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Methodology for Accelerated Tests of Electronic Elements Based on Multifactor Stress

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Currently, modern combat vehicles are independent combat complexes, versatile in performing a variety of combat tasks. Therefore, these vehicles are increasingly integrated with modern complex electrical and electronic systems to ensure the fighting ability independently, as well as to cooperate with the others in the battle formations. Vehicle survivability depends heavily on the reliability of each system in the vehicle, then their quality and life requirements must be continuously improved. One of the technical solutions to this problem is the use of suitable, reliable, and long-life electronic components for these systems. This also requires electronic elements to be tested for reliability and lifetime before being used on these vehicles. However, testing reliable and long-life elements is becoming complicated and expensive, due to the long duration of the test. So, Acceleration Test is an effective solution, widely used in reliability testing of electronic components in both civilian and military vehicles. The paper gives a methodology for accelerated tests of electronic elements in combat vehicles, in which the increased stresses are used in combination. An accelerated test based on multifactor stress with a specified electronic element is also introduced, as an application of the methodology. The experiment results will show the effect of stress combination in comparison with single stress in an accelerated test.

Keywords: Methodology, accelerated test, multifactor stress, LED, combat vehicle, electronic element.

1. Introduction

An important requirement for critical equipment is high working reliability. The technical elements, before being used in this equipment, must be tested for working reliability in specialized reliability tests. However, technical products and components are increasingly being made with higher quality, which means a longer life. This makes the time of the experiment too long. This is the main reason to apply an AT for this case. Currently, the ATs of many technical objects, including mechanical or electronic products, have been performed and introduced in several published works, such as offshore wind turbines in Mehmanparast (2000), mechanical actuation (membrane) of MEMS devices in McMahon (2012) or solder joints in the printed circuit board in Pang (2000).

The International Standard IEC 62506 (2013) gives a general basic instruction for all types of AT. However, with a specific technical object, the methodology for AT often is built, as introduced in the three above published works. A methodology is a system of specific theoretical analyses for the specific object, based on IEC 62506 and the knowledge about the tested object.

However, there are not many ATs and methodologies built for technical elements in the military area. In the military area, the technical elements have more severe working conditions, and higher working reliability. Especially, applying the Condition-based Maintenance and online diagnostics in military vehicles requires measuring the parameters regularly and directly in the vehicle (Furch, 2020). So, it requires choosing an appropriate measured parameter, which is different from the measured parameters in normal conditions. In this article, a methodology for AT of electronic elements in combat vehicles using multifactor stress is introduced, in which multiple acceleration factors are used to precipitate the test object to failure.

Light-Emitting Diode (LED) is a technical electronic element, which is widely used in both civilian areas, such as in LCD backlights, displays, transportation equipment lighting, general lighting, and in military vehicles (Chang, 2012). Here, LED is used as a tested object to apply the proposed methodology.

2. The proposed test methodology

Similar to application with civilian electronic elements, based on International Standard IEC 62506 (2013), the step-procedure of an AT of electronic elements in military vehicles includes the following steps:

- Identifying the purpose and type of AT used in the experiment.
- Identifying the experiment object – an electronic element in military vehicles – which is tested in the experiment.
- Determining the operation conditions of the tested object
- Identifying the stresses, which can be accelerated in test separately or in combination.
- Calculating the acceleration factor in the test.
- Determining the sample size.
- Setting up the experiment equipment.
- Performing the AT.
- Analyzing and evaluating the experiment data (failure and degradation data).
- Reporting test results.

The above steps will be analyzed in detail in the following sections.

2.1.1. Identifying the purpose and type of AT used in the experiment

The AT of type A, qualitative test, is performed to determine the weaknesses of the product, the failure modes, and the margin between operational limit (OL) and destruct limit (DL) but does not give the reliability measure of the product. The test of type A – typically HALT – is typically performed during product development by manufacturers, thereby giving the product specification.

