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Quality oriented maintenance scheduling

M. Siener, J.C. Aurich *

Institute for Manufacturing Technology and Production Systems, University of Kaiserslautern, Kaiserslautern, Germany

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ABSTRACT

In this paper, a concept is presented which enables maintenance scheduling to orient its processes at product quality. The central element of the concept is an artificial neural network. It allows predicting the influence of individual machines on final product quality based on expected conditions of quality relevant process objects. Besides the detailed description of the concept elements and its characteristics, the maintenance scheduling procedure using these elements is introduced. Furthermore, a use case is presented to show exemplarily how the concept for quality oriented maintenance scheduling could be applied within the production.

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1. Introduction

Besides the process parameters (e.g., forward feed, cutting speed and feed motion), conditions of process objects like machine components, tool components and auxiliary substances significantly affect the results of production processes and consequently the quality of the final products. The condition of process objects is described by the characteristics of the process objects which are influenced by deterioration. In the following, the characteristics which describe the condition of process objects or its components are named condition characteristics. While the influence of process factors on final product quality is already considered in quality management, the influence of the afore mentioned process objects is mostly not regarded.

The condition of process objects is however the subject of maintenance. But the majority of present maintenance approaches focus mainly on the availability of the process objects and less on their capability to ensure the process stability respectively the resulting product quality. Consequently, associated methods for maintenance scheduling are not designed to orient the scheduling process of maintenance tasks at the product quality. As a consequence machine, tool or auxiliary substance related rejects are produced. This leads to additional costs especially in processes with high added value or without the opportunity for subsequent work. Due to the increasing demand for higher quality and more efficient production processes, additional concepts have to be provided which enable a systematic orientation of maintenance scheduling at the product quality.

* Corresponding author.
E-mail addresses: martinsiener@gmx.de (M. Siener), aurich@cpk.uni-kl.de (J.C. Aurich).

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2. State of the art

2.1. Maintenance planning

Maintenance planning is one of the main challenges within the maintenance of industrial enterprises. It comprises every process which is necessary to schedule and to execute proactive maintenance tasks within the production. Maintenance planning processes are aligned with maintenance objectives. Typical objectives are the availability or reliability of the machinery [1]. Maintenance strategy planning and maintenance scheduling are the two main processes within maintenance planning.

Within the maintenance strategy planning, maintenance strategies for deteriorating process objects are defined and specified in consideration of the underlying maintenance objectives. Maintenance strategies can be classified as reactive, time-based or condition-based [2,3]. Within the reactive maintenance strategy, maintenance tasks are initiated when a negative impact of deteriorated process objects on the chosen maintenance objectives occurs. Generally, this strategy is used if the scheduling of proactive maintenance tasks is technically not feasible or not cost-effective. Otherwise process objects are maintained under the terms of proactive maintenance strategies. Process objects can proactively be maintained either by using time-based or condition-based maintenance strategy. Beside the selection of the proper maintenance strategy, the specification of maintenance intervals and of the critical conditions of maintainable process objects is a further challenge of the strategy planning. Within maintenance scheduling, the critical conditions of maintenance objects and maintenance intervals are used to schedule proactive maintenance tasks throughout the planning period.

2.2. Maintenance planning approaches

Different approaches exist to cope with the challenges of maintenance planning. In the following, first the maintenance planning procedures within Reliability-centered Maintenance (RCM) and Total Productive Maintenance (TPM) are introduced. Then approaches are presented which provide different methods to support maintenance planning procedures.

2.2.1. Reliability-centered Maintenance – RCM

The objective of RCM is to sustain the reliability of machines within the production. The reliability is defined as the capability of a machine to perform its intended function under stated conditions without failure for a given period of time. RCM provides a framework of different countermeasures to avoid negative impacts on reliability [4–6]. One of these countermeasures is the scheduling and realisation of proactive maintenance tasks at the machines within the production.

As preparatory work each component is classified due to its typical failure pattern. The results of the analysis are used to decide, whether to maintain the component reactive, time-based or condition-based. The intervals for time-based maintained components and the condition states for condition-based maintained components are determined in long term studies. Within these studies, the impact on reliability is used as indicator to identify the optimal length of maintenance intervals and the critical condition states of a machine. The time intervals and critical condition states are used to schedule maintenance tasks within the planning period [6].

