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ScienceDirect

Procedia CIRP 63 (2017) 348 – 353

www.elsevier.com/locate/procedia

The 50th CIRP Conference on Manufacturing Systems

Prediction of the product quality of turned parts by real-time acoustic emission indicators

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Abstract

Nowadays, the product quality of turned parts is measured downstream of the actual manufacturing process. This leads to a time-consuming quality control and the risk of a high number of waste and reworking. Even incidents like the fracture of the lathe tool remain undetected until quality issues of the turned parts are measured. Furthermore, certain material defects can't be detected by post-production quality control, which leads to customer complaints because of damages during the use of the parts. This paper presents an in-process approach for evaluating the product quality and tool defects in real-time by using an acoustic emission sensor applied to the tool holder.

This paper outlines the identification of feasible quality indicators and explains how the data is recorded and which data sources have to be correlated. This includes for example the recording and correlation of high-frequent acoustic emission signal with further acquired data like machine and computer aided quality (CAQ) data. In dissociation to previous work, this correlation is used directly to develop characteristic factors to predict product quality and to detect tool defects. An overview of several characteristic factors is given. In addition, the test setup is shown and first results are presented, followed by an outlook on further research.

The test setup is implemented at a series production without disrupting the daily manufacturing processes. It is shown that solutions in context of Industry 4.0 can be implemented in small and medium-sized companies without a loss of production capacity. The venture is realized within a funded project regarding Industry 4.0 and intelligent quality control systems. Its target is to design smart technologies for manufacturing systems.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

Keywords: Acoustic emission, Quality control system, Condition monitoring, tool wear, turning process

1. Introduction

Nowadays machining is a fully automated process which is able to produce high quality products. With an increasing demand for a highly efficient manufacturing process, scrap has to be minimized, production speed maximized and the post-process quality control should be relocated to an online process control. However, at present time many producing companies, especially small and medium sized companies (SMCs) have to rely to their knowhow and to the data they can export by the machine interface. By online process control, companies can get a competitive advantage, especially if they obtain information about the used tools. Currently a tool breakage is only noticed after post-processing quality control, which leads to a high amount of waste and costs. A possible approach is the use of Acoustic Emission (AE) Analysis to monitor the turning process and detect tool fracture and regular wear. However, it has to be taken to account, that data measured by the AE-sensor requires a lot of memory capacity. Because of that, it is important to compute so called characteristic factors decentral and machine-oriented so that it can be processed in the company's software system. The aim is to use these factors in series production.

Therefore, the algorithms have to be implemented in a self-developed, standalone software tool. This tool runs on the machine-terminal and computes the factors immediately out of the big sensor data. The statistic process control (SPC) software imports this data directly and can trigger actions like a signal for an immediate tool exchange if one of the factors runs out of its tolerance. Furthermore, the factors can be used as an input

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

doi:10.1016/j.procir.2017.03.173

for intelligent quality control software which is additionally interpreting the machine data exported by an Open Platform Communications (OPC) interface.

Therewith, tool changing intervals can be replaced by an exchange-as-required and even a prediction of a quantity of good parts till a necessary tool exchange has to be made.

Using that, application with appropriate characteristic factors enables the manufacturing SMC to monitor tool status and product quality online in their series production which greatly increases production efficiency.

To reach this aim, in a first step it is necessary to determine such appropriate factors. Several research works already show successful approaches [17], [18]. In practical applications, it is hard to forecast the suitability of specific factors for a specific system condition or product quality. Because of that, the development and the selection of factors has to be done based on received data from the monitored system. Only if the factors are chosen successfully, they can indicate the actual condition of the system and allow a correlation with product quality.

2. Fundamentals and State of the art

The most common approach to optimize cutting tip exchange cycles is a frequent quality control of the workpieces to identify tool related trends for output quality. Based on the trend and deviation of measures a suitable time for a cutting tip exchange can be anticipated. Such an approach leads to a high effort of downstream quality management and provides no advantage in terms of service cycles [1], [2].

A cost efficient approach for in-line production quality evaluation may be provided by Acoustic Emission sensor technology and evaluation. State of the art findings present the application of AE sensors as suitable for the analysis of the cutting tip's condition [3][4][5][11].

The Acoustic Emission Analysis utilizes the fact that during cutting processes, a part of the process energy is transducing into elastic waves in the solid body. The elastic waves are generated especially due to fundamental phenomena within the material, mainly initiated by tribological stress and strain. Typical sources for the then so called Acoustic Emissions are growing cracks, motion of dislocations, or elastic and plastic deformations. All these fundamental processes within the material emit a part of the released energy as high frequency elastic waves into the material (with frequencies up to 600 kHz) [6]–[8].

Consequently, the measured elastic waves in a solid body are a result of a sum of single events, which occur in the material during operation and leads to a continuously changing system and a continuous emission of elastic waves into the material [9]. Due to that, the Acoustic Emission signal contains information about a change of the system condition. Accordingly, a variation of signal characteristics can be used as an indicator for a change in the condition of the system [8].

Further potential of AE based cutting tool monitoring lies in the deduction of workpiece quality findings. Being able to identify the grade of a cutting tip's wear leads to the ability to interpret the very same AE signal concerning the workpiece quality. With this, time consuming and expensive post-manufacturing workpiece measuring could be reduced.

3. Identification of potential quality indicators

After the system of objectives for the quality control system has been defined [12], the resulting information was used for identifying potential quality indicators. For this purpose, quality management methods were used in a two-day expert workshop. Hereby, the machine process and the already identified quality failure, as part of the defined system of objectives, were used as preparation material for the expert workshops.

In a first step, the process models (based on *Icam DEFinition for Function Modeling* - IDEF0) were introduced, checked for correctness and then analyzed for quality failures. The resulting quality failure modes were assigned to machine functions and described in a failure mode and effects analysis (FMEA). For all failure modes the related failure effects were identified and the severity rated.

In the second step, a first prioritization of failure modes was conducted based on each severity rating. Therefore, an upper threshold value of the severity rating was defined together with the project partner. The remaining failure modes were structured and failure causes identified using a fault tree analysis (FTA). As recognizable in the detail of the FTA Fig. 1, the severity of each failure is linked to the quality factors, pointed out by the numbers next to the quality factors.

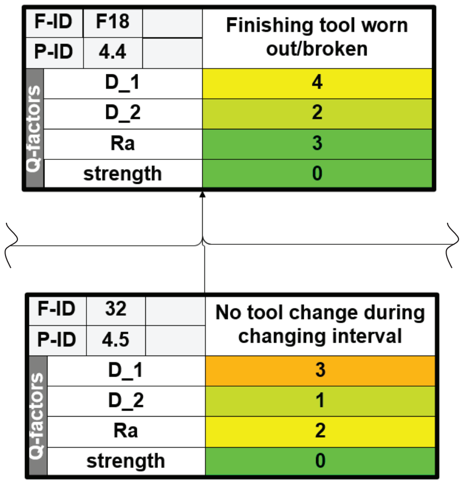

Fig. 1. Excerpt of the FTA – failures linked to the quality indicators

It has proven necessary to understand the failure mechanism of each failure [13] to identify suitable failure predictors or quality indicators. For this purpose, a failure mechanism analysis based on the Contact and Channel Approach (C&C^2-A) [14] was used.