However, due to harsher working conditions in military vehicles, before being used in military vehicles, electronic elements must be tested to verify their working reliability in the actual working condition in military vehicles. The current available standards, such as Reliability Prediction of Electronic Equipment. MIL-HDBK-217F-N2 (1995) or Handbook of 217Plus Reliability Prediction Models (William, 2006), help determine the failure rate of products quickly, but neither of the above standards can provide accurate results in terms of reliability of devices that have diverse construction and operating conditions. Therefore, the ATs of type B must be carried out to measure and verify the working reliability of electronic elements under test conditions, simulating actual use conditions in military vehicles.

Electronic elements used in military vehicles are more reliable than those used in the civilian field. It means that they have a longer lifetime, and the test time until failure appearance must be longer. The ATs of type B with single accelerated stress are still too long to proceed until failure appears. Therefore, experiments are usually performed with some accelerated stresses in combination, in which accelerated stress is applied sequentially or simultaneously.

Where possible, the use of multiple accelerated stresses simultaneously is preferred because it helps to reduce test time. Additionally, the ATs of type C - time compression and event compression - are also used in combination with type B to shorten the experiment.

2.1.2. Identifying the experiment object

The experiment objects can be individual elements or simple devices. For a device, the experiment object is the most critical and weakest assembly. For an assembly, the experiment object is the most critical and weakest component in the assembly.

When more than one object can be selected for testing, these objects are tested separately if possible. Because testing always requires knowledge of the failure mechanisms of the object and a certain laboratory requirement, then the object that best satisfies the above two conditions can be preferred.

2.1.3. Determining the real operation conditions of the tested object

Designing an AT requires knowledge about the real operation conditions of the tested object because an AT represents these conditions in the test.

The real operation conditions of the tested object depend on many factors, like the product specification, the climatic condition, the use location of the test object in the military vehicle, and the use regimes.

In the product specification, the operational limits of temperature, humidity, irradiation conditions, load mode, and impact resistance... are given. This is the initial information that determines how the product will be used in the vehicle, and what affects their working conditions. The climatic conditions, including temperature, humidity, light, and air pollution ..., are determined by geographical location, the installation location of equipment in military vehicles, time of day (day or night), and seasons of the year. The climatic conditions must not exceed the conditions given in the product specification.

The use regime determines the loading regime (mechanical stress, voltage or current, vibration, shock, temperature exposure time, temperature cycling, ON/OFF cycle ...) in the operation cycle of the product.

Due to the limited scope of the paper, the methodology proposed by the authors is presented in a simplified form, assuming an exponential distribution of the time to failure.However, the proposed method also allows the application of other types of distribution of the random variable. Details can be found, for example, in Hoang (2022).

2.1.4. Identifying the accelerated stresses

An AT is designed to test a specific failure mode separately. Then in an AT, single stress or a combination of stresses that affect the same failure mode of the product are selected to accelerate. The knowledge about the failure mechanisms of the product helps in choosing the accelerated stresses, appropriate for the failure mode. In addition, the levels of accelerated stresses depend on several factors:

- The type of AT: In an AT of type B, the acceleration is accomplished by increased stresses, called “Reliability test level” (RTL), which is greater than stress in use of product or Requirement level (RL) and lower than Design specification level (DSL), which is given in the product specification. This also ensures the general rule when choosing the level of stress, that it does not exceed the stress value, at which the properties and failure mode of the product change.
- The laboratory equipment: the specification of equipment in the laboratory decides the changing range of the accelerated stresses, applied in the AT.

2.1.5. Calculating the acceleration factor in the test.

In an AT with some accelerated stresses affecting in combination, the acceleration factor of the test was calculated by the formula (1): IEC 62506 (2013).

$$A_{\text{test}} = \frac{1}{N_s}\sum_{i=1}^{N_s}\left(\prod_k A_k\right)_i \tag{1}$$

where: A_{test} - the acceleration factor in the test; N_s - the number of stresses; $\left(\prod_k A_k\right)_i$ - the product of acceleration factor of stresses affecting the failure mode i in the test.

The component acceleration A_k factors are calculated according to the models for single stress acceleration. There are the three most used models, including:

- Inverse Power Law can be applied to thermal shock, electrical, mechanical stresses, and humidity.
- Arrhenius model is applied when the accelerated environmental stress is the constant high temperature.
- Eyring model is evolved from the Arrhenius model, however, it can be applied when the accelerated stress is temperature and other stress, such as humidity or some chemical reactions.