2.2.2. Total Productive Maintenance –TPM

Total Productive Maintenance (TPM) aligns its maintenance planning process with the Overall Equipment Effectiveness (OEE) [7,8]. The OEE is the product of the availability, the performance rate and the quality rate of the machine. TPM relies on the analysis of critical points of the machine and the organisational integration of workers for simple maintenance tasks to optimise the OEE. Beside these measures scheduling and executing proactive maintenance tasks are also recommended to improve the OEE of the production.

Similar to RCM, only a framework of specifications for the maintenance planning process exists [7]. Among other specifications the use of condition-based and time-based maintenance strategies are recommended. TPM focuses predominantly on the organisational implementation of maintenance planning within the production [8]. Consequently, methods which are aligned with OEE for determining the maintenance strategies and scheduling time- or condition-based initiated maintenance tasks are only superficially described.

2.2.3. Maintenance planning approaches

The prediction of deterioration and of its effects on the production is a central challenge within maintenance planning approaches. The main part of the models which are used to predict expected machine conditions are based on historical data or data from long term studies about the condition of the machine or its components. From these data, probability models like the Weibull distribution are derived which describe the typical deterioration process of a component [9–12]. In some cases geometric models of maintenance objects are used to simulate the deterioration process [13,14].

Beside prediction models, methods which deliver information about the impact of deterioration on the maintenance objectives are needed. One part of the methods integrates the impact model into the predicting model [10,13,14]. Other approaches use methods of decision theory for scheduling the proactive maintenance tasks in accordance with the maintenance objectives [15–18]. In most cases the reliability is used as the main objective [10,12,19]. Beside reliability, availability [16,18] and total maintenance costs [10,19] are the most favoured maintenance objectives.

2.3. Resulting areas of action

Current maintenance planning approaches focus mainly on the impact of deteriorated machine components on reliability, availability, performance, safety or environment. The associated methods and procedures for maintenance planning are merely designed to align the maintenance processes with these objectives. Product quality is mostly a subordinated objective within the existent maintenance planning approaches. However, due to the fact that companies can only be successful, if they manufacture products which fulfil customer demands, product quality should be the leading objective of an maintenance planning approach.

Therefore, concepts have to be provided which enable the existent maintenance approaches to orient its maintenance planning process at the product quality while still considering the other objectives. These concepts should be designed as a supplement for existent maintenance approaches. An approach which aligns maintenance strategy planning with product quality was already illustrated in a previous paper [20]. In the following paragraphs, a concept is presented which enables the quality oriented scheduling of maintenance tasks.

3. Framework of the concept

3.1. Elements of the concept

The concept for quality oriented maintenance scheduling consists of two main elements. The first element provides the scheduling process with information about the expected conditions of the process objects throughout the scheduling period. The second element uses the predicted conditions to anticipate the impact on the product quality.

3.1.1. Predicting of process object conditions

Within the concept, a time-based method is used to predict the conditions of the process objects. The method is based on the assumption that the execution of the same class of processes on the same machine leads always to the same complex of loads acting on the process objects. The processes can be classified by any criteria which is able to represent the load intensity of the processes. As an example, the different product types which are processed on the machine can be used as a simple criterion to classify the processes. The advantage of this approach is that the operating times related to a process class can simply be derived from the production scheduling. Further it is assumed that a defined complex of loads leads on identical process objects to similar deterioration results. Following these assumptions, it is possible to describe process object conditions indirectly by using the related operating times of every process class which is executed on the affected machine.

Therefore, for each process object a time observation sheet (Fig. 1) is designed which is able to log the operating times of the different process classes. The structure of the time observation sheet depends on the number of different process classes which can be executed on the machine, the scale used for the time axis and the different possible maintenance tasks which can be applied to the process object. The time observation sheet is designed as a table. The time axis is noted in the first column. Each row represents the condition of the process object for the date noted at the head of the row.

The condition of the process object is described depending on the different possible maintenance tasks which can be applied to

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