The Process of Developing an Electronic Product from Concept Design to a 0 Series Product.

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ABSTRACT

The process of developing an electronic product to a 0 series product. The topics include Concepting, testing and developing. The main focus is on the testing.

My goal was to make the reader more familiar with real life situations when developing an electronic product and to offer guidance with choices you can make when processing with the development.

There are also some examples given here, so that it is easier for the reader to understand these issues. Many of the examples are things that I found out when working in this field.

Keywords Testing, measurement, process, standards, issues.

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CONTENT

TERMINOLOGY USED

EMI – Electromagnetic interference.

EMC – Electromagnetic compatibility.

NMEA – National Marine Electronics Association.

Breadboard – Temporary solderless testing platform for electronics.

Operator – is person who does the tests and builds the product when the product is in manufacturing.

Steering group – group of people who oversees the development / research project and gives advice on the matter at hand.

Zero series product or Pre-production series – First unit/units product that has been manufactured by the factory without help of engineering group with normal order and logistic systems.

Dev loop – Development loop.

1 INTRODUCTION

The purpose of this thesis project is to show how to develop an electronic product in real life situations and to make reader more familiar with different processes that come with the development. This is because in real life situations the development process is quite often different from what be expected. These methods are not always the smartest way to do it, but usually are the most cost efficient in the big scale. Some of the cases that I will be telling in this thesis are issues that I have learned when I have been working in this type of developing environments and that is why there is my perspective on developing a product and well as the perspective of professionals in the field.

This thesis will go through the process that is involved with developing an electronic product and shows what concerns are important at different development phases. It also comments on product testing and shows different types of approaches that you can take in order to have a better judgment when solving the issues on your own.

I have also tried to explain a few concepts that are related to the product development. Such as standards, measurement technical information, test planning, end of design etc.

2 DEVELOPMENT METHOD

There are lot of different development types that are used in the field of technology but most of the time lean is used. Lean type of developing gives flexibility in the development cycle and it does not rely on the fact that the device is problem free at first.

Waterfall type of development in short means developing a product and then testing it. This type of development method is not usually used anymore as it is highly volatile in the sense that if there are any problems with the device everything must be done again. (Rouse, 2019)

The waterfall development cycle is: Plan → Design → Verify → Release

Do not use this type of method when developing. Always test the device before implementation when there is reasonable amount of process in the device. Reasonable amount of process in this case rely on the experience of the test engineer, but good rule is that between few minor patches the whole device should be tested.

3 PRODUCT DEVELOPMENT

In this thesis lean type of development is applied to minimize waste and to have less issues with the product when releasing it. The process map illustrated in figure 1 shows one way of developing a product in electronics engineering. The figure focuses on the development loop and the other parts are shown outside of the figure 1 as guide for other process going around the Dev loop. Figure 1 Process map has been developed during working on the subject area for few years. It reflects a normal working order in the electronical development field, however this may differ between workplaces.

When starting the development of the product it first enter to concept phase as illustrated in figure 1. In this phase standards and requirements are decided and the methods which the product is going to rely, also known as features and properties. After the requirements and standards are done, these are added to the scope which is implemented to prevent feature creeps at later stages in the development. The scope can however be changed if needed with the aid of the steering group.

“If the scope is not defined, the product becomes a wishing well of features and nothing gets done (Nikkilä, 2019).”

Proof of concept is the phase where we just test parts which are responsible for the functionality of the product. These could e.g. include things such as If the idea works, how accurate measurements certain type of method gives. Then it is added to scope as one of the features. After the scope is done, we can move to next big loop called "Development loop". In this loop we will polish and make our product better as time goes on.

Development loops around the design and improves it. At first when doing breadboard testing, only try to test out single systems on breadboard and gradually trying to make something whole that could be made into prototype circuit board. Of course, there will be problems with the design at first, but that is why there is Dev loop to accommodate these uncertainties.

