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Optimizing the maintenance policy of Electronic products with condition based maintenance

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Abstract

ALSTOM Transport Information Solutions‘ RAM Center of Excellence has been investigating methodologies based on the analysis of physical and chemical degradation phenomena, in order to optimize or at least improve the maintenance policy for new electronic products. A methodology has been developed to model reliability in terms of the degradation phenomena which affect the device. This methodology, articulated around eleven steps, will be applied to electronic devices in the design phase in order also to design the products for high reliability and availability.

The same methodology can be the basis for defining condition-based maintenance policies.

The general idea is to identify "critical" parameters, representative of the state of the product, and their thresholds. When the parameter crosses a certain threshold, a failure is likely to occur within a short time span.

The analysis is carried out first at component level, then at board level and finally at function level

Steps of the analysis are:

- *To understand the **physical inner structure** of devices under study;*
- *To understand the **physical causes of degradation and failures** in the devices;*
- *To characterize the impact of component **parameter variation** on the degradation;*
- *To extrapolate a **law** that describes the degradation phenomenon as a function of such key parameters.*
- *To identify the **threshold** linked to the failure.*

This behavioral study is based on the design-of-experiments method [1]. In order to determine the critical parameters, screening designs of experiments are performed. Then another design of experiments, in conjunction with electronic board simulations, is performed in order to determine response surfaces, i.e. the degradation laws.

So far, the methodology has been launched on I-coupler technology isolators and solid-state relays.

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The expected result is the estimation and modelling of the product's failure rate as a function of time. The latter will generally increase after a certain time period (Bertholon distribution [2]). Indeed, contrary to classical assumptions, failure rate, even for electronics, is often not constant; early wear-out is often a result of increased miniaturization (this is the reason why the MIL-HDBK-217 guideline is currently being updated).

On this basis, it is possible to select the best periodicity for preventive maintenance replacement. Moreover, the same degradation indicators that have been used off-line on predicted reliability, can also be used on-line for condition monitoring and condition-based maintenance. An example at component level is given in reference [3].

The next step of this project will be to work with maintainers in order to adapt maintenance tools. Indeed, in order to define a condition based maintenance policy, tools must be built in to monitor the relevant degradation parameters in real time and to provide alarms to maintainers when thresholds are crossed.

It is expected that products maintenance policy will thus be improved, with positive impact on Life Cycle Cost and Availability.

Keywords – Degradation phenomena, electronic products, reliability, design of experiment, condition based maintenance

Introduction

Both the calls for tenders and the industry standards impose increasingly stringent reliability requirements, which impact electronic products directly. More than in the past, reliability becomes a selection criterion.

Bidders must control their products' reliability more strictly than in former days, and must demonstrate that their products meet the reliability requirements.

Therefore the prospective bidder must navigate between two major hurdles: on the one hand, he must avoid committing to excessively demanding targets, which the product will fail to achieve on the field; and on the other hand, he must avoid sounding uncompetitive by committing to too easy targets. The bidder's predicament of course translates into constraints for the system and product designers.

Reliability requirements relate, not only to service reliability, i.e. the failures that impact operations, but to intrinsic reliability as well, i.e. all failures that cause an unscheduled maintenance intervention. This is because clients are concerned at the same time with service quality (as measured by service reliability or availability), and maintenance costs (as measured in particular by corrective maintenance frequency, directly related to intrinsic failure rate).

It is therefore not sufficient to address those requirements by systematically resorting to redundant architectures; while redundancies help with service reliability and availability (provided they are true redundancies), on the contrary they undermine intrinsic reliability since they increase the quantity of equipment. More generally, redundancies increase life-cycle cost.

With this situation in mind, ALSTOM Transport Information Solutions' RAM Center of Excellence has launched the Electronic Module Reliability R&D project focused directly at improving intrinsic reliability and maintenance policies at electronic board and function level. This methodology is expected to apply especially well to failure modes that lead to a failure rate variable with time (degradation and drift phenomena,…) and relate to a measurable performance (voltage, current intensity, torque, force, …).

