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Use of Life Cycle Data for Condition-Oriented Maintenance

M. Winkens, M. Goerke, P. Nyhuis

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***Abstract*—**This technical contribution treats of a novel approach to condition-oriented maintenance as elaborated by Collaborative Research Centre 653 at the Leibniz University in Hanover. The objective resides in the targeted analysis of information about a component's lifecycle for maintenance purposes. The information in question is collected by means of the Collaborative Research Centre's innovative technologies. This enables preventive maintenance of components on the basis of their condition. This contribution initially explains condition-oriented maintenance, before introducing the Collaborative Research Centre and finally presenting the methodology for analyzing the information. The current state of development is described and an outlook provided for expanding the methodology.

***Keywords*—**Gentelligent Components, Preventive Maintenance, life cycle data.

I. Condition-Oriented Maintenance

MAINTENANCE is a key success factor for manufacturing companies [1]. It is meanwhile defined as the combination of all technical and administrative activities and management measures dedicated to restoring the functional condition during the lifecycle of a unit so that the required function can continue to be served [2]. The literature differentiates between three different maintenance strategies - reactive, preventive and condition-oriented [3]. Current studies indicate potential cost savings of up to 30% if a condition-oriented maintenance strategy is applied. What this requires are modern condition-oriented maintenance approaches [4]. The attendant challenge concerns the ability to determine a component's condition precisely. The current service life of a component must be known at all times to enable its preventive replacement before failure. Selecting the latest possible replacement date meanwhile helps to make full use of a component's remaining service potentials. In addition to this, condition monitoring also serves to markedly reduce the probability of failure in comparison with the other two maintenance strategies [5]. High availability can thus be ensured for the entire plant. Despite these advantages, condition-oriented maintenance is not widely applied yet. Instead, many systems are subjected to preventive maintenance cycles. The consequences are planned, but partly unnecessary downtimes of plants that are actually fully functional [6]. System components are being exchanged before their remaining service potentials have been put to full use. Amongst other reasons, condition-oriented maintenance is not being introduced because determining a component's condition with the existing approaches is labour-intensive and because reliability models are not making sufficient use of real data [7]. Another obstacle is the fact that monitoring approaches for wear and tear are already known as condition-monitoring, while fatigue monitoring hardly exists in practice, given the high cost involved [5]. The importance of material fatigue should not be underestimated, however, because its consequences will set in spontaneously and hence unpredictably, in the form of fatigue fractures. The deterioration in a material's stability, and that of the components made from it, often proceeds quietly, imperceptible from the outside as a process. This leads to unscheduled and usually maintenance-intensive plant downtimes. The maintenance approach developed by the Research Centre is hence focused on material fatigue and shows solutions enabling a component's fatigue status, and hence maintenance requirements, to be determined before it fails.

M. Winkens is with the Institute of Production Systems and Logistics, Leibniz University Hannover, An der Universität 2, Germany 30823 Garbsen (phone: 0049-511-76218131; fax: 0049-511-3814; e-mail: winkens@ ifa.uni-hannover.de).

M. Goerke is with the Institute of Production Systems and Logistics, Leibniz University Hannover, An der Universität 2, Germany 30823 Garbsen (phone: 0049-511-76218181; fax: 0049-511-3814; e-mail: goerke@ ifa.uni-hannover.de).

P. Nyhuis is Head of the Institute of Production Systems and Logistics, Leibniz University Hannover, An der Universität 2, Germany 30823 Garbsen.

II. Collaborative Research Centre 653 – Gentelligent Components in Their Lifecycle

The Collaborative Research Centre 653 (CRC 653) at Leibniz University in Hanover has been engaged in researching technologies and methods in the field of production engineering since 2005. The vision of CRC 653 is the creation of intelligent, communicative and adaptive components and systems that are modelled on nature, and the development of what is referred to as gentelligent components. Gentelligence, a contraction of the words genetics and intelligence, describes the ability of components to collect and analyse information during their lifecycle, and pass it on to later generations [8]. The attendant focus is on the lifecycle stages design, production and utilization (Fig. 1).

Technologies have already been developed, and their functionality demonstrated [9]. These technologies are for example integrated in a sensitive machine tool and a sensitive component, permitting stress information to be collected in the production and utilization stages [10], [11]. The collected information can be compiled directly in the component, in an inherent memory, and exchanged by means of inherent transmission technologies [12], [13].