When issues are found they are separated into three main issue types: design, test environment and test setup. Then these issues are looped according to the Dev loop and rooted out. When the issues are fixed or if improvements are found while fixing the design these are added to design documents. Also, the test plans are in constant motion as the product goes through the Dev loop. This is because when we are improving the design, some of the test parameters might change or we could gain better understanding of the device and test it more appropriately.

Development loop will end when there are no more issues found, even though this is not entirely true, as some issues are found in later phases. Even still the objective is to launch the product as issue free as possible. After the final testing is concluded the release review will start where the product is reviewed against the requirements and the standards and checked if all of those are accomplished. In review phase the product is either approved by the review board or rejected. If it is approved then product goes forward in the chain, but if the product is rejected then it goes back to development to fix the issues that review board noticed. If the issue is a lack of feature then it needs to be added into the scope, this is handled by the steering group. If the issue is design error or something that is already specified in the scope, then we will go back to the development loop. In reality these reviews are done almost at every step of the way, but for the sake of simplicity these are only represented at the end of process map (Fig. 1) after the product is accepted by the review board then we will freeze the development of the product.

Zero series product or Pre-production series work start after the development freeze is in effect. In this phase, be sure that the production line and logistics are working as intended to make the product. When the pre-production series are being developed in the factory, do not try to help the process, as doing so we would not see what places would need additional instructions or where could we need more strict development guidelines if there is phase in the production line where there is higher chance that the product would end up being faulty.

Process map

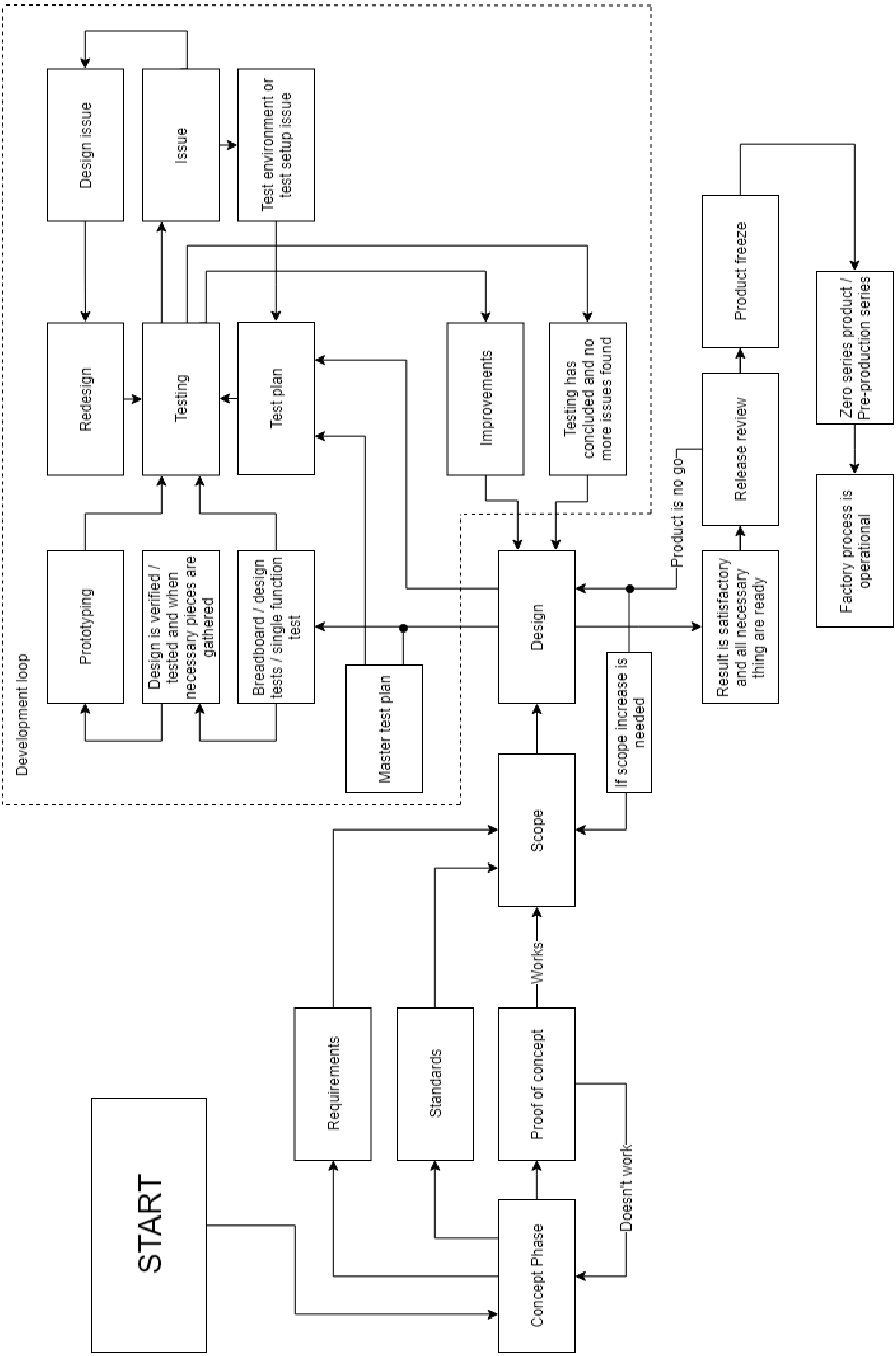

Figure 1 Process map - has been developed during working on the subject area for few years.

3.1 Concept Phase

The biggest issue when starting to make specifications to the product is that the specifications are not quite clear. It has to be avoided making the product specifications too vague as projects like these will have more difficult development cycles and typically have more issues.

When making products, in almost all cases the product is something that is already out there, so when making the product, do not compete with technology, but with specifications. Because in the end only thing that matters is the specification of the product. The better the specifications the better the sales are. Avoid overshooting too much specifications as it makes no sense to promise something that the product does not have. However, many companies tend to make so called “marketing specifications” promising a bit too much.

When considering the right specification to the product there is five main categories that they can be sorted to. It makes easier to understand them when assessing importance of them.

1. **Standard** – There are specifications that are required for the product to achieve and have a certification of it. These include e.g. IP class, EMC, security and more. These standards are made by third parties and the developer must make the product follow those standards by making the specifications accordingly standard.
2. **Requirements** – are a bit different than standards in the sense that standards must be followed in an exact manner, if these standards are needed. Requirements are specification that are needed on product to achieve desired functionality. E.g. it needs to have NMEA communication protocol or the customer is required that the product has certain measuring accuracy.
3. **Safety** – If the specification is related in any way to safety it should never be ignored, and it always must be included in the final product. Safety can be included in the standard category as some standards are safety related.
4. **Regulatory definitions** – These are defined by the government and are to be followed, if the product falls into this category. Safety and regulatory definitions are usually linked together in some way.
5. **Certifications** – these are paid licenses that are owned by third parties. Such as Underwriters Laboratories.

The first matter when considering specifications for a product is to know the environments that the product is going to be used in. It is always good to think this first as it impacts most of the product standards. It also might change how the product would be made in the first place so it is important to know the application site.

Setting the specifications threshold value to the right amount at the start is important. When deciding on those specifications do not add any margin to the values. This is because in the testing they will test a little bit over the set threshold value so that they know if the product can meet the specification. If little margin is set to the value in the testing phase it will double the margin amount, and this might have effect to the overall design. E.g. product will not go through the initial intended specification thresholds and will fail due over specification.

There are some common specifications that should be known beforehand. (Note that some of these can only be used in products that are some type of Sensor device or measuring device.)

1. Measuring accuracy
2. Measuring accuracy error ← comes from Unit to Unit variation
3. Measuring uncertainty. Comes from Unit to Unit, Temp and RH correlation, Resolution, Repeatability, unknown uncertainties, etc.
4. Operation range
5. How and where can the product be stored? e.g. Temperature and humidity

Deciding the right **component size** is also important when making the design. This is to prevent shaking related issues. Tall component could cause them to tear off from the PCB if the impact would be great enough. This also effect the casing size that the product is built on. There is no need to decide the component size at the beginning as it does not matter then, but it should be taken into consideration before the casing and the final PCB are starting to form.