Background

It is important to recall that reliability does not just reduce to "MTBF". Only when failure rate is constant does the MTBF characterize entirely the reliability characteristics (It is then, and only then, equal to the reciprocal of the constant failure rate).

Nevertheless, constant failure rates are used because they simplify calculations. Empirical reliability predictions typically correlate poorly to actual field performance since they do not account for the physics or mechanics of failure.

To perform product reliability prediction, different ways can be used (standards, Physics-of-Failures method, etc).

A. Reliability standard Data bases

To be able to perform the reliability prediction of these products, some standards have been created (MIL HDBK 217, IEC TR 62380).

For these standards, reliability predictions are based solely on constant failure rates which are meant to model only random failure situations. When failure trends are modeled as only random events via the exponential distribution, infant mortality and wearout related failures are not accounted for.

This is the reason why the MIL-HDBK-217-F guideline is currently being updated (Revision G) [4].

B. Physics of Failures and Field data

ALSTOM Transport Information Solutions' RAM Center of Excellence and the SNCF have cooperated on an R&D project [5] whose aim was to improve the reliability prediction of a field equipment (a track circuit). In this project, SNCF provided field data and ALSTOM developed a methodology based on the physics of failures to understand and explain the field results.

The data collected over some 40 years by SNCF, and correctly processed from a statistical point of view, have shown that many trackside signalling products, and in particular track circuits, do exhibit wear: not initially, but after some time. Then preventive renewal becomes an interesting option for those elements. Reliability then can no longer be modelled by a constant failure rate (or an exponential time to failure) but rather by a failure rate which grows with time (typically, a 2-parameter Weibull distribution), or a failure rate which is initially constant, until some time, after which it starts growing: this is then the 4-parameter“Bertholon” distribution [2].

The aim of this study has been to develop a predictive reliability model for track circuits based on the physics of degradations and failures. This, in order to understand the results of return of experience (RoX) from SNCF but also to optimise maintenance and to optimise the design of future ALSTOM track circuits. This model is very important from a maintenance point of view, because the more is known on the reliability behaviour of a product, the more cost-effective its maintenance can be made.

For this investigation, we have selected the HVI (High Voltage Impulse) track circuit, one of the most widely used track circuits on the French railway network. First of all, we have performed a functional analysis (APTE® method) [6] in order to define precisely how this device operates. Subsequently, an FMEA has served to identify the ways in which the track circuit can fail and the different physical phenomena responsible for degradations and failures. We have identified two phenomena: electronic component drift and mechanical joint and rail deformations. Then we have developed a probabilistic model with the help of Petri nets [7].

The final step of this project has been the simulation and the estimation of the model parameters (cf Figure 1).

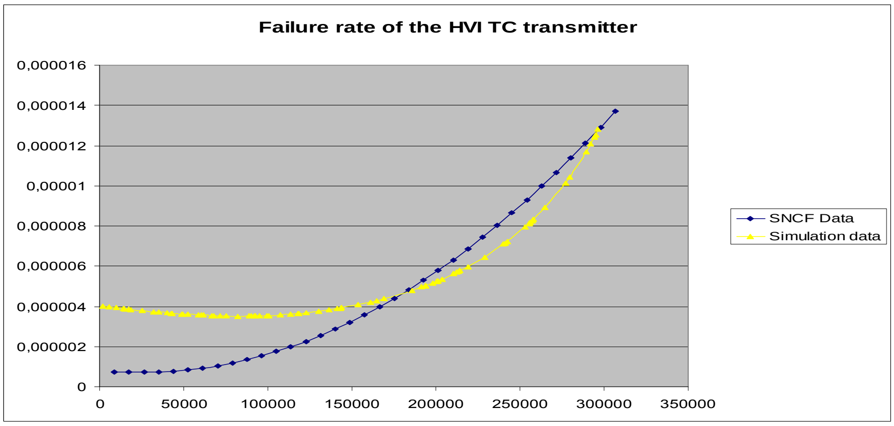

Figure 1: Results of this study

Electronic Module Reliability

Based on the study realized on the HVI track circuit, a methodology to model reliability in terms of the wear phenomena which affect the device has been developed. This methodology is articulated around eleven steps.

