Accelerated Testing of Mirka Deros Speed Controller

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BACHELOR'S THESIS

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Abstract

This Bachelor's thesis was done for the Power Tools department at Mirka Ab. The aim of this thesis was to study different ways to accelerate the lifetime of the speed controller in the Deros sander and provide a standardized test method for accelerated testing. The reason for using a standardized test method is to compare earlier designs against new ones in the product development process. This test method will also reveal weaknesses earlier in the development phase.

The accelerating methods used were: constant stress, step stress and cyclic stress. All these tests were performed in an environmental chamber. The factors used for accelerating the product were temperature, humidity, vibration and overload.

The results show that it is possible to accelerate the lifetime of the speed controller in the Deros sander. A test proposal has also been made, describing how the standardized test method should be done.

Language: English Key words: Mirka, Power Tools, Accelerated Testing, HALT

EXAMENSARBETE

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Titel: Accelererad testning av Mirka Deros styrkort

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Abstrakt

Detta examensarbete gjordes åt Power Tools avdelningen på Mirka Ab. Syftet med denna avhandling var att studera olika sätt att accelerera livstiden hos styrkortet i en Deros slipmaskin och att utforma en standardiserad testmetod för accelererad testning. Anledningen till att använda en standardiserad testmetod är för att kunna jämföra tidigare designer mot nyare i produktutvecklingsprocessen. Denna testmetod kommer också att kunna avslöja svagheter tidigare i utvecklingsfasen.

De använda accelerationsmetoderna var: konstant stress, stegstress och cyklisk stress. Alla dessa tester utfördes i ett klimatskåp. Faktorerna som användes för att accelerera produkten var temperatur, fuktighet, vibrationer och överbelastning.

Resultaten visar att det är möjligt att accelerera styrkortets livstid i Deros slipmaskinen. Ett testförslag har också gjorts, som beskriver hur den standardiserad metoden skall göras.

Språk: engelska Nyckelord: Mirka, Power Tools, Accelererad Testning, HALT

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1 Introduction

This bachelor’s thesis was done for the Power Tools department at Mirka Ab in Jeppo, Nykarleby. Power Tools develop advanced handheld electrical sanders. Power Tools product volumes are growing and the reliability of the products are of great importance. The assignment was to study different ways to accelerate the life time of the speed controller in the Deros sander and then give a recommendation on an internal standardized test method for accelerated life time testing. The electronics in the Deros sander is a printed circuit board which is called speed controller.

The reason for doing this is to find failures faster in the development phase of a product, instead of finding failures in the manufacture phase or in service. This will also reduce cost, because finding failures in the development phase is a lot cheaper than finding them in service.

1.1 Purpose and scope

The purpose of this assignment is that Mirkas volume of products is growing and the reliability and functionality of the electronics is a central part of that. That is why a standardized test method for life time testing would help to earlier in the product development process evaluate differences between different solution proposals. The testing is limited to the printed circuit boards of the Deros platform.

The scope is to study different ways to accelerate the life time of the speed controller in laboratory conditions and based on that study, provide a recommendation on a standardized test method.

2 About the company

Mirka is a global company that operates in Europe, Middle east, North America, South America and Asia. Mirka manufactures high quality abrasives and is specialized in dust free sanding. Mirka is a Finnish company which was founded in 1943 and have its headquarters in Finland. Over 97 % of Mirkas products exports to more than 100 countries all over the world. (Mirka Ab, u.d.)

2.1 Power Tools

The Power Tools department develops handheld sanders and polishers, both pneumatical tools and electrical tools. This thesis will be focused on the electrical tools.

The Power Tools unit has been developing electrical sanders since 2007. The first electrical sander was called CEROS (Compact Electrical Random Orbital Sander). The second electrical sander platform was launched in 2012 and this machine was called DEROS (Direct Electrical Random Orbital Sander). (Laitala, 2018)

The Deros sander uses a brushless motor and runs on 220 V – 240 V. It has power input of 350 W and has a speed option from 4000 – 10000 RPM. The sander weighs around 1 kg. (Mirka Ab, u.d.)

Figure 1: Deros 650 sander

3 Problem specification

Today at the Power Tools department there is no standardized accelerated test method in use to evaluate the lifetime of different electronic designs. This makes redesigning and improvement of the electronics challenging and very time consuming. Since there is no standardized test in use, it is unknown on how to best accelerate the lifetime and a better understanding of accelerated testing is needed.

Using a standardized test method would help to evaluate the lifetime of the electronics. It will be easier to already in the development and prototype stage evaluate how the new design differentiates to earlier designs where the lifetime is known.

4 Theory

In today's modern computer-based systems its common that the design gets very complexed and if failure occurs, it is usually very time consuming to solve them. When a system gets more complexed the probability of failure increase. (Denice, et al., 2015)

Avoiding failures in product development is almost impossible. It is very difficult making a flawless design. In the design phase of a product there is some testing that can be done to prevent failures from occurring. This testing is called reliability testing and should be considered as a part of a test programme. See Table 1. (O´Connor & Kleyner, 2012)

The reason for reliability being this important is because it affects a company's reputation and customer satisfaction. It also affects warranty costs, repair costs of a product with warranty will affect profit negatively. Public predicted reliability numbers also have competitive advantage against other competitors. (Weibull, u.d.)

Table 1: Example of test programme in product development. **(O´Connor & Kleyner, 2012)**

Functional testing, to confirm the design can handle basic performance requirements.
Environmental testing, to ensure the design can operate under expected range of environments.
Statistical testing, to optimize the design of the product.
Reliability testing, to ensure that the product can operate without failure during its expected life.
Safety testing, ensuring the product is safe to use.

Below is listed some of the common factors that affect the reliability of a system:

- Operating stress
- Working ambient conditions
- Bad design
- Mishandling
- Aging

These factors over time will degrade the performance of a system and result in failure. It is possible to categorise these failures as described in Figure 2.

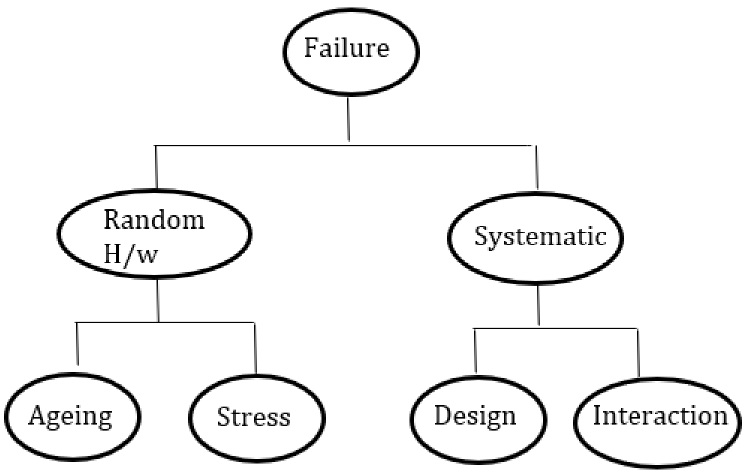

***Figure 2: Failure categorization with causes*. (Denice, et al., 2015)**

As Figure 2 shows, failures can either be random or systematic. Random failures are typically hardware failures and systematic failures are usually software failures. To narrow this down even a bit more, random failures can be caused by excessive stress or ageing. Systematic failures can be caused by design malfunctions or human interaction failures. (Denice, et al., 2015)

4.1 Accelerated testing

One type of reliability testing is accelerated testing. This means that the product will be tested above its specification limit. The reason for doing accelerated lifetime testing is to evaluate life quickly and to reduce the time to market for the product. It can also be used to identify dominant failure mechanisms. (Denice, et al., 2015)

Accelerated testing can be divided into two types, qualitative tests and quantitative tests.

Qualitative tests are used to reveal probable failure modes. Examples of test methods is highly accelerated life testing (HALT) torture tests and shake & bake tests. These tests are highly accelerated, and several different stresses can be used. This approach only uses a small number of test samples. If the test sample survives it passes the test. If it does not survive, appropriate actions are taken to improve the products design. (Denice, et al., 2015)

Quantitative tests are designed for obtaining data, such as the time-to-failure information under accelerated conditions. This data is later used for data analysis programme. This programme will extrapolate an estimated probability density function for the product when in normal use conditions and then give an estimated lifetime for the product. (Weibull, u.d.)

