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Methodological proposal for Accelerated Screening Test design on stepper motors

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ABSTRACT

In the industrial world the need to guarantee a product out of the infant mortality zone has become almost imperative. Stress screening testing of mechatronic subsystems under nominal operating conditions may be *time-* and *resource-consuming*, making sometimes such procedures expensive and impractical. As a result, technologies for accelerated testing have been developed, to design high level stress tests (e.g. temperature, voltage, pressure, corrosive media, load, vibration, etc.) by means of thermal chambers and shakers which stimulate the device under test with external stresses. However, not all industries have access to such expensive equipment.

In this research, a methodology for implementing Accelerated Screening Test by varying internal system variables is proposed and applied to a subsystem with a stepper motor. Some interesting preliminary experimental results are reported and commented. Accelerated Screening Test has the aim to precipitate early failures without inducing fatigue failure mechanisms. Actually this kind of procedure is difficult to optimize and requires some concern to model the infant mortality. This paper investigates also the use of Accelerated Screening Test for the characterization of a subsystem, to demonstrate the general validity of the proposed methodology.

1. Introduction

When new mechatronic systems are designed it is necessary to verify the behaviour of the whole system as well as of each subsystem, in defined conditions. Moreover in several applications, such as military, aerospace, marine, industrial, medical, automotive, it is also fundamental to guarantee high robustness and reliability levels. In particular, the assessment of these levels, for a new mechatronic system, is ever a non-trivial challenge, because of the new configuration and components and the absence of field data.

As well known, electronic and mechanical components, with stringent functional specifications (i.e. bearings, shafts, or gears), could exhibit a high mean lifetime between failures. Therefore, life testing under operating conditions would require much time and resources. Accelerated Life Test (ALT) is a widely accepted solution to this issue in manufacturing industries since is used to speed up failures of a critical product in a short time period for predicting its reliability. Methodologies and applications concerning accelerated life testing have been proposed by a lot of authors, such as: Nelson that in [1] presented statistical methods for accelerated testing with the aim to contribute

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to more efficient planning and to valid and more accurate data analysis; Kececioglu that in [2] showed analysed several models for accelerated life test, with particular focus on mechanical stress; in [3] Lu and Meeker proposed to use degradation measurement for obtaining reliability information when life tests result in few or no failures; Boulanger and Escobar that, as alternative approach to monitor the devices for a long period of time, proposed a methodology for designing experiments for degradation processes in which the amount of degradation over time levels off toward a maximum degradation that is a function of stress [4]; only to cite some works. All these studies gave a significant understanding on the modelling and analysis of accelerated degradation tests. In accelerated life testing there is always a number of key operating parameters that should be taken into consideration, however the overall severity level could result increased by the combination of them, motivating the formulation of new degradation models.

A different purpose of accelerated testing is to force the product to fail in order to discover failure modes that would occur in actual use. For this reason such testing is widely used during product development or production process debug, and includes HALT (Highly Accelerated Life Test), HASS (Highly Accelerated Stress Screening, and ESS (Environmental Stress Screening). These techniques are considered non-statistical and do not yield estimates of product life [5,6]. In particular ESS has been extensively used to reduce infant mortality by precipitating defects. The existing ESS plans precipitate defects by stressing all products for specified durations. The plans usually require long screen durations to allow nearly all defective items to fail, and thus generate excessive aging effects on good items [7].

So, in order to the developed optimal ESS plans, reducing life-cycle cost, shorting part-level screen duration and alleviating aging effects on good products, this research activity proposed to address the issue of Accelerated Screening Test (AST), choosing vibration as stress to precipitate early failures. Starting from nominal conditions of the Device Under Test (DUT), the stress severity was determined by varying specific internal control parameters of the DUT [8], and was not generated artificially by a shaker, as usually in Environmental Stress Screening (ESS) [9]. In order to process the data, considering that the analysed variable is acceleration or vibration, the frequency domain analysis is used to extract relevant information from acquired signals [10]. Discrete Fourier Transform is a powerful tool for system characterization [11], and more generally for waveform record characterization [12]. The proposed methodology is detailed in Section 2.

In Section 3 the test bed is described. Considering that this subsystem chosen as case study could be integrated in a number of critical applications (e.g. biomedical and industrial) it is necessary to ensure its robustness, and ability to sustain the unavoidable electrical, mechanic and environmental stresses that could take place during the operating life. In Section 4 the discussion of results and the possible implication of the proposed methodology are discussed.

2. The proposed methodology

The development and the realization of new mechatronic technologies calls for more and more strict reliability (and, in general, quality) requirements. By the manufacturer's point of view, the risk to put on sale devices which have really good functional performances but fail over a short time is one reason which can pull a firm out of the market. So, a producer has to control his manufacturing process in a way that it can remove weak products, i.e. those which are prone to infant mortality (failure in the first 10^2–10^3 operating hours).

Environmental Stress Screening (ESS), the testing of devices in simulated operating environment conditions, is a good answer to this problem, but it is necessary to choose the kind of solicitations (stress) that should be used and their level (intensity), mode and duration of application to cause all (or most of) infant mortality failures. During screening, the substandard products have to degrade rapidly, resulting in early failures, while the good ones degrade gradually causing a slight aging.

The design and execution of an ESS test, should address the following tasks:

- To precipitate latent defects in early failures.
- Not to activate failure mechanisms which would not be working in standard operating conditions.

Generally speaking, at component level (e. g. resistor, single chip, etc.), the manufacturing process is commonly well known as well as the physics of phenomena which may cause early failures; therefore there are a lot of relevant references. On the contrary, in the case of assembled devices, little is known about the physics of failure and on the relative fault mechanisms, therefore it could be difficult even to predict the weakness of a board, since the board is not always the sum of its components. In fact, many of the faults are due, for example, to solder cracking or other causes which are not directly imputable to a component failure; in such a case it is difficult to choose what solicitation level and duration should be used to cause manufacturing defects to show up early failures at assembly level. Nonetheless, it is widely recognized that thermal cycling and random vibrations are the most efficient solicitation stimuli that can be used to precipitate early failures, both at component/part and board/device level [9,13]. Vibration is one of the most efficient kind of solicitation used in ESS, because simulates the typical mechanical stresses to which are subjected devices installed, for example, on ships, trains, planes and so on [14].

The requirements for higher robustness and reliability have increased the need for accelerated testing of materials, components and complex systems in order to compress time, so that relevant information can be obtained more rapidly [15–18]. This issue motivated research activities for the development of methods to assess the first product life, the infant mortality zone, while reducing testing time. Accelerating tests can be carried out in different modes: