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Remaining storage life prediction for an electromagnetic relay by a particle filtering-based method

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ABSTRACT

In this paper, we propose a particle filtering-based method for predicting the remaining storage life (RSL) of electromagnetic relays. The RSL prediction problem here addressed has the following three distinctive features: i) limited measurement data available; ii) incomplete run-to-failure data; and iii) no model available for the physical degradation process. Then, to develop the method for RSL prediction, storage testing and degradation mechanism analysis have been carried out to obtain the knowledge and information needed to develop the physical model that supports the RSL prediction procedure. We discuss the three main steps of the proposed prediction method: parameter estimation, model validation and RSL prediction. Data from nine relays are used for estimating the initial parameter values distribution and data from one relay are used for RSL prediction. The RSL prediction results are compared with those obtained by a nonlinear curve-fitting method and a basic particle filtering algorithm. The comparison shows that the proposed method is more effective in predicting the RSL than the other methods.

1. Introduction

The evaluation of the long-term storage conditions of electronic components has recently become an emerging issue in the military and commercial fields. For example, such evaluation is extremely important for some weapons systems (missile systems) that are required to operate after a long-term storage (about 10–20 years), during which period they are exposed to humidity, temperature cycling and mechanical shocks. To give another example, commercial manufacturers in China use components stored for a long time to make their products, due to purchasing restrictions and inventory management issues. This raises the concerns of storage degradation and storage reliability, particularly for some expensive electronic systems. More generally, it is well known that for the availability of systems in operation, the reliability of spare part components in storage can be quite important: a reliable supply of stored replacement components can guarantee that the systems remain fully functional and ensure business continuity for the design period and beyond. Given the above, accurate reliability prediction of stored components becomes essential.

In this paper, we focus on RSL prediction of electromagnetic relays, which are among the types of relays most widely used in military and commercial applications. The main function of this type of device is to switch high voltage or current by low power circuits [1]. An electromagnetic relay uses an electromagnet to operate a switching mechanism. It also provides isolation between high power circuits and low power circuits. Failure mechanisms of electromagnetic relays during storage have been analyzed as described in Ref. [2]. Failure analysis is used to discover the root mechanisms of failures during storage. The knowledge and information gained through the analysis is needed for building the model of physical degradation to be used for RSL prediction. Furthermore, the prediction of RSL should be based also on measurement data and the prediction results should be updated when new, informative data are collected.

In this paper, the same type of electromagnetic relay used in Ref. [2] has been considered for the development of the prediction method. During storage, these electromagnetic relays are kept in a warehouse at relatively stable conditions of 25 °C and RH 20%. Specific performance parameters are regularly measured to monitor degradation. These measurement data are used for RSL prediction, with the following characteristics: i) limited number of data available - given that measurements might bring undesirable effects on the stored components, the frequency of such measurements is low; and ii) incomplete run-to-failure data - as the storage degradation process is long, it is almost impossible to get complete run-to-failure data.

In general terms, prognostics is concerned with the prediction of future degradation trends and the related remaining life of an equipment [3–5]. Methods for this can be broadly categorized into data-driven and model-based methods [6,7]. Model-based methods use a physical model and some measurement data to estimate model parameters