The big challenge in accelerated testing is to identify the dominant failure mechanism in a sub assembly. It is a lot easier to determine on one individual component but when you have many components the risk of different failure mechanism increase. (Denice, et al., 2015)

Another challenge is that when a product is under accelerated conditions failure mechanism may shift and new types of failure occur. (Denice, et al., 2015)

4.2 Highly accelerated life testing

Highly Accelerated Life Testing (HALT) is a series of stress tests where the product is stressed well beyond the product specification. HALT testing can be done as a part of the design process. The main reason for doing HALT tests is to quickly accelerate and identify design weaknesses. After a weakness has been found it should be improved and be tested again until another has been found. This should be done until the test reveals no more failures. (Qualmark, DLi Labs, 2011)

Figures 3 and 4 describe that HALT identifies the products operating limits and its destruction limits. When knowing the operating limits of the products, it is also known where the customer operating limits should be set. (Qualmark, DLi Labs, 2011)

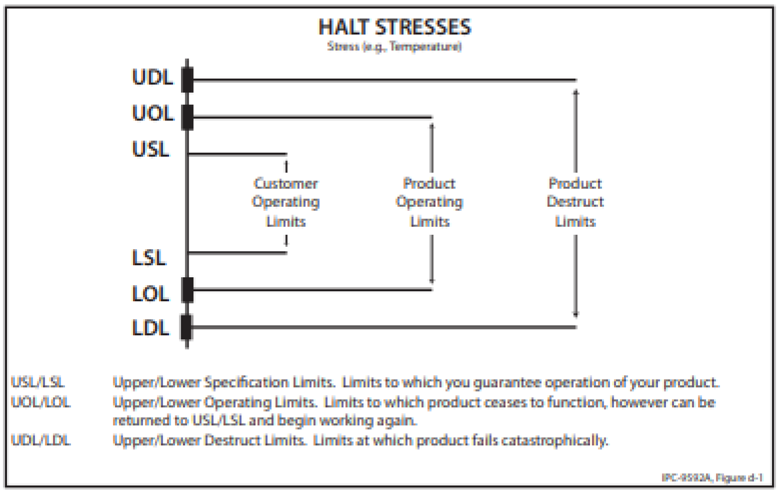

Figure 3: HALT identifies operating and destruction limits. **(Qualmark, DLi Labs, 2011)**

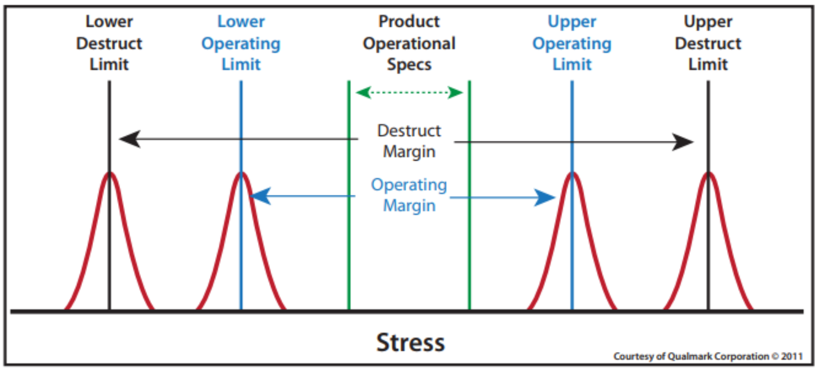

Figure 4: HALT also identifies the margins between specification and actual limits **(Qualmark, DLi Labs, 2011)**

Testing a product above the specification limits makes it fail sooner and that also provides information about its strength. The higher the stress level the sooner will the expected failure rate on the products life be. (O´Connor & Kleyner, 2012)

4.3 Stress factors

The type of stress factors used to accelerate a product to failure should be chosen by considering the normal environment the product is exposed to. (Denice, et al., 2015)

The most common factors that can stress an electronical product are listed in Table 2.