Power consumption also comes to play when electronic device in question. This should be high priority when the product can be battery powered or they could be used in low power applications. Also, if there is different modes, they should be list of the current draw with all modes so that the customer knows how much the product draws current in the different situations.

These modes could be:

1. heater inside the product
2. low power and high power mode e.g. transmitting power
3. other added functions that add power consumption

Some of the common low power applications uses solar panels / batteries so, it would be good to make the product be able to work with low power of solar panel / battery.

Unit to unit variation must be better than the measuring accuracy. This is because if the product has between units a lot of spread in the reading it cannot be said that it is accurate. This also effects measurement uncertainty to great degree.

When unit to unit variation comes to play, the factors that determine those variation should be discussed with larger team as this will save a lot of time than just randomly testing all variations and variables.

Unit to unit variation can be mitigated to certain degree by making the production of the product more streamlined and eliminating random factors from the equation. These random factors are usually human applied steps in the production such as measuring by hand and application of glue or other chemicals that are applied by hand. Making these types of steps with robot or other human operated machine will greatly reduce variation between units.

Most common variation that is not human applied are component tolerance issue in the product. These types of issues can only be fixed by changing the component or the design. Other fix is tuning, in these cases there is good precision in the data, but not good accuracy. *more about this in the tuning/calibration section under 3.2.2*

3.1.1 Proof of concept

Proof of the functionality in the product is needed to demonstrate concepts feasibility, as there cannot be work done to a project before the concept is tested. In electronics the usual method is through trial and error. Most of cases it is just putting pieces together and trying to come to a reasonable similarity with the concept.

Proof of concept is more than often constructed to breadboard, as it is faster than making actual circuit board and it lessen needless development with the board. It also minimizes risk when there is working breadboard design. All features are to be tested before those are implemented. It is good to have the proof of concept when applying for a patent because it is often required, as proof that the product is capable of what it claim.

3.2 Accuracy, precision and resolution

Are terms often used in the measuring field and though they might sound the same they are quite differently used to describe different values.

- **Accuracy**: The error between the real and measured value.
- **Precision**: The random spread of measured values around the average measured values.
- **Resolution**: The smallest to be distinguished magnitude from the measured value.

“**Accuracy** is an indication of the correctness of a measurement.” (meettechniek, 2017) It tells how big difference there is to the real measured value. The real measured value is measured with another measuring device that have been tested and proved to be use for as reference. There is usually more than one reference devices that are used to find the real value of the measurement. The measurement value cannot never be better than the real value measured by the reference device.

“The term **precision** is used to express the random measurement error.” (meettechniek, 2017) There is always random deviation from the measured value. These are usually noise of the measurement device such as thermal in circuitry case. Measurement precision can be improved by oversampling or filtering, this improves the individual measurement thus giving better precision.

“The **resolution** of a measurement system is the smallest yet to distinguish different in values.” (meettechniek, 2017) Meaning that smallest yet usable measurement is the resolution. Like in the case of ruler if the smallest measurement on it is 2mm then the resolution is 2mm. Illustrated in figure 2.

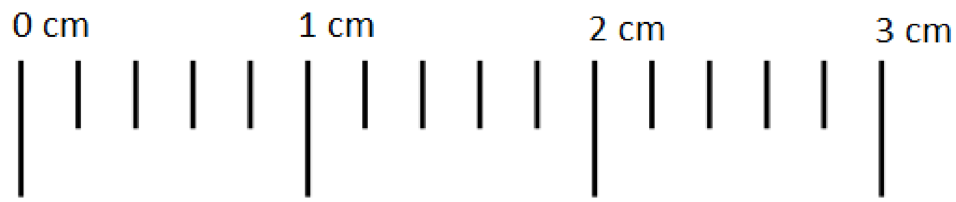

Figure 2 Ruler

If there are random small values in the measured data, it does not necessarily mean it is a part of measurement resolution.

