Chapter 11

Prognostics Design for Structural Health Management

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ABSTRACT

The chapter describes the application of prognostic techniques to the domain of structural health and demonstrates the efficacy of the methods using fatigue data from a graphite-epoxy composite coupon. Prognostics denotes the in-situ assessment of the health of a component and the repeated estimation of remaining life, conditional on anticipated future usage. The methods shown here use a physics-based modeling approach whereby the behavior of the damaged components is encapsulated via mathematical equations that describe the characteristics of the components as it experiences increasing degrees of degradation. Mathematical rigorous techniques are used to extrapolate the remaining life to a failure threshold. Additionally, mathematical tools are used to calculate the uncertainty associated with making predictions. The information stemming from the predictions can be used in an operational context for go/no go decisions, quantify risk of ability to complete a (set of) mission or operation, and when to schedule maintenance.

INTRODUCTION

Prognostics is a core element of Prognostics and Health Management (PHM), which sets out to actively monitor and manage assets based on their state of health as opposed to scheduling periodic inspection and maintenance based on statistics of mean-time-to-failure or similar information. Prognostics is the science of determining the remaining useful life (RUL) of a component or subsystem given the current degree of wear or damage, the component’s load history, and anticipated load and environmental conditions. A quantification of the degree of a component’s wear or damage and the estimate of end-of-life (EOL) gives decision makers important information about the structural health of a system. This information

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Prognostics Design for Structural Health Management

can be used for risk reduction in go/no-go decision, cost reduction through the scheduling of maintenance as-needed, and improved asset availability. Prognostics employs techniques that are often based on an analysis of historical data or an analysis of the fault modes and the modeling of the physics of both the component itself as well as the attributes that characterize the fault. Damage progression models include the effects of damage accelerators or stressors (such as load or environmental conditions). Algorithms that estimate the remaining life use estimation techniques that propagate the anticipated degradation into the future and provide as output the time where the component does no longer meet its desired functionality.

FUNDAMENTALS

Predictive information about a component fault/damage can be a valuable resource in determining an appropriate course of action to avoid failures. Potential of prognostics in positively contributing to safety and improving life-cycle costs is equally relevant to existing legacy systems and new system designs. Legacy systems adopt additional sensing and processing with a potentially high price of retrofitting and additional validation and/or certification costs to gain extended system life and safety factor. New system designs can significantly reduce these costs if prognostics and health management are adopted early in the design to facilitate a more optimal sensor placement for observability and coverage. This, however, requires integration of health management design into the systems engineering process. The following section briefly discusses various design considerations involved in design and development of PHM.

Design Considerations for Prognostics Health Management

With the term “design” one means in general a method of conceiving and planning to realize a solution to a particular engineering problem. This entails formulating a plan and drawing up a scheme how to realize the plan. Generally, the design process is partitioned into the stages

1. Analysis,
2. Concept, and

One needs to start out with having a good understanding of the underlying goals. That is, an understanding of what the prognostic system is meant to accomplish. This could be a reduction of life-cycle cost, or a safety improvement, or an optimization of uptime to better guarantee mission availability or commercial dispatch readiness. The design process is shown in Figure 1 and explained below.

During the Analysis phase, requirements for the overall system are created based on the stated goals. Requirements for prognostic system design are guided by the end use of prognostics (Saxena, Celaya, Saha, Saha, Roychoudhury, et al., 2010). There are different motivations for prognostics, such as improving safety, reducing costs, or increasing availability. However, to realize an effective health management system, requirements for prognostics and structural health monitoring (SHM) should be developed with those of the system. This requires forward thinking about what components or subsystems need monitoring and accordingly determine an appropriate sensor network design, which then can be integrated into the structure design in a more cost-effective manner. The application scenario dictates what mitigation action will be most beneficial given a prognostic estimate of remaining-life-of a structure. At the same