Table 2: Common stress factors. **(O´Connor & Kleyner, 2012)**

Vibration	Voltage
Temperature	Power input and output
Humidity	Dirt/dust

Vibration is an important factor in accelerated testing, especially if the product is exposed to vibration conditions in normal use. Failures from vibration testing is usually from fatigue. Vibration should be input to the device under the test and preferably on more than one axis. (O´Connor & Kleyner, 2012)

Temperature is also a key factor in accelerated testing. Temperature testing for electronical equipment is important because reliability is often affected by operating temperatures. The most common temperature tests are constant temperature, temperature cycling and thermal shock. The tested subject should be powered and operating when temperature testing is done, otherwise the results will be unrepresentative. (O´Connor & Kleyner, 2012)

Temperature and vibration combined is also a common way to accelerate in the electronics industry. (O´Connor & Kleyner, 2012)

5 Test examples

The following stress examples are methods that can be used to stress a product in reliability testing.

5.1 Constant stress

This method uses a constant stress during the entire test. For example, a test subject is accelerated by extreme constant high temperature for a specified length of time. Constant temperature tests are most used in the electronics industry. They are designed to evaluate operational or storage capabilities in extremely low or extremely high temperatures. (O´Connor & Kleyner, 2012).

5.2 Step stress

This method is progressively increasing the level of stress for a specified length of time. If the tested specimen survives, the stress increases for another specified length of time, see Figure 5. This method is used because it quickly yields failures, because of the increasing stress levels. This method is used in highly accelerated life testing. (Qualmark, DLi Labs, 2011)

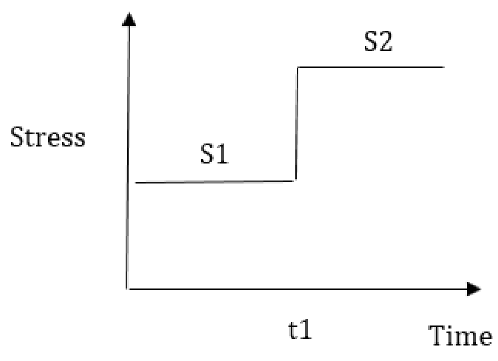

Figure 5: Step stress illustration. **(Denice, et al., 2015)**

The disadvantage of using this method is that failure modes that occur in the high stress levels can be different from those at use conditions. (Denice, et al., 2015)

5.3 Progressive stress

In the progressive stress method, the stress levels are increasing at a given rate for a specified length of time, see Figure 6. Progressive stress tests also quickly yield failure. This method has the same disadvantage as the step stress method. Failure modes that occur in the higher stress levels can be different from those at use conditions. (Denice, et al., 2015)

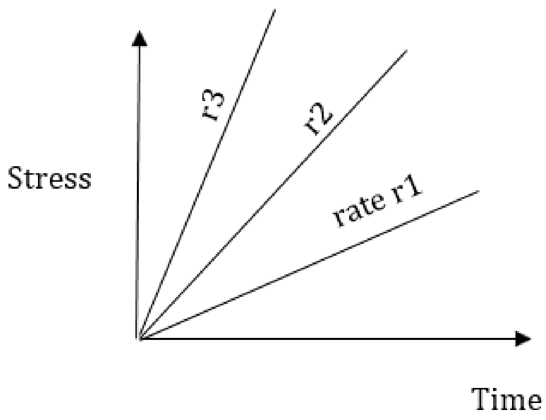

Figure 6: Progressive stress illustration. **(Denice, et al., 2015)**

5.4 Cyclic stress

Cyclic stress is just as the name suggests a test where the unit is subjected to cyclic stress for a specified length of time. One extreme high value and one extreme low value must be set. The rate of transition between the two must also be set. Thermal cycling can reveal coefficient mismatch between materials. Failures occurring from temperature cycling are often fatigue failures. (O´Connor & Kleyner, 2012)

5.5 Implementation tests

There are also standards for reliability testing. In the following two headlines are one HALT standard and two environmental testing standards described.

5.5.1 IPC 9592A Standards

IPC 9592A is a highly accelerated life test standard which is used in all aspects of the electronics industry. This standard is defined for AC to DC and DC to DC modules and printed circuit board assemblies. (Qualmark, DLi Labs, 2011)

The test system needed to perform the HALT test as defined in 9592A is:

- A minimum vibration level of 50 gRMS.
- A thermal range between - 80 ºC to + 170 ºC.
- A thermal change rate of at least 40 ºC per minute.
- A minimum of 3 test samples per test.

In Figure 7, it is described how many samples needed and what kind of stress tests that should be done.

