Reliability Considerations: Optical Sensors for the Control and Measurement of Power

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Abstract: The Aerospace, Space and Military industries have succeeded in using the discipline of Reliability Engineering to predict the Mean-Time-Between-Failure (MTBF) and the Mean Time to Failure (MTTF) for complex electronic, optical and mechanical systems. As the power industry adopts new technologies to control and protect its assets, complex electronic and optical systems are becoming prevalent with the consequence that reliability analysis tools are becoming increasingly relevant and useful. Techniques such as Parts Count Method, Parts Stress Analysis (PSA) and Failure Mode and Effects Analysis (FMEA), themselves staples of the aforementioned industries, will become a regular part of the design process for power industry equipment. NxtPhase Corporation is currently adapting the Fiber Optic Gyroscope Sensor (FOGS) technology from Aerospace industry applications to systems that will provide accurate measurements of current, at transmission line voltages, over a 30-year lifetime. Extensive use of Reliability Engineering tools will ensure that the reliability performance achieved by the FOGS technology in Aerospace applications is replicated in products for the optical power measurement domain.

Keywords: Reliability, Mean Time Between Failure (MTBF), Mean Time To Failure (MTTF), Parts Stress Analysis (PSA), Failure Modes Effects Analysis (FMEA), Lowest Repairable Unit (LRU), Environmental Stress Screening (ESS), Production Reliability Acceptance Test (PRAT), Cross-Strapping, Availability

I. INTRODUCTION

The increased usage of electronic systems in the network has meant that utilities must consider the effect that the introduction of these complex systems has on the reliability of the complete network. The Military, Space and Aerospace industries, who have long had to deal with this issue and to mitigate the risk of designs being conceived that are susceptible to failure, have devised and documented certain guidelines and practices to minimize poor reliability appearing in product designs.

The underlying principle adopted throughout the reliability guidelines is that reliability must be planned into the product at the onset of any design program. The objective of this paper is to provide a framework for such a reliability program and indicate how such a program may be planned and successfully implemented. The fact that the reliability plan outlined here is based upon military standards, handbooks and specifications should not cause us to ignore its validity to the power industry. The practices identified here will enhance product reliability; they are equally applicable to the utility industry where reliability is just as critical.

It is not the intention of this paper to describe how to perform the reliability analyses. Military standards and handbooks have already covered this material in great detail. Our purpose is to identify a reliability program framework that imbibes reliability from cradle to grave.

II. THE REQUISTE MILITARY STANDARDS AND HANDBOOKS

So what are the principle standards and specifications used by reliability engineers? The following is a list of the principle standards and handbooks adopted by the Reliability Engineering discipline:

- MIL-STD-785
- MIL-HDBK-217
- MIL-HDBK-2164
- MIL-HDBK-470

MIL-STD-785 is entitled Reliability Program for Systems and Equipment Development and Production. The spirit of MIL-STD-785 is that if reliability is planned and incorporated into a design the reliability of the final product will be inherent. This standard therefore outlines guidelines, in the form of tasks, which need to be completed as part of an overall reliability program.

MIL-HDBK -217 is entitled Reliability Prediction of Electronic Equipment and details two methodologies for reliability estimates: the parts count method and the parts stress analysis method. Full details on how these methodologies are applied to product designs are described in the standard.

MIL-HDBK-2164 is entitled Environmental Stress Screening for Electronic Equipment and provides a technique for identifying latent defects in production systems.

MIL-HDBK-470 is entitled Designing and Developing Maintainable Products and Systems and describes, in a similar vein to MIL-STD-785, how maintainability can be planned into a product with all the benefits that ensue.

The Failure Modes Effects and Criticality Analysis used to be covered by MIL-STD-1629A. However, a notice was issued that cancelled this standard and now refers the reader to research other national and international standards for analysis techniques and information.

III. A COMPLETE RELIABILITY PROGRAM

So what would a complete reliability program look like? MIL-STD-785 identifies tasks that must be performed and completed to effectively design reliability into a product. Section 100 has five tasks, each related to the reliability program implementation and control. Section 200 has nine tasks related to reliability modeling and analysis. Finally, section 300 identifies four reliability test methodologies, each identified as a separate task, which can be used to quantify reliability performance. Overall, an all encompassing reliability program would include:

- Section 100, Program Surveillance and Control
  - Task 101, Reliability Program Plan - identify program activities
  - Task 102, Monitor/Control Subcontractors and Suppliers – ensure that all suppliers are on-board with the reliability strategy
  - Task 103, Program Reviews – identify the intervals at which reliability reviews will be conducted
  - Task 104, Failure Reporting, Analysis and Corrective Action System (FRACAS) – ensure that field failures are identified and repaired with feedback provided to the design team for effect corrective action
  - Task 105 – Failure Review Board (FRB) – ensure the output from the FRACAS with appropriate corrective action is formally reviewed on a regular basis
- Section 200, Reliability Modeling
  - Task 201, Reliability Modeling – define the system block diagrams together with mathematical models required to estimate the product's reliability
  - Task 202, Reliability Allocations – ensure that the product has reliability apportionments applied to the lowest levels of repair
  - Task 203, Reliability Predictions – estimate the product reliability and ensure that the product design meets the reliability apportionments
  - Task 204, Failure Modes and Effects Analysis (FMEA) – identify potential design weaknesses
  - Task 205, Sneak Circuit Analysis – identify latent paths that may cause unwanted functions or inhibit desired functions
  - Task 206, Electronic Parts Tolerance Analysis – analyze components with respect to ambient temperature and apply de-rating to maximize a component lifetime (also known as a Parts Stress Analysis (PSA))
  - Task 207, Controls and Selection of Standard and Non-Standard Parts – apply standard parts where possible and assess the use of non-standard parts where their need is required to satisfy system performance
  - Task 208, Reliability Critical Items – identify and control items that require special attention
  - Task 209, Effects of Functional Testing, Storage, Handling, Packaging, Transportation and Maintenance
- Section 300, Development and Production Testing
  - Task 301, Environmental Stress Screening (ESS) – provides a method to implement a series of tests in a attempt to remove latent defects in production systems
  - Task 302, Reliability Development/Growth Test (RDGT) program – provides a test to be performed on pre-production units in an attempt to uncover design reliability problems
  - Task 303, Reliability Qualification Test (RQT) program – provides a test to be performed on a system as part of a reliability design verification program
  - Task 304, Production Reliability Acceptance Test (PRAT) program– provides a test to be performed if the production units have updated designs or altered production processes

The program identified above is extensive and very costly especially if the full suite of Development and Production Testing is performed. This paper in no way advocates that every task needs to be performed. However, the complete list can be used as a menu from which a reliability program can be tailored to suit any design program.

IV. A TYPICAL RELIABILITY PROGRAM

The first activity required in any reliability program is to define the scope of the reliability program and document which activities will be performed. All five tasks in section 100 need to be implemented for all and any reliability program. Having completed those tasks, there are some further tasks that are essential to any reliability program.

Section 200, Task 201

Here the mathematical models, used to derive the reliability estimate, are defined. MIL-HDBK-217F defines the part failure rate model in the following way

$$\lambda_p = \lambda_b \pi_T \pi_A \pi_R \pi_S \pi_C \pi_Q \pi_E$$

where,

λ_p is the part failure rate/10^6 hours

λ_b is the base failure rate usually expressed by a model relating the influence of electrical and temperature stresses on the part

π factors modify the base failure rate for the category of environmental application and other parameters that effect the part reliability (i.e. π_E is the factor used to account for environmental application, see MIL-STD-217F for further information)

MIL-HDBK-217 provides data for λ_b and the π factors.

Section 200, Task 202

Here, the reliability apportionment is applied. Usually, a system is modular by design, so apportionment is applied down to the module level.

Section 200, Task 203

In this section, the parts count method outlined in MIL-STD-217F, Appendix A is applied. This methodology is, as the military standard states "applicable during the early design phase". In general the Parts Count Method will usually result in a more conservative estimate (i.e. higher failure rate) of system reliability than the Parts Stress Method.

Section 200, task 204

The next activity to be performed is a Failure Mode Effects Analysis (FMEA). This is a very long and tedious exercise. All failure modes for modules, sub-assemblies and assemblies are identified together with all the visible symptoms related to that fault. This type of analysis is useful when identifying the product's alarm strategy. Since all failures have a visible symptom, it is unlikely that a fault will occur that is not immediately obvious leading to a long fault identification interval; minimizing the fault identification time is vital in keeping Mean Time to Repair (MTTR) to a minimum.

Section 206, Task 206

In this section, the parts stress analysis method outlined in MIL-STD-217F is applied. De-rating of components is applied to maximize their lifetime and factors such as temperature and mission life are applied to the reliability estimate.

Section 300, Task 301

Environmental Stress Screening (ESS) is an effective way to remove latent defects in manufactured electronic assemblies. The objective of this phase is to document an ESS test method that is applicable to the product being manufactured. MIL-HDBK-2164 suggests a two-phase approach: a pre defect-free test that includes random vibration followed by thermal cycling; and a defect-free test that includes thermal cycling followed by random vibration.

V. AVAILABILITY, MAINTAINABILTY AND INTERCHANGEABILITY

Reliability is obviously critical to product performance but it is not the only critical parameter. Another measurement that is crucial to a product's performance is ***availability***. In the event that a random failure does occur, the ease with which the fault can be identified, the faulty component replaced and the system pronounced fully functional minimizes ***downtime*** and optimizes the availability of the system. Availability is as critical as reliability; during the lifetime of a system it is probable that some random failures will occur.

