World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:9, No:1, 2015

Determining a Suitable Maintenance Measure for Gentelligent Components Using Case-Based Reasoning

M. Winkens, P. Nyhuis

Abstract**—**Components with sensory properties such as gentelligent components developed at the Collaborative Research Centre 653 offer a new angle in terms of the full utilization of the remaining service life as well as preventive maintenance. The developed methodology of component status driven maintenance analyzes the stress data obtained during the component's useful life and on the basis of this knowledge assesses the type of maintenance required in this case. The procedure is derived from the case-based reasoning method and will be explained in detail. The method's functionality is demonstrated with real-life data obtained during test runs of a racing car prototype.

Keywords**—**Gentelligent Components, Preventive Maintenance, Case based Reasoning.

I. Gentelligent Components in Their Life Cycle

CURRENT approaches in preventive maintenance neglect monitoring and interpretation of material fatigue, as the assessment of fatigue status during the operational phase is very difficult [1]. In spite of preventive maintenance there might be cost-intensive sudden failures due to material fatigue [2]. Gentelligent components are a new option for determining fatigue status [3]. Since 2005, "Gentelligent components in their life cycle" are explored and developed at the Collaborative Research Centre 653 (CRC 653). The CRC's vision is to create intelligent and adaptive components. For this purpose, these components are enabled to absorb information from their environment, process it further and pass it on to subsequent component generations [4]. The detection of environmental influences such as the stresses a component is exposed to during its service life and passing this information on to subsequent generations enables the adaptation of components to current requirements. This is done by adjusting the component shape in subproject “Algorithmic design evolution based on product lifecycle information” [5].

The stresses detected in the service life of the component are also included in the determination of maintenance requirements. The maintenance method was developed by subproject “Component status driven maintenance“. It aims at analyzing the obtained stress data and determines preventive maintenance measures on the basis of these data in order to prevent stress-fatigue related component failure and to take full advantage of the component’s remaining service life [6]. The sensory properties of the gentelligent components allow stress data to be collected without great effort. In this context, an innovative magnetic magnesium alloy is used. It allows continuous detection of individual stresses in the course of the component's life. This new alloy was developed in subproject “Magnetic magnesium alloys” [7].

Fig. 1 Race car prototype with gentelligent wheel carrier

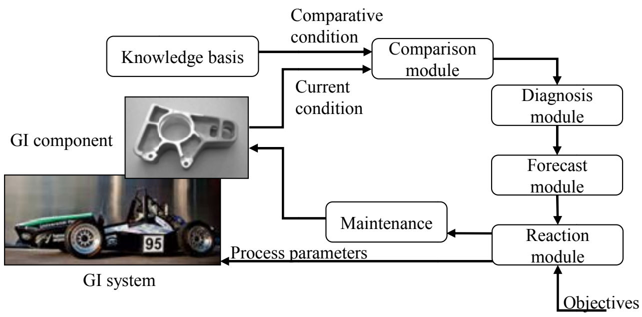

Fig. 2 Component status driven maintenance control loop

A wheel carrier made of this innovative material was used for validation and demonstration purposes. The wheel carrier was installed in a race car prototype, see Fig. 1. The test runs served to collect stress information, thus proving the material's sensory properties. The data were read out during pit stops and evaluated by using the maintenance method. The method then determined a suitable maintenance measure to be carried out at this time.

II. Component Status Driven Maintenance Method

The procedure of this maintenance method can be illustrated by means of a control loop.

A. Maintenance Control Loop

The control loop includes a knowledge basis, a comparison, diagnostic, forecast, and reaction module, see Fig. 2 [8]. In order to evaluate the stress data, the control loop modules are processed sequentially. The results from the first modules are

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).

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

the input parameters for the subsequent modules. Finally, all module results are used to identify a suitable maintenance measure in the reaction module. The results of the comparison and forecast module are of particular importance and are presented next.

B. The Comparison and Forecast Module

The first evaluation of the detected stress data is carried out in the comparison module. Inspections verify the occurrence of any unusual operational loads up to this time. Such excessive stresses might for example be due to impacts on the wheel carrier caused by driving over a high speed bump. The information gained from the gentelligent wheel carrier during the test run resulted in the stress profile shown in Fig. 3. The maximum load is 1,432 MPa which is equal to the stress level of the components from the knowledge basis [8]. As a whole, only usual operational stresses were detected. The result of this comparison is passed on as a binary value to the reaction module [9].

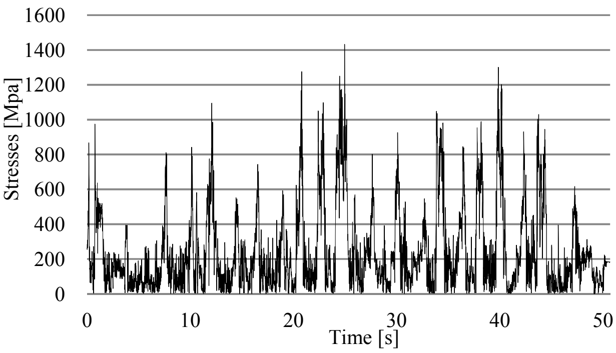

Fig. 3 Stress profile of the gentelligent wheel carrier during the drive on a circuit track

The forecast module now determines the remaining service life of the current component and again uses the stress profiles of the components in the knowledge basis. The evaluation of comparative characteristics identifies components with similar stress profiles. Due to the similar stresses that occurred until the pit stop it has to be assumed that future stresses of the current component are of a similar nature as in the identified components. A statistical analysis of the time of failure of these components is carried out to estimate the current component's remaining service life [9]. The remaining service life is indicated on a percentage basis as a function of service life. The obtained characteristic value is then passed on to the reaction module.

III. Determination of a Suitable Maintenance Measure

The reaction module evaluates the input parameters in order to determine a suitable maintenance measure for the current component. The algorithm that the module is based on is modelled after the case-based reasoning method.

A. Case-Based Reasoning Method

In case-based reasoning (CBR), solutions are chosen from a set of solutions that were previously developed for problems similar to the current one. These are then adapted and applied to the problem at hand [10].

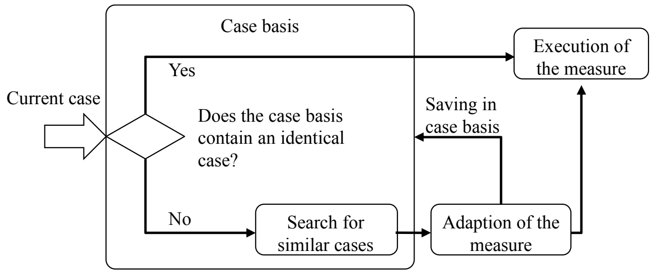

Fig. 4 Method of case-based reasoning, modelled after [10]

The reaction module's general process is modelled after this method, as shown in Fig. 4. A case is created at the time of the pit stop which describes the current state of the wheel carrier. A set of characteristics were defined for this purpose. The results of the individual modules serve as characteristics and include the remaining service life and examination for unusual operating stresses. The current case is the problem to be solved. The desired solution is a suitable maintenance measure for the wheel carrier's current state. For the purpose, an algorithm is used to extract similar cases from the case basis. For the cases on file, component states and performed measures are known. The algorithm identifies all cases and determines the degree of conformity with the current case. If a case is fully conforming, the measure used for this case is also applied to the current case. If similar cases exist, the maintenance staff chooses a measure. If required, this measure might be adapted before it is applied to the case. The performed measure is then linked with the current case and filed in the case basis, see Fig. 4.

B. Algorithm for Determination of Identical or Similar Cases in the Case Basis

The algorithm evaluates all characteristics relevant to the case. These consist of the results from the comparison and forecast module. Component master data such as component type or component ID are also used. Furthermore, the maintenance staff needs information on the planned operating time (PT). This time (until the next pit stop) has to be known, because it is not possible to perform another evaluation or carry out maintenance activities during this time. All case-relevant characteristics are listed in Table I.

The algorithm aims to identify cases from a multitude of cases that are similar to the current one. For the purpose, the algorithm processes the characteristics from the individual cases in a sequential manner. The procedure is illustrated by a Nassi-Shneidermann diagram, see Fig. 5. This diagram type was chosen, because it breaks down the procedures into the essential basic structures in a clear manner [11]. The algorithm is subdivided into two sequential queries and three subsequent sequences. The sequences serve to identify comparative cases and are initiated depending of the two query results.