3.2.1 Measurement uncertainty

Measurement uncertainty is an error in measurements caused by measuring equipment, tools, noise, environment and other abnormalities. These errors can be divided into two categories: Systematic errors and random errors. Random errors represent the noise and induced voltage and/or current and systematic errors are equipment, tools and environmental as they are more likely to occur in a same way.

Getting as close as possible to the constant value makes the device more accurate as there is less accumulative error in the calibration chain. In general, these uncertainties are usually hard to find and some of them do not even get recognized. Knowing uncertainties will help in the future to tune the measuring device. (Ruohola, 2019)

In the case of a digital multimeter, if its specifications has accuracy of 6% when the 100V, then the uncertainty of measurement is 6% + error over full scale that is 2.5% in this case. These percent values are given in the device, but sometimes the full scale errors is not given as it is taken into account on the accuracy. Also, the error of digits in the multimeters display must be considered when calculating uncertainty. (meettechniek, 2017)

The example uses the following values:

- Accuracy: 6% (2.5% Full scale)
- Range: 100V, Reading: 60V
- 4 digits in the multimeters display

If the multimeter has a reading of 6% and 2.5% of the full scale, then these must be combined after the measurement error has been found. If the range 100V is selected and the multimeter reads 60V then the error of the reading is ±3.6V. (for.1) and the error over full scale is ±2.5V. (for.2) (meettechniek, 2017)

$$\frac{\%\text{Reading}}{100\%} \times \text{Reading. V} \tag{1}$$

$$\frac{\%\text{Full scale}}{100\%} \times \text{Range} \tag{2}$$

After these two have been calculated the error of digits can be added in this case there is 4 digits, so the error is ±0.04V. In this case for every digit ±0.01V error is added. This digit error usually differs between measuring devices. (Uncertainty in Meter Readings, N/A) This means that the uncertainty of the measurement is ±6.14V or 10.23%. (for.3)

$$\frac{\text{Uncertainty. V}}{\text{Reading. V}} \times 100\% \tag{3}$$

There are a few ways to show this uncertainty with a graph. In figures 3 and 4 two of this are shown. The figures 3 and 4 were drawn for this thesis.

