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Failure prediction of diesel engine based on occurrence of selected wear particles in oil

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ABSTRACT

When assessing reliability, the principles of system failure prognostic are basic requirements. Condition-based maintenance is more demanding when estimating a system failure and residual/remaining technical life time (RTL). This paper introduces analytical and prognostic methods used for assessing system material wear to predict a failure occurrence. The principles presented in the article are based on indirect but real diagnostic oil data. We concentrate on wear metal particles such as iron (Fe) and lead (Pb) as potential failure indicators. Our approach is very different from other papers published in this area as their data were often artificial or viewed as potentially useful, but they never existed. The advantage and novelty of the outcomes presented in the article are that they might be used mainly for predicting failure occurrence and also for optimising intervals of preventive maintenance (PM), analyzing cost-benefit and planning operation/mission.

1. Introduction

Reliability, safety and availability of complex and time dynamic systems such as mechatronics, communication, space and smart systems has attracted more and more attention in recent years, see e.g. [1]. The systems we would like to present work in various and mostly adverse operating conditions due to their applications. System failure, as defined in [2], is the termination of the ability to perform a required function. According to a general classification we divide failures into "soft" and "hard" ones, as stated in [3]. In our case we do not assume that a hard failure would occur suddenly, without any preliminary "warning". A hard failure occurs when degradation reaches its upper limit, as put in [4]. Failure prediction and condition-based maintenance have become attractive research areas in the past decades, see e.g. [5–8]. But despite this fact, for the equipment under our observation there is no link, guideline and firm threshold for fixed time maintenance intervals specified in standards such as IEC, ISO, or specific ones such as MIL-STD and STANAGs. The majority of operation times and maintenance procedures, specifically the PM intervals, are firmly given and based on historical observations, similar products' experience or expert decisions. However, the firm limit of operating time and PM intervals are obsolete and very rigid in terms of current technical needs. Real-time reliability and availability assessment may play a vital role in service operation and in condition-based maintenance. This may help to make further maintenance and operation optimisation decisions, see e.g. [8,9]. For example in [10] there is a problem to predict the real-time conditional reliability of an individual tool after its performance data were obtained. In [11] there is proposed an on-line reliability estimation method of an individual

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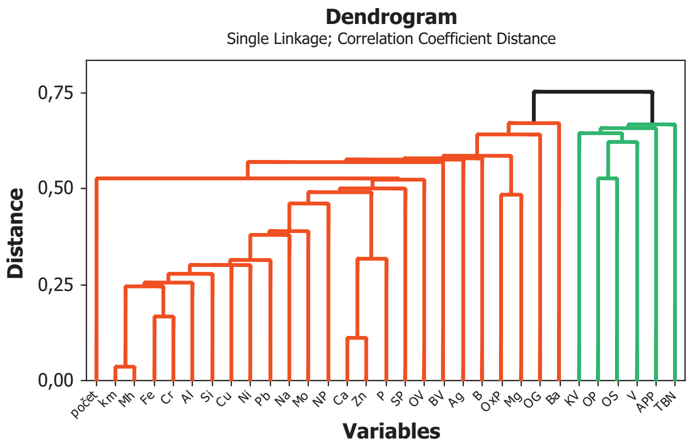

Fig. 1. Hierarchical cluster dendrogram for observed variables.

component based on degradation signals in which the performance was modelled. The products with exponential degradation paths were studied e.g. in [12], while degradation signal modelling based on exponential smoothing was modelled e.g. in [13,14] – there are the degradation measures with finite duration impulses. In [15] the authors addressed the existence of multivariate performance measures, and in [16] there is an approach which combines degradation process monitoring with environmental variation.

In our article we do not focus only on determining a system state, but mainly on predicting a failure. A failure, either soft or hard, occurs when the degradation rate reaches its critical limit, lower or upper. The filed data we possess have been obtained both due to parts syntactic methods (AES – Atomic Emission Spectrometry) and morphology observation (FTIR – Fourier Transformation Infra Red and LNF – Laser Net Finder). Both of these methods are offline methods analysing oil samples of very small volume. Procedure of taking oil samples is based on certified methodology and is described in the following section on "Origin of the data". On the basis of this data we present the indicators which describe system and material real deterioration. As the oil data come from oil taken straight from the system, our approach is probably the most accurate way of determining system state and degradation. The course of degradation as introduced in our paper indicates indirectly a coming failure. The degradation is expressed by function g as a respective continuous process Z in time t which acquires random values of a degradation measure X: $Z(t) = g(t, X)$. A critical failure threshold is for a soft failure designated as X_S and for a hard failure X_H. Our aim is to model the degradation in time with cutting metals Fe (iron) and Pb (lead) on the basis of the results of field data analysis. We are going to simulate the degradation numerically until we get the thresholds X_S, X_H since we know critical values for single elements Fe and Pb. The reason why we have selected the elements Fe and Pb is that the tested mathematical correlation rate from operating time is the highest. The Fe represents group of elements with similar way of correlation on Mh (Motor hours) and calendar time. While Pb represents group of other elements with different way of correlation on Mh and calendar time. Both Fe and Pb has the highest correlation rate therefore we chose these elements not from traditional mechanical point of view only. We also implemented clustering methods like hierarchic and non-hierarchic for supporting the correlation rate calculation. All of the outcomes indicated the same results for our decision to deal with Fe and Pb particles. Those elements are also natural from the mechanical perspective as they are main and significant building metals in major kinematical joints. Example of the hierarchic cluster dendrogram for observed variables is on the Fig. 1. The visual outcome is made in the software MiniTab release 16.

The degradation thresholds X_S, X_H will be instants of time of the confidence intervals of probability distribution when a cutting element reaches a critical value. No such previous observations and assessment on operating objects of this size and set volume have been conducted. Previous works, see e.g. [17], do not address very deeply technical observations and tribo-data from special big systems such as diesel locomotives, mine lorries and war ships. Moreover, no investigation to such a degree has been conducted on medium lorries and common road vehicles. We know without any doubt that the tribo data have the real potential to estimate indirectly failure occurrence and show a system condition.

Therefore we hope that based on our analytical principles presented here it will be very much possible to predict failures and plan preventive maintenance, costs, and mission. The paper is subdivided into five sections. The Section 2 is devoted to Motivation and Data Origin, in 3rd section there is a literature survey, 4th section addresses assessment and modelling, and finally 5th section contains Outcomes and Discussion.

2. Motivation problem and data

There is a vast amount of equipment which the entrepreneurs run in a firmly given exploitation scheme. This scheme covers main activities and actions in the operation and maintenance phase of a technical system life cycle. Unfortunately