The issue of maintainability is complex since it encompasses module design, alarm notification together with failure identification, failure propagation, ease of module removal, spares policy and interchangeability. The initial conceptual design and architecture of any product design must determine the maintenance philosophy and strategy. The best design (from a maintenance standpoint) is a modular one. Each module can then have some form of failure notification and be easily removed and replaced with a fully functional spare. Now the question of ***interchangeability*** comes into play. Are adjustments necessary to get the system into a fully function condition? The ultimate answer should be no. However, this is not always possible and some form of recalibration may be necessary to return the system to its fully functional mode. The ultimate goal of a maintainability strategy is to minimize downtime. The removal of any recalibration or system testing will only serve to minimize the downtime interval.

It is certain that Intelligent Electronic Devices (IEDs) that are used in a network will introduce additional maintenance burdens when compared to conventional technology. However, with sufficient planning maintenance programs can be implemented that are not onerous to an organization. Be sure that a maintenance program will need to be implemented. These devices cannot be left without maintenance for 40 years like conventional VT and CTs.

VI. DESIGN CONSIDERATIONS

From a reliability standpoint some design considerations are worthy of note.

The Parts Stress Analysis requires an understanding of the internal thermal performance of the system. Thermal modeling of the system needs to occur prior to the Parts Stress Analysis being initiated.

It is important to identify the level at which a repair needs to take place. This usually results in a modular approach for the product design. Using the two concepts of repairability and functional portioning, system modularization results in the lowest repairable unit (LRU) for a given system module.

A reliability program can be tailored to suit the design program being undertaken. However, MIL-STD-785 does issue a warning to this effect "Tailoring should not be interpreted as license to specify a zero reliability program. Necessity and sufficiency are the key criteria to be met in determining whether tasks are tailored into, or excluded from, a reliability program".

Any failure should collapse into a safe mode of operation. A failure should not cause a domino effect propagating a cascade of multiple failures that would destroy multiple modules. One technique that analyses such effects is called a Failure Mode and Effects Analysis (FMEA). The analysis provides a systematic evaluation of equipment failure modes and assesses their likely effect; be it a total loss of function or degradation in performance. If a criticality is to be determined for each failure then analysis may be broadened to a Failure Mode Effects and Criticality Analysis (FMECA).

One technique that can be employed to overcome a low reliability estimate is to provide redundancy. This can be either hot (powered) or cold (unpowered) redundancy. The trade-off is between low reliability and enhanced reliability through redundancy is always difficult due to extra cost introduced through redundancy. Ultimately, a total replica of the system that automatically operates when a failure occurs provides 100% reliability but at a cost that is usually not economic. When redundancy is employed it is usual to employ some form of "cross-strapping". Such circuitry permits the redundant side to operate immediately upon failure in the primary side. Cross-strapping can take the form of a simple diode-or gate circuit, for instance, at the input power node or sometimes more elaborate circuits may be needed for cross-strapping between signal processing modules.

One other method to improve reliability is to perform scheduled maintenance. Such a course of action mitigates the chance of system failure by determining the probable lifetime of the module and replacing it before that lifetime is exceeded.

Finally, there are some limitations with MIL-HDBK-217 methodologies, particularly with respect to component data. The rate of acceleration of electronic components development has meant that devices that appear in new designs are very often not supported by reliability data. If component data is not available then reliability tests may be performed in the form of Highly Accelerated Life Tests (HALTs).

Other limitations are also identified within MIL-HDBK-217 itself. The handbook recognizes that the failure rate models are only point estimates based upon available data and are only valid strictly for the conditions under which data was obtained. Also, system applications may affect failure rates especially in cases where environmental stresses can vary significantly from system to system, such as avionic applications.

VII. CONCLUSIONS

The Fiber Optic Gyroscope Sensor (FOGS) program, which forms the basis for the NxtPhase current transducer design, was designed for Aerospace and Space applications and was subject to reliability programs and reliability analysis. Thus, these tools and techniques are well known within NxtPhase and have been transferred to all existing, and future, sensor product development programs. In this respect, reliability will be inherent to all NxtPhase products. Utility engineers should be aware of such techniques so that they can specify such requirements when procuring equipment.

The overall message here is that reliability, maintainability and interchangeability cannot be added later in a design; it must be designed in at the product's conceptual design phase. Note that this is not an exact science; however the techniques used to assess a design will significantly enhance a design's reliability estimate and decrease the probability of random failure.

VIII. REFERENCES

[1] MIL-STD-785, Reliability Program for Systems and Equipment Development and Production

[2] MIL-HDBK-470, Designing and Developing Maintainable Products and Systems

[3] MIL-HDBK-217, Reliability Prediction of Electronic Equipment
[4] MIL-HDBK-2164, Environmental Stress Screening for Electronic Equipment
[5] www.astimage.daps.dla.mil for Military Specifications, Handbooks and Standards

IV. BIOGRAPHIES

Gary Nicholson was born in Surrey, England, in 1959. He received the B.Sc. (Hon.), from Kingston University England in 1981 in electrical and electronic engineering.

Gary has worked in the military and space industries since 1983 where, as a project engineer, he has been involved in the design of thermal imaging devices for military applications and GaAs FET switch matrices for commercial satellite applications.

He also has a Masters in Business Administration from the City University in London, U.K., and is an Associate Member of Institute of Electrical Engineers.