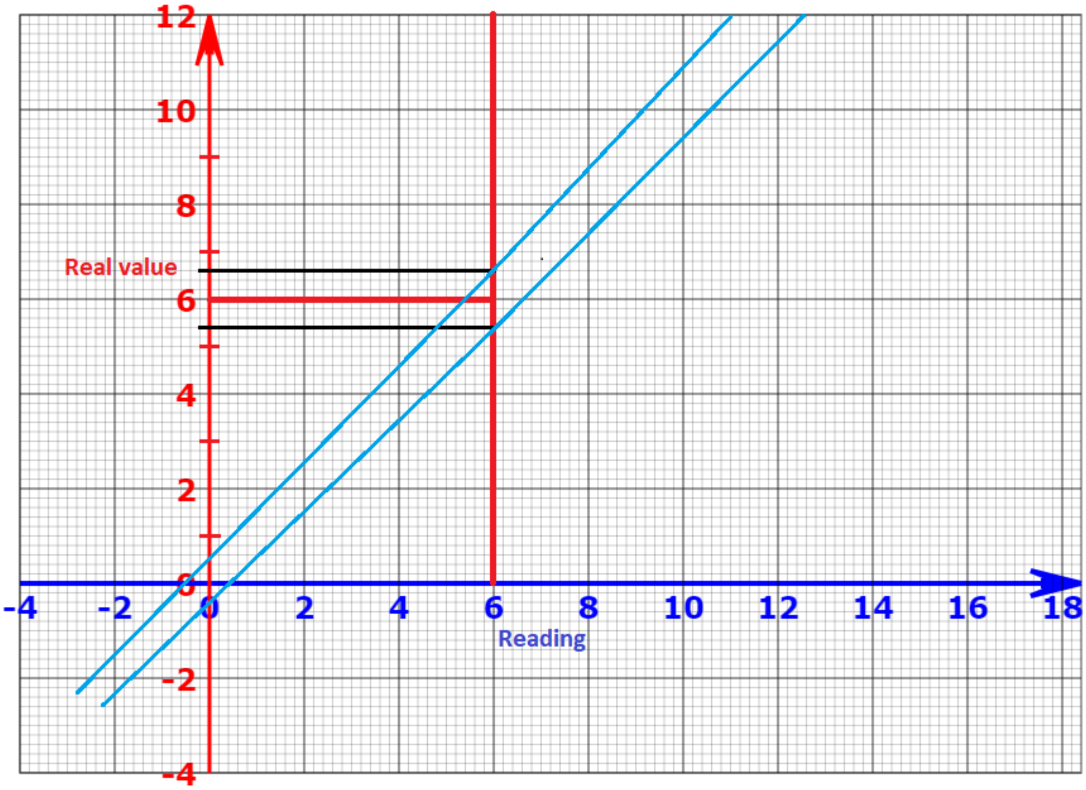

Figure 3 Measurement uncertainty. Real value presentation.

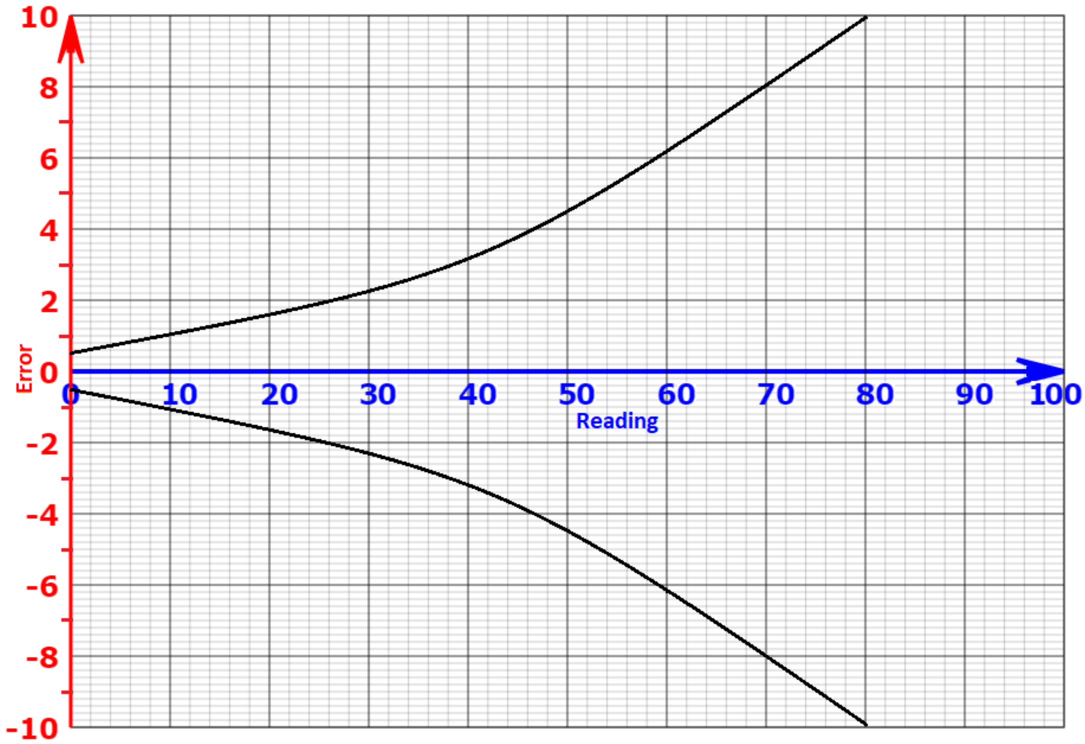

Figure 4 Measurement uncertainty. Tube presentation.