TABLE I
CHARACTERISTICS FOR AN UNAMBIGUOUS DESCRIPTION OF A CASE

Symbol	Characteristic feature	Unit	Source
-	Component type	-	Master data
ID	Identification number	-	Master data
OH	Operating hours	s	Comparison module
SC	Stress comparison[a]	-	Comparison module
MS	Maximum stress	MPa	Forecast module
SL	Remaining service life	s	Forecast module

[a]The result is a Boolean value.

The first query is the stress comparison (SC). In this step, the value obtained from the comparison module is analyzed. If a "0" was transmitted for the current case (CC), this means the component was subjected to more than just normal operational stresses. Thus, the result of the first comparison is "no". Sequence 3 is started in order to identify comparative cases. If the result of the comparison is "yes", the component only experienced normal operational stresses. The next query that is performed is the comparison of remaining service life (CSL). In this step, the values for remaining service life are compared with the planned operating time. If the value for remaining service life is higher than the planned operating time, the result is "yes". Then sequence 1 is run in order to identify comparative components. If the result of the second query is "no", sequence 2 is started.

1. Sequence 1 (Fig. 5, left column)

Sequence 1 is started if there are normal operational stresses in the current case and the planned operating time is shorter than the remaining service life forecast. Now the sequence is looking for cases, the characteristics of which show the same profile. For this purpose, it processes each case in the case basis in a sequential manner. If one case shows the same profile during stress comparison and service life comparison, the case is classified as a comparative case. Then the degree of conformity with the current case is computed. For the comparative case, this is done by calculating the maximum conformity of operation hours (COH) by using (1), maximum stress level (CMS) by using (2) and remaining service life (CSL) by using (3).

$$\mathrm{COH}_{\mathrm{i}} = 1 - \frac{|OH_{cc} - OH_i|}{OH_{cc}} \tag{1}$$

$$\mathrm{CMS}_{\mathrm{i}} = 1 - \frac{|MS_{cc} - MS_i|}{MS_{cc}} \tag{2}$$

$$\mathrm{CSL}_{\mathrm{i}} = 1 - \frac{|SL_{cc} - SL_i|}{SL_{cc}} \tag{3}$$

An overall conformity is calculated on the basis of individual matches. Then the comparative cases are sorted by overall conformity in descending order.

2. Sequence 2 (Fig. 5, centre column)

Sequence 2 is started if there are normal operational stresses in the current case, but planned operating time exceeds the remaining service life forecast. Then the result of the remaining service life comparison is "no". Special measures are called for if the component is used as before and a failure is bound to occur before the next pit stop. First, the sequence computes the service life deficiency (SD) based on the remaining service life forecast and calculates the planned operating time of the current component by using (4).

$$\mathrm{S}D_{\mathrm{i}} = SL_i - PT_i \tag{4}$$

In the subsequent loop, the individual cases in the case basis are checked.

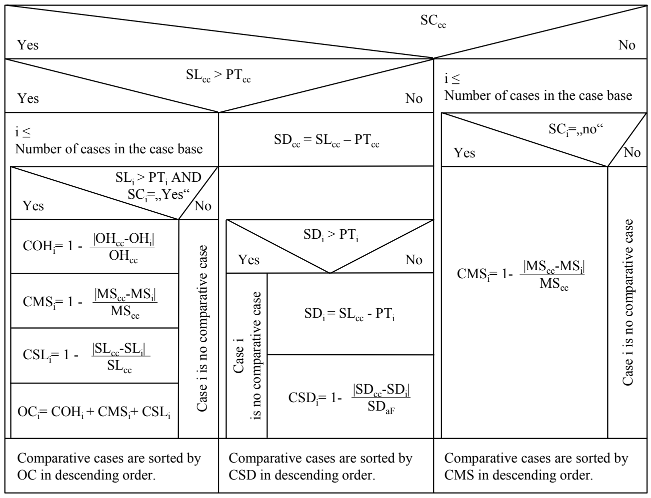

Fig. 5 Algorithm for identification of comparative cases

This step identifies those cases, which also show a service life deficiency. These are classified as comparative components.