Table 5-1 Minimum Sample Size for HALT Tests

	Low Temperature Step Test	High Temperature Step Test	Rapid Thermal Cycling Test	6-DOF Random Vibration Test	Input Voltage Test	Output Load Test	Combined Stresses Test
All Classes and Categories	3	3	3	3	3	3	3

Note 1: For Categories 1 and 3 (Power Supplies/Adapters), users have the option of starting with less than 21 samples and re-using samples which survive a given sequence of testing. Users are cautioned that some HALT failures require extensive repairs after failures during early testing and may not be suited for subsequent testing. Category 2 (BMPM) must begin with 3 new units for each test sequence, except for units which have not failed a HALT test when the equipment capability limits have been reached. These units may be used in the next test rather than replacing them with new units.

IPC 9592A Table 5-1

Figure 7: Table from IPC9592A, defining sample sizes and tests.

As Figure 8 shows, the testing is done by first applying these stresses separately and then in combination. All these separate stresses are also applied as a step stress. For example, in the cold thermal step stress the cold increases. (Qualmark, DLi Labs, 2011)

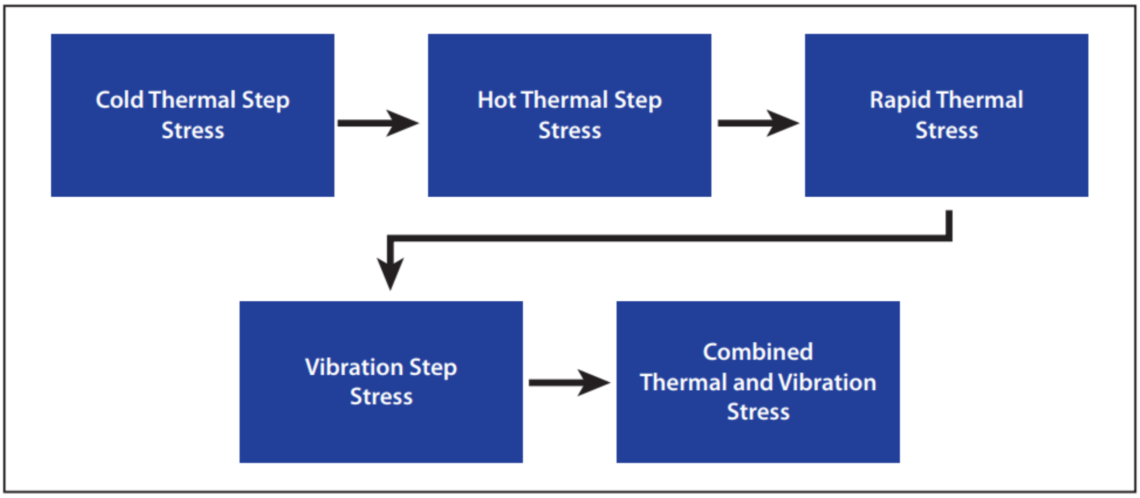

Figure 8: Image from IPC9592A, showing sequence of stresses used in the HALT process.

After doing these tests as the IPC9592A suggests, all failures that have been found should be analyzed to their root cause. The key output in HALT is failure modes. (Qualmark, DLi Labs, 2011)

5.5.2 IEC 60068-2 and US-MIL-STD-810

IEC 60068-2 and the US MIL STD 810 are both standards in environmental testing. The purpose of these standards are to show that the product will not fail or be damaged under test conditions. Most of these tests also don’t require that the tested subject should be operating during the test. (O´Connor & Kleyner, 2012)

IEC 60068-2 is a collection of methods used for environmental testing of electronic equipment. The products are tested to perform under environmental conditions such as extreme cold and dry heat. (Delserro Engineering Solutions, u.d.)

The US MIL STD 810 standard is used by the United States Military and contains methods and planning of the influences that environmental stress can have on materials and equipment on all phases of their service life. This standard is commonly used to test product limits. (Delserro Engineering Solutions, u.d.)

6 Test procedure

Different ways of accelerating the electronics was performed and studied. All tests were performed in the Power Tools laboratory. All the run time hours are replaced with a run time index because of corporate privacy.