The above models are introduced in detail in IEC 62506 (2013). In addition, the formula (12) proposed by BMW is also used quite often to calculate acceleration factors due to the convenience of the calculation (BMW, 2010).

$$A_F = 2^{\frac{\Delta T}{10}} \tag{2}$$

where: T_0 and T_{test} – the absolute temperatures in use and testing condition, respectively; $\Delta T = T_{\text{test}} - T_0$ - the temperature increment (K).

The parameter "10" (see the exponent in Equation 2) was applied taking into account the recommendations of the BMW standard (2010) and also because the results of previous experiments carried out with different types of LEDs have shown that, on the whole, it characterizes well the acceleration factor for this type of electronic components.

2.1.6. Determining the sample size

When using AT of types B and C, the sample size depends on the purpose of the experiment, such as estimating the product reliability in an expected lifetime or estimating the time to failure. In the exponential case, the sample size and the cumulative test time are proportional. It means that the test time can be reduced by increasing the sample size or can be longer with small sample size.

However, both the sample size and the cumulative test time must be selected to match the actual circumstance, when the sample size can be limited by the actual laboratory equipment, and the testing time must not be much longer than the survival time in the test of products, which can be obtained from expert's experience.

An example of sample size is given in IEC 61649 (2008) for the case of estimating the time to failure and the failure data following the Weibull distribution: the test goal is obtaining 5-10 failures; and because a Weibull test is often stopped when one-third of tested items have failed, then the sample size can be 15-30 items.

2.1.7. Setting up the experiment equipment

For an experiment, firstly, the test samples must be prepared. Note that, when testing electronic elements, the tests are performed on test structure instead of on the actual functioning component. Therefore, the test samples must be made in a way that is simple and convenient for the experiment, while still fully describing the actual working conditions of the element.

The measured parameter in an AT must be the parameter containing the most accurate information about the degradation process or technical condition of the product. A product may have several parameters that reflect the technical condition as well as information about the deterioration process but depending on the measurement capabilities of the testing equipment, the measured parameter must be easily and accurately measured in laboratory conditions as well as on military vehicles.

The experiment equipment also needs to be set up. To complete all goals of the experiment, the equipment selected for the test must have technical specifications that satisfy the requirements of the experiment.

In this step, the devices in the experiment must be connected and tested for functionality, ensuring the completion of the goals of the experiment.

2.1.8. Processing of test data

The test result of this test type usually includes degradation data and failure data. The failure data can be analyzed by exponential distribution to calculate the MTTF of hard failure with its confidence interval. IEC 60605-4 (2001). Additionally, the failure data can be used to define the critical level of the product degradation process by the method, proposed in the published work of Hoang (2022).

The degradation data can be analyzed and evaluated by some mathematical statistical models. From the mathematical statistical model and critical level of the degradation process, the MTTF of soft failure (the FHT) and the RUL of the product can be estimated.

3. Application of methodology for LEDs in the military vehicles

In this section, the above-introduced step-procedure for an AT is applied for a specific electronic element in military vehicles.

3.1.1. Determination of the purpose of the AT

The method determining the critical level and the mathematical statistical model introduced in the published work of Hoang (2022) can be applied to Condition-based Maintenance Policy and online diagnostics in military vehicles. For applying them and verifying the effectiveness of this tool in the evaluation of degradation data, complete data with both degradation data and failure data of an element in military vehicles are required. Then obtaining these data is the main purpose of the experiment.

This AT also has the general purpose of an AT for electronic elements in military vehicles – that is verifying the reliability of products.

For this purpose, the AT type identified is type B in combination with type C – time compression, where the LED idle time is ignored.

3.1.2. The object of AT

LEDs are used in the display screen of the military systems or laptops, or some type of light sources such as Rear Tail and Brake LED light, Interior LED light, or IR Driving Front LED light and has an important role in the operation of military vehicles. The degradation process and failure mechanisms, and failure modes of LED have been studied relatively thoroughly in Chang (2012). LED has a small dimension, so it is suitable for performing ATs under laboratory conditions. With the above analysis, LED is a reasonable object on military vehicles to perform an AT.

Specifically, in this AT, Warm white LED 10W 700LM/90° was chosen as the test subject, with the following basic specifications: the luminous flux – 700 ÷ 800 lm; forward current – 1.05 A; forward voltage – 9 ÷ 11 V; the power dissipation – 9.45 W.

3.1.3. The real operation condition of LEDs

The real operation conditions of LEDs in military vehicles are determined through the average parameters: average working temperature, average operating time, and average number of ON/OFF cycles. The following test condition simulates the average working regime of military vehicles in Vietnam.

In the tropical climate such as in Vietnam, the average working temperature in military vehicles is taken as 30 °C. This average working temperature of LEDs is higher than the average ambient temperature outside the vehicle, which is about 23 °C, due to the enclosed body of the vehicle and the heat generated by other devices operating inside the vehicle.

The average operating time of a military vehicle is eight hours per day, whereas the average time in the ON mode of electronic equipment is assumed to be one hour.

The average number of ON/OFF cycles per day is assumed to be two cycles.

3.1.4. Identifying the accelerated stresses

The information about failure position, failure mechanisms, and failure modes given in Chang (2012) shows that the main factors causing the LED failure are temperature, current or voltage, and humidity. In addition, vibration is also a factor that precipitates LED to failure. In military vehicles, LEDs are usually installed inside the body of the military vehicle, with an outside protective case, moisture-proof seal, and shock absorber to help minimize impacts during work. Under such conditions, the effects of vibration and humidity can be considered negligible.

All failure mechanisms of LED are accelerated as the temperature increases. So, the first chosen acceleration factor is temperature. According to the LED specifications, the increased temperature of AT is chosen at 90 °C.

The nominal forward current of LED is 1.05 A. Using the forward current, as an acceleration factor, greater than the above value can bring risks to the experiment, because undesirable failures may occur due to overload. Hence a loading current value equal to or lower than 1.05 A, such as 0.95 A and 0.85 A, has been chosen to study the effect of the loading current on LED degradation.

The experiment also investigates the effect of ON/OFF cycling on the degradation process of LEDs, corresponding to an ON/OFF working mode with two cycles/day frequency mentioned above. To do this, the LED in ON/OFF working mode is powered by some fluctuating loading currents with different amplitudes. The chart of the loading current fluctuation with different I_f values is shown in Fig. 1.

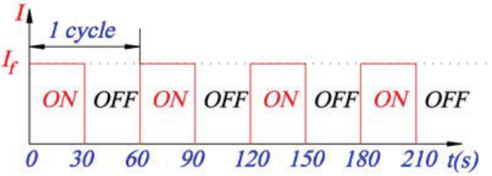

Fig. 1. The fluctuation of loading current provided for each LED in ON/OFF mode (Hoang, 2022).

3.1.5. Calculating the acceleration factor

The chosen experimental temperature is 90 °C. Thus, based on the available information, the acceleration factor of this experiment can be calculated. In this experiment, the acceleration factor only includes the acceleration factor of temperature.

In this case T_{test} = 90 °C and T_0 = 30 °C. According to the equation (2):

$$A_F = 2^{\frac{90-30}{10}} = 64$$

This means that an operational minute of the LED in this accelerated test is approximately equivalent to one operational hour in the actual condition. In one minute of the experiment, the LED works only 30 seconds in one cycle, so the one operational minute of LED in this AT is equivalent to two operational cycles of the LED in the experiment as well as in the practice (one operational hour in real life) with two ON/OFF cycling. So, the experiment ensures to properly simulate the working mode of the LED in the military vehicles.

3.1.6. The sample size of AT

Due to the limitation of laboratory equipment, only fifty LEDs can be tested simultaneously. The main test sample is performed with a nominal constant current of 1.05 A at ON/OFF working mode. So, the LED number in this test regime is the biggest with 20 LEDs. With the remaining three experimental modes, each is performed with 10 LEDs. The quantity, loading current, the testing regime of LEDs groups, and the climate chamber, in which the LEDs are placed, are given in Table 1.