Using (5) the conformity of service life deficiency of these components is calculated based on the current case (CSD).

$$CSD_{\mathrm{i}} = 1 - \frac{|SD_{cc} - SD_i|}{SD_i} \tag{5}$$

Then the comparative cases are sorted by conformity in descending order.

3. Sequence 3 (Fig. 5, right column)

Sequence 3 is started if the result of the stress comparison is "no". During the use of the current component there were more than just normal operational stresses. The sequence starts with a loop. As a first step, this loop identifies all cases in the case basis of which the stress comparison render a negative result. Next, the degree of conformity of these comparative cases is calculated for the current case by using (1). Then the comparative cases are sorted by degree of conformity.

All three sequences end with issuing a sorted list of comparative cases. This way, the algorithm concludes the search for similar cases in the case basis. The list of comparative cases is then provided to the maintenance crew, who represent the last level of decision-making. The crew selects a comparative case with maintenance measures. This selection is based on the ranking of comparative cases as provided by the algorithm. Based on its expert knowledge, the maintenance team adapts the measure to the current case and applies it in a final step.

IV. Conclusion

Based on stress data obtained from gentelligent components, the maintenance method determines suitable, knowledge-based maintenance measures. The reaction module approach for identifying suitable measures is modelled after the case-based reasoning method. The method has been partly validated. Its functionality has been proven with real data collected during test runs. The case basis was established with partly construed cases, because the number of test runs was not sufficient for building up an extensive case basis that can be evaluated statistically. In the future, the sensory properties of gentelligent components will enable the wide-spread application of sensory components and thus a rapid development of an extensive case basis.

Acknowledgment

The work presented was carried out within the scope of the collaborative research centre 653 "Gentelligent components in their life cycle". The authors thank the German Research Foundation (DFG) for its financial and organisational support for this project.

References

[1] Madsen, H.O.; Torhaug, R.; Cramer, E.H. (1991): Probability-based cost benefit analysis of fatigue design, inspection and maintenance, Marine Structural Inspection, Maintenance and Monitoring Symposium, Arlington, Virginia, March 18–19 1991, Society of Naval Architects and Marine Engineers.
[2] Strunz, M. (2012): Instandhaltung. Berlin, Heidelberg: Springer Berlin Heidelberg.
[3] van Thiel, B. (2013): Entwicklung einer Methodik zur Zustandsüberwachung von Bauteilen aus sensitiven Werkstoffen. Berichte aus dem IFA, 1.
[4] Denkena, B.; Henning, H.; Lorenzen, L.-E. (2010): Genetics and intelligence: new approaches in production engineering. Production Engineering, 4-1, p. 65-73.
[5] Lachmayer, R.; Mozgova, I.; Sauthoff, B.; Gottwald, P. (2013): Product Evolution and Optimization based on Gentelligent Components and Product Life Cycle Data. Smart Product Engineering, 23rd CIRP Design Conference, Bochum.
[6] Winkens, M.; Busch, J.; Nyhuis, P. (2013): Method of component-status-driven maintenance for gentelligent components. 19th international conference JAABC - The Journal of American Academy of Business, New York, p. 111-117.
[7] Klose, C.; Demminger, C.; Mroz, G.; Reimche, W.; Bach, Fr.-W.; Maier, H.J.; Kerber, K. (2013): Influence of Cobalt on the Properties of Load-Sensitive Magnesium Alloys. Sensors 2013,13-1, p. 106-118.
[8] van Thiel, B.; Nyhuis, P. (2010): Database for a Gentelligent Maintenance Planning. 15th Annual International Conference on Industrial Engineering - Theory, Applications & Practice, Proceedings of the IJIE.
[9] van Thiel, B.; Winkens, M.; Nyhuis, P. (2012): Forecasting Component Service Life by Gentelligent Components. 1st Joint International Symposium on System-Integrated Intelligence: New Challenges for Product and Production Engineering, Hannover, p. 142-144.
[10] Freudenthaler, B. (2008): Case-based Reasoning (CBR), VDM Verlag Dr. Müller, Saarbrücken.
[11] Küveler, G.; Schwoch, D.(1999): Informatik für Ingenieure. 2. Aufl., Vieweg Verlag, Braunschweig.