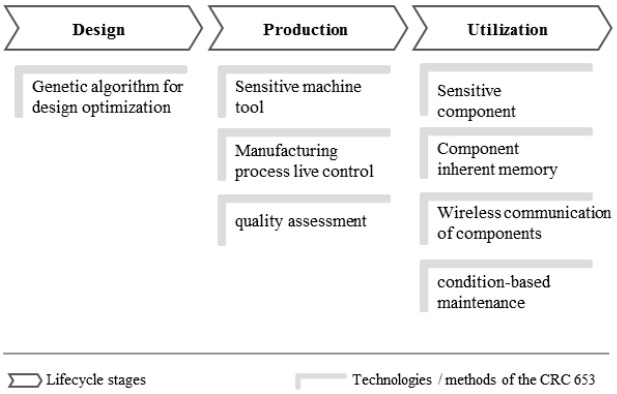


Fig. 1 Research topics of CRC 653

The information serves as a basis for designing performant processes. Live control of the manufacturing process and quality assessments are provided on the basis of cutting forces, for example [14], [15]. The design stage uses information about the stress experienced by structurally identical components to provide later component generations with an optimal design [16]. In addition, the technologies developed at CRC 653 offer new potentials for the performance of condition-oriented maintenance. This for example includes the ability to collect maintenance-relevant information during a component's lifecycle and store it inside the component with little effort. This information could concern the stress a component is exposed to in the utilization stage, for example, but also forces and temperatures its material was subjected to in the manufacturing process.

III. Demonstrators and Lifecycle Information

Two demonstrators have been set up to illustrate the developed technologies, one a machine tool and the other a racing car prototype.

They are based on conventional systems, furnished with gentelligent attributes by the replacement of key components. The machine tool was provided with a sensitive tool slide and a sensitive clamping system. In the racing car, parts of the wheel suspension were replaced by sensitive components. The demonstrators show the lifecycle of a component. The observed component is a wheel carrier. This wheel carrier is made in a sensitive machine tool (production stage) and then installed and put under strain (utilization stage) in a racing car prototype, see Fig. 2.

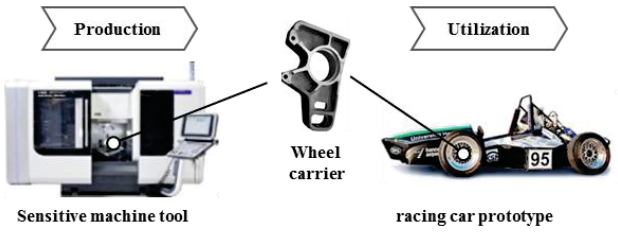


Fig. 2 Demonstrators of CRC 653

Utilization changes the condition of the wheel carrier, and hence its remaining utilization potential. The maintenance requirements are derived by analysing information about its lifecycle. The maintenance-relevant information being tracked at CRC 653 is shown in Fig. 3 and described below.

The design stage involves the creation of a manufacturing plan and definition of a marking for the component. This information is stored inherently in the component by the defined inclusion of foreign particles in its actual material. This ensures the realization of an unforgeable marking [17]. In the production stage, the wheel carrier is machined in the sensitive machine tool. The machine's sensitive properties permit the attendant process forces to be registered in real time. The machine is able to register mechanical and thermal loads [18].

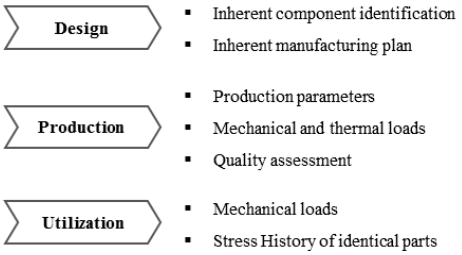


Fig. 3 Lifecycle information at CRC 653

The machining is followed by the creation of a quality log including assessment results for geometrical deviations, the surface quality and surface tension, and process parameters such as the feed rate, cutting speed and infeed [19]. The wheel carrier is next installed in the racing car and put under strain. The innovative sensitive material the wheel carrier is made from permits continuous registration of the mechanical loads applied in its use. It is made from a novel magnetic magnesium alloy that permits conclusions to be drawn about load levels from strain-induced changes in the density of the magnetic flux [20].

