

Physics and Measurement of Early Wire Insulation Chafing

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ABSTRACT

This paper discusses the physics of development of electrical defects as the result of wire chafing, and how this can be used to extend the prognostics capability of GE's Smartwire Diagnostic System (SWDS). Chafing, a top symptom of failures (37% in one study [4]) is frequently caused by mechanical vibration of wiring harnesses, which are often strapped to the aircraft structure or run through other types of cable supports (trays, bends, etc.); ambient aircraft structural vibrations are a primary mechanical driver of long term chafing.

The US Navy's charter to reduce annual wiring maintenance expenditures by an estimated \$57 million provided the driving force for this research effort. No system is available today that can detect and locate a wire insulation chafe without the user disconnecting the wires or passing a high voltage through them. The overall objective of SWDS is to address this gap in wire health monitoring. One of the main goals of SWDS is to detect small wire chafes before they can cause catastrophic electrical failures.

The SWDS consists of GE flex sensors, a high-speed data acquisition system and advanced algorithms. In this paper we assess the capability of the sensor to assess various stages of insulation damage, including small but developing defects. The ability to detect very early stages of insulation damage prior to conventionally detected electrical failure is termed "prognostics". In this paper we will also summarize the present technological barriers to effective and reliable detection and diagnosis of early wire insulation chafing and will discuss the future of prognostic system development for wire chafing in aircraft.

BACKGROUND

The Smart Wire Diagnostics System (SWDS) is a research project [1] that started in 2003 and has been funded by the US Office of Naval Research (phase 1-2)

and by NavAir (phases 1-4). SWDS is a passive monitoring system: the major components are lightweight GE flexible sensors, high-speed data acquisition system, and advanced wiring diagnostics algorithms. The first two phases were aimed at maturing the concept of partial discharge technology for detecting wire chafes, designing the flexible sensors and constructing a high speed data acquisition system using commercial off the shelf (COTS) components. Phase three was to validate the technology of detecting the existence and location of wire chafes in helicopter (H53) ground tests. During Phase three, extensive laboratory testing was performed at NavAir and the algorithms were trained for the defect signals obtained for a single wire or multiple wires that were subjected to chafing. The data acquisition system requirements were optimized. The algorithms and the data acquisition were then tested in H53 ground tests. Two rounds of ground tests were performed; one when the helicopter was powered and the other when the rotors were cranked. In both situations, pre-chafed wires were added to the harness and the pre-chafed wires were subjected to vibration. The SWDS was 100% successful in detecting the wire chafes and 67% successful in locating the chafes. The current phase (phase 4) is preparation for an in-flight demo in the H53. Also, in this current phase the wire health information is integrated with the structural health of the aircraft. Wire defect messages are sent to Goodrich's Integrated Mechanical Diagnostic Health and Usage Management System (IMD HUMS).

SYSTEM OVERVIEW

An overview of the SWDS is shown in Figure 1 [2] [3]. The GE Flex sensors are of two sizes, 0.65cm diameter and 2.54cm diameter. The data acquisition system (DAQ) is designed to handle low-energy fast transients. The algorithms play a key role is discerning the noise from a useful wire defect signal [4].