Table 1. Quantity, loading current, and testing regimes of LEDs groups

Quantity (LEDs)	Loading current I_f (A)	Testing regimes	Climate chamber Votsch
20	1.05	ON/OFF	VC3 7034
10	0.95	ON/OFF	VC3 7034
10	0.85	ON/OFF	VC3 7034
10	1.05	ON	VT 4004

3.1.7. Experiment equipment

The experimental samples were prepared as follows. The LEDs are fixed on the aluminum boards (10 LEDs/aluminum board), as shown in Fig. 3, and divided into two groups; each group consists of five LEDs connected in series (see Fig. 2).

The aluminum board plays a role as both mounting brackets and heat exchangers between the LEDs and the working environment. Each group of five LEDs is powered by high-precision digital DC power units (KEYSIGHT E3634A), which are controlled by the central control computer, and the constant loading current in the ON testing regime or fluctuating loading currents in the ON/OFF testing regime with different amplitudes are given to each LEDs group.

In the civilian area, the degradation parameter of LED is output light, which decreases over time when LED degrades. However, in the military vehicle, the output light will be affected by many light sources operating inside the vehicle, so measuring this parameter to determine the technical condition of LEDs cannot be performed exactly. So here, the voltage between two terminals of LED is chosen as the measured degradation parameter of LED. This parameter carries information about the degradation process and can be measured accurately with the built-in devices of the vehicle, supporting regular monitoring of the technical status of LEDs as well as performing online diagnostics.

To maintain the constant testing temperature, the first eight groups of LEDs on the four aluminum boards, which are tested in the ON/OFF regime, are placed collectively in the climate chamber Votsch VC3 7034. The last two groups are placed in the climate chamber Votsch VT 4004 (see more in Table 1). Two climate chambers are controlled by SIMPAT (Simulation pack for test system integration) software in the central control computer.

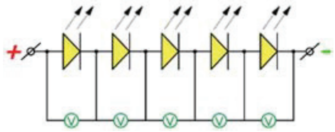

Fig. 2. Diagram of series LEDs in a group.

The measuring part of the test system includes several devices as follows:

- The temperature sensor PT100 - is placed inside each climate chamber to measure the temperature of the LEDs in the test. This sensor is a high-sensitivity temperature sensor with a nominal resistance of 100 Ω at 0 °C, a wide temperature measurement range (-200 °C to 850 °C).
- The KEYSIGHT 34980A Multifunction Switch/Measure Unit with High-density 34922A 70-Channel Armature Multiplexer (70-Ch Arm MUX) is used to measure the voltage of each LED every five minutes, store data in the central control computer as well as calculate and convert data as needed. The 70 channels of module 34922A give it the possibility to connect and measure the voltage of all LEDs simultaneously and ensure smooth work of the test system.
- The central control computer with BenchLink Data Logger Pro software is responsible for controlling the measurement part of the system, receiving, and storing measurement data.

Hence, all the devices used in the test have technical specifications that satisfy the requirements of the experiment. The connection diagram of the experimental equipment is shown in Fig. 3.

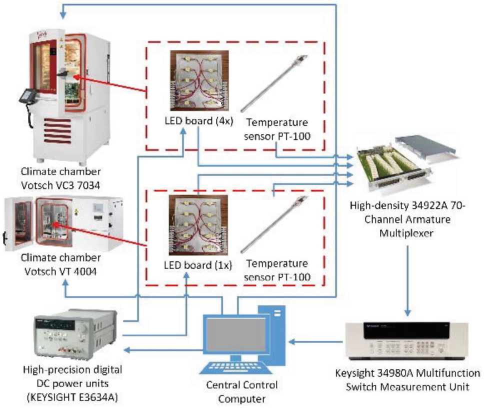

Fig. 3. The connection diagram of the experimental equipment (Hoang, 2022).

3.1.8. Performing the AT

To obtain complete data with both degradation and failure data from the test, the experiment will be performed until failure occurs with all LEDs. This means that the test plan is [n, U, n] with an unknown cumulative test time.