6.1 Test Equipment

The following equipment was used:

- Deros 650 sanders were used as test object. These were ordered directly from the production line.
- An environmental chamber was used. This chamber could operate from – 50 ºC to + 150 ºC. It was also possible to set the desired humidity in the chamber. See Figure 9.
- An internal test program for remote control of the sanders.
- A load fan was mounted on the sanders to create a massive load, to simulate that the sanders were used against a surface and therefor will operate with a higher power output. This load fan also creates high vibration values.
- An internal test program for temperature measurements on the PCB and motor.
- A timer for getting the run hours.

Figure 9: Environmental chamber used.

6.2 Constant stress

In this test, the Deros 650 sander was mounted in an environmental chamber. A load fan was also mounted on the sander, then the sander could operate on high power. No remote control for the sanders was used in this test. The sander ran on 10000 RPM. The load fan mounted on the Deros also created high vibration values. Five Deros sanders were tested.

The environmental chamber temperature was set to + 75 ºC and the humidity to 60 %. When the chamber temperature was + 75 ºC the internal temperature on the printed circuit board was above the operating limit. The test was run until failure occurred or 5000 on the run time index was achieved.

6.3 Step stress

In this test, the Deros 650 sander was mounted in an environmental chamber. A load fan was also mounted on the sander, then the sander could operate on high power. The sander ran on 10000 RPM. The sander was run through an internal test program for remote control. The load fan mounted on the Deros also created high vibration values.

The chamber was set to 100 ºC and the test started from that point. The sander was operated for 10 minutes on 100 ºC and afterwards the stress level where increased with 10 ºC. The test was run until failure occurred, this test was done because it could quickly yield failure.

6.4 Cyclic stress

In this test, the Deros 650 sander was mounted in an environmental chamber. A load fan was also mounted on the sander, then the sander could operate on high power. The sander ran on 10000 RPM. The load fan mounted on the Deros also created high vibration values. The sander was run through an internal test program for remote control. Six Deros sanders were tested.

The chamber temperature settings were – 20 ºC and + 65 ºC and 55 % of humidity. The idea of this test was to run the sander from – 20 ºC until the chamber reached + 65 ºC then the Deros sander would pause until the chamber reached – 20 ºC again. When – 20 ºC was reached the sander would start again. This was done until failure occurred or 5000 on the run time index on the machine was reached.

7 Test Results

In the following headlines, the results from the stress tests that has been done in the Power Tools laboratory are listed. Because of corporate privacy the run time hours are just an **operating time index** and not the real hours.

7.1 Constant stress results

The constant stress tests results are described in Table 3.

Table 3: Results from constant stress test. X marks failure.

Machine number	PCB damaged	Motor issues	Motor damaged	No fault found	Cable issues	Run time index
6	-	-	**X**	-	**X**	5200
7	-	-	**X**	-	**X**	600
8	**X**	-	**X**	-	-	100
9	**X**	-	**X**	-	-	133
10	-	-	**X**	-	**X**	1133

Table 3 shows that the PCB (Printed Circuit Board) was damaged in two of the tested machines. The results also show that the motor was damaged in all the five tested machines, so higher constant temperatures seems to damage the motor. A cable issue was also found. This cable issue could be caused by the higher vibrations the load fan creates.

7.2 Step stress results

This test did not give the wanted results. During the test, the Deros sander could not operate at the higher temperatures. This was because of an internal safety function in an integrated circuit chip used on the printed circuit board.

7.3 Cyclic stress results

The cyclic stress results are described in Table 4.

Table 4: Cyclic stress results. X marks failure.

Machine number	PCB damaged	Motor issues	Motor damaged	No fault found	Cable issues	Run time index
0	**X**	**X**	**X**	-	**X**	4300
1	**X**	-	**X**	-	**X**	4867
2	**X**	-	-	-	-	167
3	-	**X**	-	-	-	5833
4	-	-	-	**X**	-	3567
5	-	-	-	**X**	-	3033

Table 4 shows that the PCB (Printed Circuit Board) was damaged in three of the tested machines. Especially one case was interesting where there were no other failures except on the PCB. The results also show that the motor was damaged in two of the tested machines. The cable issue was also found in two of the tested machines.

8 Test proposal

Based on the test results, it is possible to accelerate the lifetime on the printed circuit boards in the Deros sander. The results also show that this can be done in an environmental chamber.