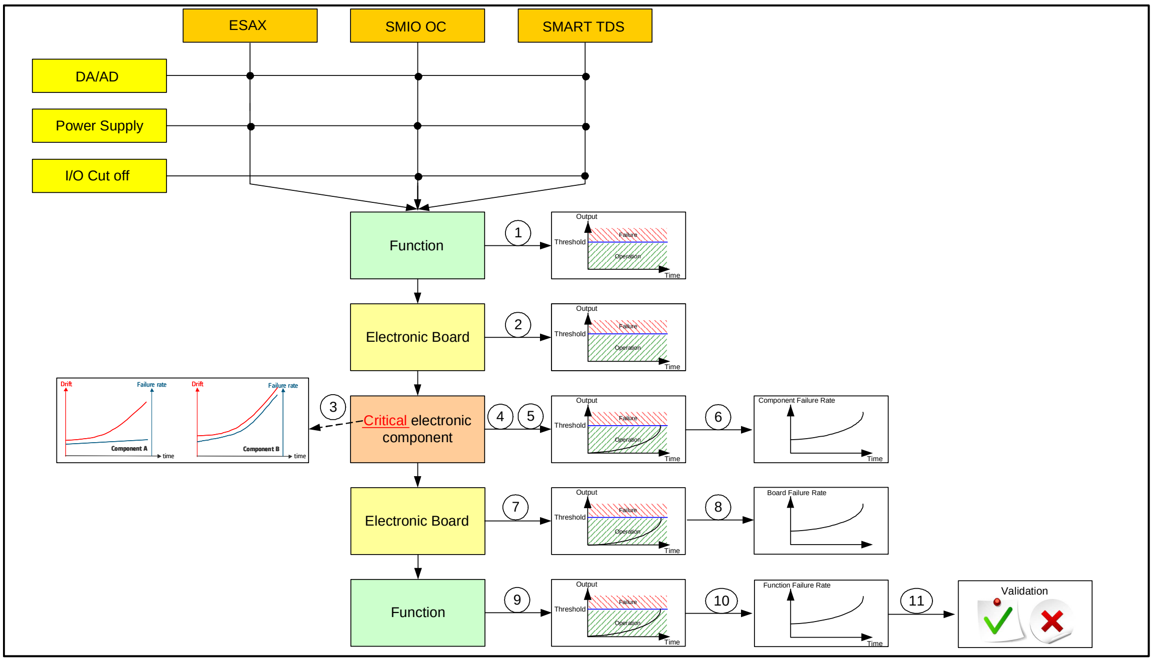

Figure 2: Electronic methodology

A. Pilots products selection

The first step has been to select some "pilot" products to apply the methodology. We chose three different signaling electronic products which are in the design phase. We performed this choice to be able to improve their design following the results of this project.

On these products, we decided to focus on two main functions (Digital to Analog conversion and Power Supply). We compared the design of these two functions in terms of reliability. It is expected that the outcome of this study will be to improve the design of the future ALSTOM electronic products.

B. Critical component selection

The second step is to select the critical components of each electronics board. The selection of the critical components is an important step of the methodology. The "criticality" of a component is defined by the impact and the probability of occurrence of its failure on the product failure rate. A component is critical if the reliability of the board is sensitive to its evolution (drift, wearing,…).