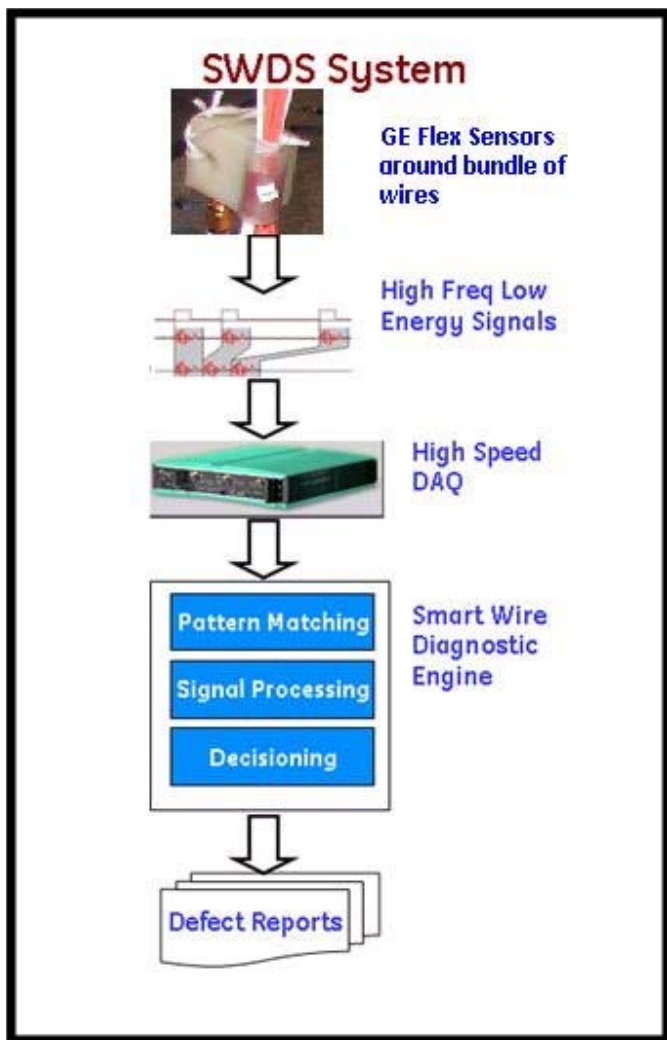


Figure 1: System Overview

Measurement of Early Wire Insulation Chafing

The non-intrusive detection and location of existing wire chafes is a difficult technical problem, and the SWDS is one of a handful of technologies now beginning to show promise for further development. The detection of chafing is of interest not only as a lower-cost inspection method, but also as an on-board monitoring method. In many cases, open chafes may exist for years before a serious incident occurs, and methods such as SWDS offer promise of greatly improving the detectability of chafes and of reducing the time to detect an existing chafe. Use of this technology can significantly reduce the risk of an electrical incident by reducing the likelihood and time of exposure to undetected chafing.

Since many chafes develop gradually, over a period of weeks, months, or years, it has always been a goal of maintenance personnel to virtually *eliminate* the risk of chafes by detecting very early signs of chafing *before* it is large enough to create an electrical incident.

Accordingly, this paper reports initial results by GE concerning the ability to detect very early chafing.

In most cases of gradual wear, purely *mechanical* signs of insulation chafing will occur prior to electrically-detectable symptoms. Detection methods have been proposed to detect these symptoms [4], but they are expensive to implement and are relatively un-tested. Such methods are likely to have high false alarm rates, since not all mechanical chafes lead to electrical faults. These methods lie outside the scope of the present investigation.

Instead, this paper concentrates on the feasibility of detecting very early *electrical* evidence of chafing. A barrier, historically, has been the lack of a physical model of the early chafing process, and that is where progress can now be reported. In fact, it now appears likely that a performance extension of SWDS sensors and signal processing can be used to detect very early electrical evidence of chafing. This evidence-based electrical detection of early chafing is termed *prognostics*. From an overview of the physics of chafing, it will become apparent that this definition of prognostics *also* coincides with the usual notion that detection is possible at a time *prior* to the time when resulting electrical damage can occur.

PHYSICAL PROCESSES OF EARLY INSULATION CHAFING

The physical and electrical processes of early insulation chafing have been characterized as evolving in four stages:

STAGE 1: VOIDS, SCISSIONS AND LEAKAGE -

Electrical wiring is often coated with enamel as well as an electrical insulator. Polyimide (chained polymers) used in the 1970's and 1980's as insulators have been shown to age, become brittle due to hydrolytic deterioration and to develop voids or microscopic cracks called scissions. In more recent equipment older polyimide have been replaced by cross-linked polymers such as ETFE, which are more resistant to these effects [5]. Voids and scissions cause electric field non-uniformity within these insulators, leading to heating, condensation, and accelerated deterioration. In the presence of moisture and enamel abrasion or cracking, leakage currents may occur, due to reduced local resistance between a signal wire and shielding or ground wire. Microscopically, some insulation samples show evidence of current flowing parallel to fissures, or shell-shaped paths running parallel to the insulation [6], [7]. These effects are normally difficult to detect. Detection of resistive leakage current, in addition to being signal-dependent, usually requires some form of modification of wire bundle connectors and the use of an embedded current sensor; hence, this type of measurement has not normally proved to be economic for signal-level wiring.