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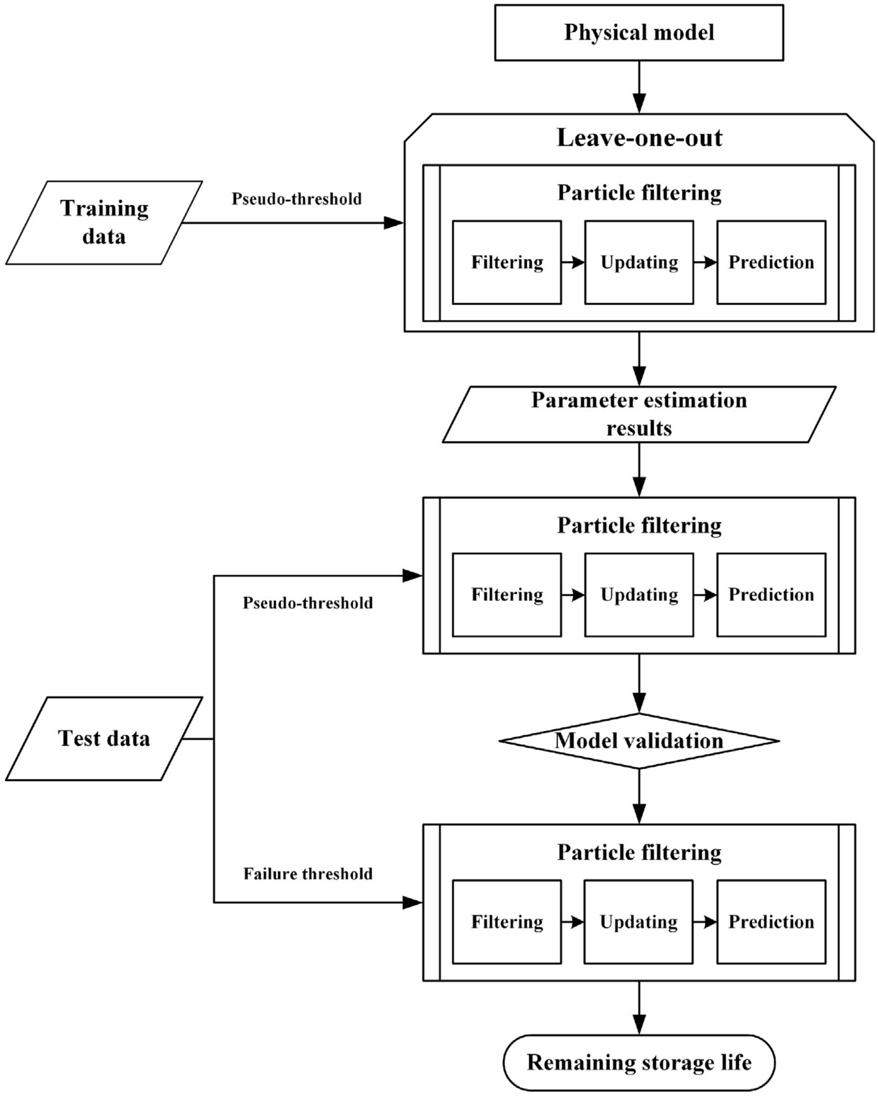

Fig. 1. The proposed RSL prediction method.

and predict future trends [8]. Within this category, particle filtering (PF) [9,10] is widely used because it can be applied to nonlinear models. One drawback of the classical particle filtering method is particle impoverishment [11]. The application of PF for remaining useful life (RUL) prediction of electronic components has been widely studied. In Ref. [12], an on-line particle filtering-based framework was proposed, which considered the implementation of two autonomous modules. In Ref. [13], an improved unscented particle filtering was used for predicting RUL of a battery. In Ref. [14], a method combining particle filtering and kernel smoothing was proposed to overcome the problem of particle impoverishment. In Ref. [15], the particle filtering algorithm was applied to model the degradation process of a capacitor. In these works, particle filtering has been applied in cases with such information, in terms of degradation data, parameter distribution knowledge, etc. However, RSL prediction distinctive features are limited measurement data available and scarce knowledge on the prior distributions of the model parameters. The existing approaches are not fit to accurately predict RSL under such conditions.

Specifically, with respect to RSL prediction, there are limited works in the literature. In Ref. [16], a method based on stochastic filtering was used for RSL prediction of a gyroscope. In Ref. [17], a general lifetime prediction model was proposed based on manufacturing yield statistics for microcircuits in storage and non-operating conditions. In Ref. [18], a multi-phase Wiener degradation model was used to predict storage life. For storage reliability analysis of components, accelerated testing and nonlinear curve-fitting are methods commonly used to predict future components performances. In Ref. [19], Cu wire interconnect reliability was evaluated by using in-situ high temperature storage life tests and least squares (LS) fitting. In Ref. [20], LS fitting was used for estimating the values of the parameters of the storage reliability model. In

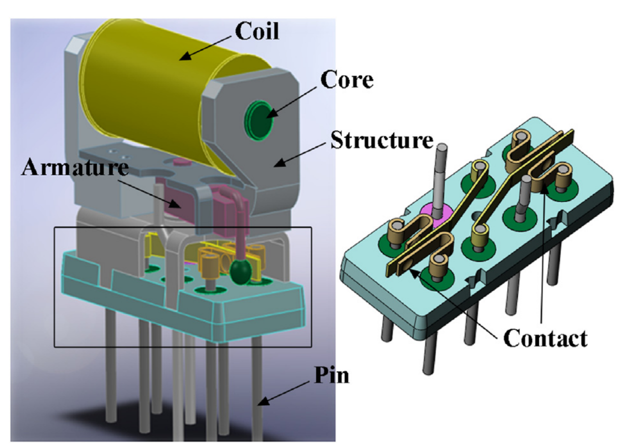

Fig. 2. The basic structure of an electromagnetic relay.

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