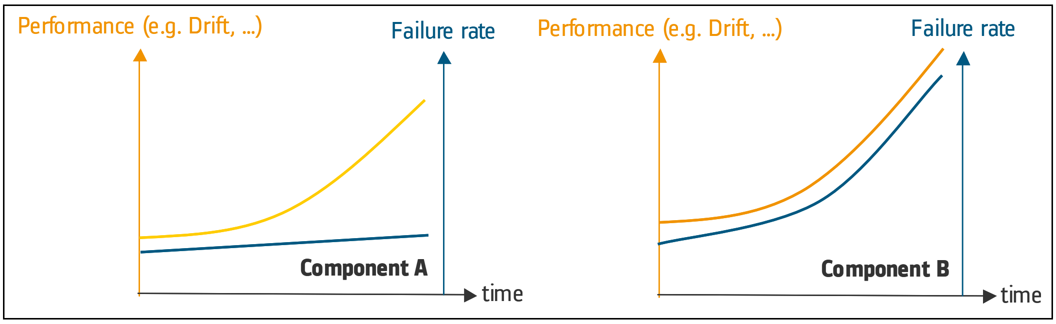

Figure 3: Criticality of electronic components

In Figure 3, component B is more critical tan component A because a small drift of component B increases the failure rate of the board unlike for component A.

To derive the list of critical components, we used different tools. The first one was to realize a FMECA (Failure Mode, Effects and Criticality Analysis). This analysis allowed to obtain a list of a few components.

In order to validate and to reduce this list, we will perform a Design of Experiment (DoE) [8] for screening study. To be able to use DoE, we must first simulate the different studied functions with the help of CAD software (Orcad Pspice), by modeling all components with that software.

Thanks to this tool, we will be able to delete from the list some components which have no real impact on the function when they fail.

C. Critical parameter selection

After the component selection, we must work at three different levels (function, board and component). For each level, we must select one relevant parameter which can be easily monitored. This parameter should be representative of the state of the function/board/component. We must also identify a threshold such that when the parameter crosses it, a failure is likely to occur within a short time span.

1) At function level

For the two functions studied (AD/DA and Power Supply), we defined an indicator. To do this, we discussed with the designers in order to know which is the main parameter for each function. This parameter must also change due to the wear of the function.

For example, for the function AD, we chose to focus on the time T1 as explained in the Figure 4:

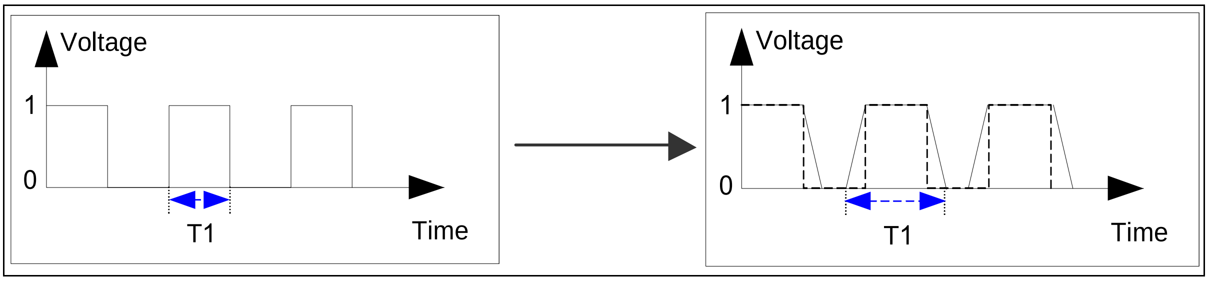

Figure 4: Critical parameter for the function AD/DA

Due to the wear of electronic components, the time T1 will become longer and longer. When this time crosses a certain threshold, it will mean that the function AD/DA cannot be performed correctly any longer.

After this choice, the designers must define a threshold for each parameter. When the parameter crosses this threshold, it means that a failure is likely to occur soon.

2) *At board level*

Just as for the functions, one parameter must be selected to monitor the board's "health". This step should be carried out in the case when a function is distributed over several boards. In this project, the functions are implemented on one board each, so that the selected parameters are the same at board and function level.

Just the same as for the function level, designers must define a threshold for each parameter.

3) *At component level*

We must also define a parameter for each component identified as critical during the previous step. This step is more complicated at component level than at board or function level because for some components, many parameters are present. Thus, to be able to select only one parameter, we must make some assumptions. To be as close as possible to reality, first of all, we asked the designers to provide a short list of critical parameters regarding the design of the product. Then, thanks to an other Design of Experiment (screening study), we will be able to optimize this list and to keep only one parameter for each component. This methodology for the selection allows to be as close as possible to reality.

