relate to the performance of a specific kind of machine tool, aiming at being of general nature. Section 2 shows the proposed methodology and describes the best practices in algorithms development and in measurement activities, together with the tested system as a part of a real centerless grinding machining tool, used for validation purposes. The obtained results are described and discussed in Section 3. Conclusions and future works end the paper.

Nomenclature

a_{acc} output signal given by the accelerometer [V]
a_{vibr} acceleration estimated from the laser vibrometer [m/s^2]
d dimension of the feature space
K_j j-th class for training data of the algorithm (j=1,…n)
m_i i-th feature in the feature space (i=1,…d)
n number of classes of damage
R_j j-th maximum Euclidean distance between Z_j and row vector of each class (j=1,…n)
S sensitivity of the measuring instrument
v_{vibr} velocity given by the laser vibrometer [m/s]
X signal for the test data of the algorithm
x_i i-th feature vectors of the test classes matrix X
Z_c central point of the matrix of training classes
Z_j j-th training class matrix (j=1,…n)

2. Materials and methods

2.1. Description of the axis test rig

Figure 1 illustrates a basic structure of the axis test rig of a centerless grinding machine, which is used to collect data at different operating parameters for several ball screws to evaluate the CM applications [12-14]. Generally, the feed drives for machine tool are responsible for manufacturing precision. These are exposed to high levels of mechanical stress and its maintenance or replacement in case of failure is very time-consuming.

The CM application is based on vibration and acoustic emission (AE) signals used to detect changes or faults at the wear-susceptible components. In facts, among the methods available for the monitoring of machining and manufacturing operations, the most strengthen and typical ones and a combination of them are taken into account in this work.

As described in [10], a single signal feature is not often sufficient for a complete justifying of the need for an integration of multiple sensors. The choice of the vibration and AE signals can be widely found in literature [6, 8, 15]. One of the most critical components, which cause machine breakdown is the ball screw drive, since it determines the dimensional and surface precision of the workpieces, depending on wear. The wear is due to the exchanged forces and solicitations whose behavior is difficult to predict theoretically [16-17] and for this reason the accuracy requirements satisfaction can be verified by means of an experimental monitoring [18]. It is to be pointed out that the continuously increase of accuracy requirements asks for a continuous improvement of CM performances. Consequently, the optimal planning of the maintenance events can be implemented, which can increase the maintenance costs save other resources, focusing the CM attention on the ball-screw drive system.

2.2. Steps for CM applications

A CM application is composed of several steps which are necessary to detect the condition of the component under consideration [12]. The following main steps are taken into account.

- Input data acquisition

The data acquisition system is a multi-channel National Instruments system, operating with Labview® software.

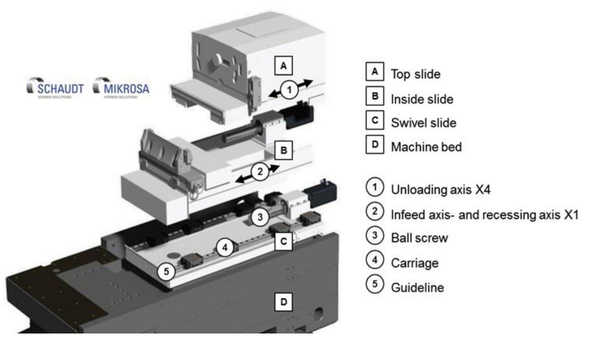

Fig. 1. Schematic presentation of the axis test rig (Schaudt Mikrosa®)