Before starting the test, SIMPAT software in the central control computer loads the control program into two climate chambers to maintain a stable temperature at 90 °C. When the temperature in the two chambers has stabilized, the KEYSIGHT E3634A power units supply the corresponding current to each group of LEDs. The central control computer also gives commands to the Multifunction Switch/Measure Unit to measure the voltage between the two terminals of the LEDs continuously every 5 minutes. These voltage values carry information about the degradation of LEDs. However, because the first 40 LEDs work in ON/OFF mode, the temperature inside these LEDs is unstable. To ensure measurement accuracy, the degradation measurement is only performed once per day for 30 minutes between 11.00 AM to 11.30 AM. During this time, all LEDs are working at an ON regime with different constant loading currents. It ensures that the temperature of the LEDs at the measurement moments is approximately the same. The test result is received and saved on the central computer.

3.1.9. Analyzing the experiment results

Currently, this AT has been performed for 416 days and is still running. The data from this AT are big data with various data types. The first two samples have all the LEDs failed, the third sample has both failed and working LEDs, and the last sample has all the LEDs still working. The specific results from this AT, the MTTF calculated based on IEC 60605-4 (2001) of three first samples with failures is given in Table 2. Based on the MTTF in test (day) and the acceleration factor A_F, the MTTF in use (h) of LEDs has been calculated and also given in Table 2.

Table 2. The experiment results

Loading current I_f (A)	Testing regimes	Failure number	MTTF in test (day)	MTTF in use (h)
1.05	ON/OFF	20	104.7	80410
0.95	ON/OFF	10	175.2	134554
0.85	ON/OFF	5	534	410112
1.05	ON	0	N/A	N/A

4. Discussion

The results given in Table 2 show that the MTTFs of LEDs in use with ON/OFF regime and different currentsm I_f are big enough. Here, the average working time of equipment using LEDs is only one hour per day, then the MTTFs of LEDs in three ON/OFF regimes in years are 220.3, 368.6, and 1123.6, respectively. If the average working time of equipment using LEDs is eight hours per day, then the MTTFs of LEDs in three ON/OFF regimes in years are 27.54, 46.08, and 140.45, respectively. In the harshest work regime simulated by the first test regime, the MTTF is 27.54 years. The average lifetime of a military vehicle is about twenty years, then a conclusion can be done here, that this type of LED has enough work reliability to be used in military vehicles.

The LEDs sample in ON test regime is still working and has not had any failure. It means that using the acceleration factors in combination with ON/OFF cycling really precipitates the LEDs to failure, and significantly shortens the test time in an AT.

The results of this AT also show the effects of used loading currents and ON/OFF cycling to MTTF of LEDs. Specifically, when the loading current used in the test is lower, the MTTF of LEDs is enhanced. When using LEDs with frequent switching on and off, the MTTF of LEDs decreases.

5. Conclusion

Thus, in this paper, a methodology for AT of electronic elements in combat vehicles based on multifactor stress is introduced. This methodology has shown the main differences when performing an AT with electronic elements in military vehicles in some points: firstly, the actual working condition in military vehicles is often harsher than the working condition in civilian areas, then the testing condition in the AT must be different; secondly, the electronic elements in military vehicles have higher reliability and lifetime, that to precipitate the tested object to failure, it requires applying multiple stresses separately or in combination, in which applying in combination is preferred but it must not change the failure mode of the tested object; lastly, the measured parameter in the AT must be chosen so that it can be easily and correctly measured directly in military vehicles, to support the application of Condition-based Maintenance and online diagnostics to these vehicles

The proposed methodology has been applied with a typical electronic element in military vehicles – LED. The AT has been performed for a long time, and the purpose of this AT has been completed. Specifically, complete data with both degradation data and failure data are obtained. Based on these data, a preliminary evaluation based on IEC 60605-4 has been done. The results show that the LEDs tested in this AT have enough working reliability to be used in military vehicles and increasing the loading current or ON/OFF cycling has a negative effect on the lifetime of the LEDs.

And this methodology can not only be applied with LEDs but also can be applied with different electronic elements in military vehicles.

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