For example, we consider that the electrolytic capacitor is a critical component for the design of the products. For this component, the parameter selected to be monitored is the ESR (Equivalent Series Resistance) (cf Figure 5). This is the sum of the resistances due to aluminum oxide, electrolyte, spacer and electrodes. We know, that, due to the wear of the component, this parameter will increase over time (Figure 5) [9].

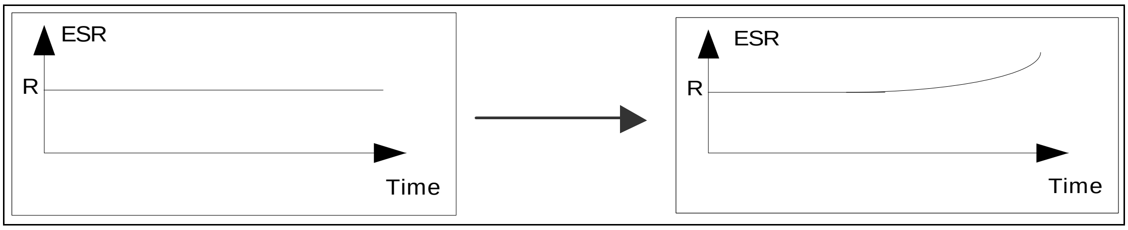

Figure 5: ESR behavior

For each parameter, designers will define a threshold.

D. Critical parameter behavior

After parameter selection, the next step consists of characterizing the behavior of each parameter over time. We work at the three same level as previously.

1) *At component level*

This is one of the most difficult steps of the methodology because one needs to have a very good knowledge of the electronic component. Indeed, one must understand each physical and chemical phenomenon which can affect the parameters.

There are different ways to define the behavior of the parameters at this level. First of all, some information can be found in the scientific documentation. Indeed, for few components, some studies have already been done to model the degradation of parameters over time.

For relatively new components, these studies have not yet been performed and so we must proceed differently to obtain information. We established some partnerships with electronic laboratories, which will be able to perform Accelerated Life Tests (ALT). On that basis, the behavior of critical parameters of each component over time will be modeled.

2) *At board level*

In this step, the equation of the behavior of the critical parameter at board level is identified. To do this, we use an other Design of Experiment for response surface study. The variables of this equation are the values of the parameter of each critical component. After this, one equation is obtained for each electronic board.

Thanks to the behavior of each previously defined component, we can perform a Monte Carlo analysis to simulate an important number of electronic boards over time.

Then, we compare the value of each board with the threshold. This action allows to characterize the reliability function of the electronic board.

3) *At function level*

We apply exactly the same methodology as at the board level to define the parameter behavior and the reliability function of each studied function.

E. Validation

The last step of the methodology consists of validating the results obtained with the simulation of our models. Indeed, as the studied products are in the design phase, no field data are available yet.

The idea is to perform Accelerated Life Tests on the two studied functions. We will compare the results obtained with the models and with the ALT to assess whether the methodology provides adequate results.

For now, we have already tested partially the methodology with the HVI TC example explained previously.

Maintenance benefit

The interest of this project is not only to improve the reliability of the future electronic products during the design phase but also to improve the maintenance policy for these products. Indeed, with the results of this study, it is expected to implement condition-based maintenance.

If the results obtained with the models are close to the results obtained with the ALT, it means that the parameter chosen at a function level is a good indicator of the state of the function.

With this information, we have already the parameter to be monitored and its threshold, if we want to implement condition-based maintenance.

Summary & Conclusion

This project will make it possible to improve the reliability of the electronic products during the design phase thanks to a physics-based modeling of some functions which can be found in many electronics products. In the process, weak points of electronic boards and the different physical phenomena responsible for degradations and failures are identified. Moreover, thanks to the results of this study, it is expected to define some rules to apply condition-based maintenance on these products.

The next step of this project will be to cooperate with maintainers in order to adapt maintenance tools. Indeed, in order to define a condition based maintenance policy, tools must be built in to monitor the relevant degradation parameters in real time and to provide alarms to maintainers when alarm thresholds are crossed.

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