The main challenge with accelerating the printed circuit board is when there are so many other factors that can be accelerated in the Deros. To overcome this problem is to only accelerate the printed circuit board and have the rest of the Deros sander running outside the chamber. The results also show that temperature, vibration and humidity is factors that could be used for this.

The proposal is to build a test setup that can hold five printed circuit boards and they will have wiring through the side holes in the environmental chamber to the rest of the Deros sanders. This way the only thing that will be accelerated is the PCB and the Deros sander can still be powered and operating under the test. Using this kind of test setup, it will be easy to do many different accelerated tests in the future.

If the standardized test for the electronics in the sanders are to be used in the product development phase, the suggestion is to do it accordingly to the model in the IPC 9592A standard, see Figure 10. This is a good way to provoke early failures and finding the products destruction limits. When knowing the products destruction limits, the operating limits can also be set.

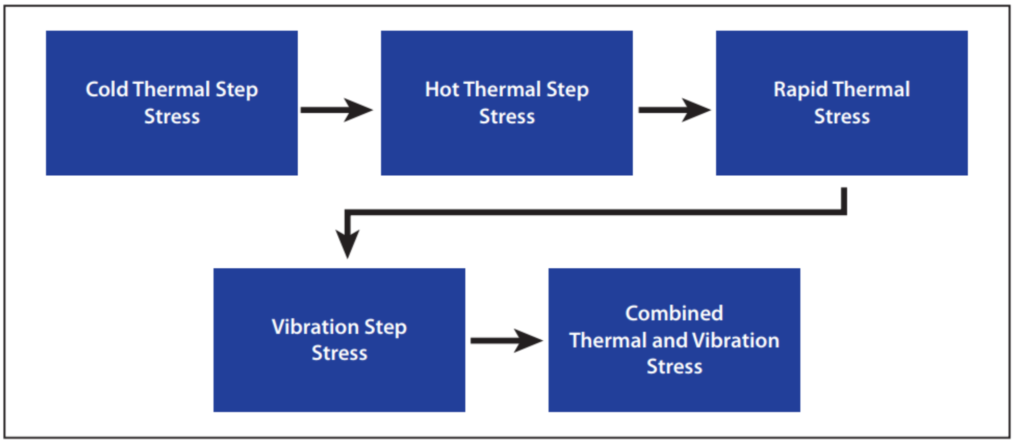

Figure 10: IPC 9592A standard test model. **(Qualmark, DLi Labs, 2011)**

9 Discussion

In the beginning of this assignments I had too much focus on the failure modes, so I did not see the big picture. A lot of time was spent in the Power Tools laboratory doing many different tests, that did not lead anywhere. In the beginning I also only tested one Deros at a time for a shorter time and hoping it would give some failures instantly. That is not how you should do accelerated testing. It was first when I applied a more systematic approach with longer test runs I started to get results. Accelerated testing of a product needs a systematic approach with a clear test plan and at least five test objects for each test. Finding failures is not an easy task and it also takes time and experience with the product.

Another thing to have in mind is that the Deros is a completed product that is in service. Doing accelerated tests on completed product is a big difference compared to doing it on a product that is only in the design or development phase. Many of the failures that can be found in the development phase from accelerated testing has already been corrected on a product that is already in the customers hands.

Another challenge in this assignment was, that it was not possible to accelerate the Deros in very high temperatures. This was due to an internal safety function in an integrated circuit chip on the printed circuit board. The testing performed couldn’t be done well beyond the product specification limits. As described in the theory of this thesis, when doing accelerated testing the product should be tested beyond the product specification limits and high temperature is one of the most common ways to do it. This problem was time consuming.

My way to overcome this problem was to test where the safety limit was triggered and to do the accelerated testing below that limit. It must also be in consideration that the Deros, when operating produce heat itself. Another way to overcome this problem was to do temperature cycles from low to high temperatures.

The biggest challenge in this assignment was that there are so many factors that can be accelerated in the Deros. That is why the test proposal suggest a test setup where the printed circuit board is the only thing accelerated.

Even if the Deros is a completed product in service a direct result of the accelerated testing was made. This was the cable issue that is mentioned in the results. This was considered as a potential weakness, so an improvement was suggested and have today been implemented in the product.

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