IV. Methodology for Condition-Oriented Maintenance

A methodology is being developed for evaluating the information from the lifecycle. It determines the current condition of the component and then predicts the remaining service life, while deriving preventive maintenance measures on this basis. The methodology is arrived at in two phases. The first phase is focused on evaluating information from the utilization stage. The second phase involves an additional analysis of information from the production stage to determine the condition of the component, thus ensuring that all the information about the lifecycle is taken into account.

The first phase has already been completed, and the results have been published. References [21] and [22] describe the individual steps of the elaborated methodology in detail. The following will provide a brief summary. The first step is an analysis of the strain levels applied to the monitored wheel carrier. These are transferred to strain collectives and then mathematically converted into partial damages. To do this, the

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linear approach to damage accumulation has been expanded so that information about the sequence and point in time of strains that also have an influence on a component's lifetime can be taken into account. The second step serves to classify the determined individual damage history of the monitored wheel carrier and compare it with that of structurally identical components. This helps to identify components with similar impairments. The failure times of these identified components are then statistically analysed to predict the remaining useful life of the wheel carrier. To do this, the failure times are grouped in failure classes (Cn). The latter serve as a basis for calculating the probability of failure (P(F)). The distribution of failure probabilities narrows down the time range to be expected for failure, as illustrated in Fig. 4 by way of example. A third step now serves to identify suitable maintenance activities on the basis of the predicted lifetime. To this end, the method systematically relies on empirical values by way of case-based reasoning. A suitable maintenance measure for the wheel carrier is selected from filed activities by way of analogy. As a result, the wheel carrier can be serviced preventively, and a spontaneous failure based on material fatigue avoided.

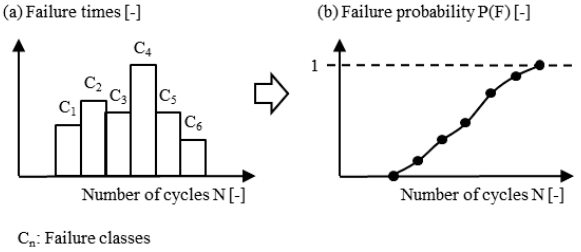


Fig. 4 (a) Histogram of failure times, (b) Failure probability

Reliable forecasting of the remaining service life is essential for determining the maintenance requirements. The forecast narrows the failure time of the wheel carrier down to a defined time period. The probability of failure is calculated within this period (Fig. 4). Trial samples have been exposed to stress and their stress history has been analysed to validate the methodology. The probable failure period could be narrowed down successfully with the methodology, and the probability of the monitored sample's failure calculated [21]. The test results showed different lifetimes despite identical strains. They fluctuated and led to a median variance of around 20 % [21]. The reason being that a component's lifetime is not only determined by the stress experienced in the utilization stage, but also by its resilience. This resilience is individual and depends on the selected material, amongst other factors. The production quality also has an impact that needs to be considered [23]. The second phase is hence aimed at expanding the methodology in a manner ensuring that maintenance-relevant information from the production stage will also be considered for determining the maintenance requirements, besides the information from the utilization stage. The manufacturing process considered by way of example is that of machine cutting. The latter is performed using a sensitive machine tool. Continuous and discrete features are registered in the process. This for example includes the determination of a mechanical and thermal load curve. Available in addition to this is information on all the manufacturing parameters of the machine cutting process such as the feed rate, cutting speed and infeed. The latter affects the surface roughness and surface tension, and therewith the resilience of a component. The objective resides in enabling a connection to be established between the manufacturing information and later resilience of a monitored wheel carrier, and to be described in a model. Consideration of the strains and individual resilience serves to further narrow down the component's predicted failure range, thereby improving the forecasting of its service life.

V. Conclusion

Maintenance is a key success factor for manufacturing companies. The approaches pursued by CRC 653 harbour potentials for enabling more efficient maintenance by registering lifecycle information. Material fatigue is rarely taken into account today because of the high costs involved. But precisely this cause of unforeseen failure will lead to cost-intensive production downtimes and maintenance activities. The CRC 653 maintenance approach is hence focused on material fatigue and enables information to be stored inside the component and passed on, on the basis of the sensitive materials being researched. The introduced methodology uses this information to narrow down the time of failure to a defined time period. Initial trial results highlighted a need to also consider further lifecycle information in addition to the strain information from the utilization stage. The methodology is therefore expanded by an analysis of information from the production stage in a second phase. This is aimed at rendering the prediction of lifetimes more precise, in order to allow the remaining use potentials of components to be exploited with greater safety.

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