Figure 3 shows the measured value compared to the real value (Note that values are shown as 10 times smaller). Real value is a value that is measured with reference measuring device, in this case we are assuming that the reference measurement has no error of its own. In this case the measurement uncertainty values is ±6.14V.

Black lines represent the outer most measured values. The vertical red line represents value that our measuring device measured. The horizontal red line represent the value that is known to us from the reference measuring device. The light blue line is the values measured over the spectrum that are converted to shown as lines.

Figure 4 compares the measurement uncertainty to read value. In this example the error in the measured values is ±6.14V when device is measuring 60V.

These values are much better in actual use, but for the sake of simplicity the values are shown here over exaggerated.

3.2.2 Calibration and tuning

Calibration is often used wrongly in context of making a device more accurate. It is used to describe the action of finding out how much there is inaccuracy in the device.

Tuning on the other hand means the process of making the device more accurate. In the process of tuning the purpose is to make a device more accurate, this is achieved by moving the “hits” according to the reference device. This is usually done in practice by introducing correction values to the device, these correction values moves the “hits” closer to the real value. As illustrated in figure 5.

This correction can be only done with devices that have a high precision to begin with. If there is low precision, it is almost impossible to say where the “hits” are going to land. Precision can only be improved by making the individual measurements more accurate.

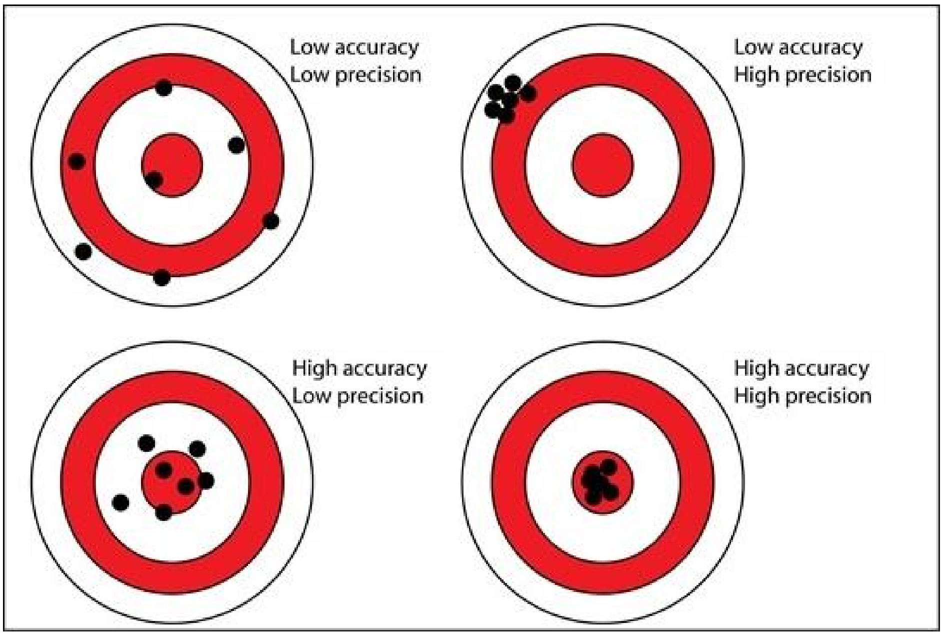

Figure 5 Accuracy and Precision (Yong, 2015)

3.3 Standards and Requirements

When trying to fit the product to meet standards, which are needed for the product, it also might reach another standard that we did not need or something that was not considered due it not being necessity. If so, there should be mention on the products data sheet even though there is no need for it but remember that when doing this it is still required to disclose that it has been tested with the said standard.

Applying to licensed standard it usually means that someone from the standardization company comes to see if the tests that are used to verify the standard is valid for the product. This is called auditions in most companies. Every year there is random test that the license standardization company does to check that the product has the documents in order. In the case of product is newly made these auditions at first happens just before the factory is in operational for the new product and after the factory is in full production.

Then why to get these licensed standards? Well this is to assure the buyers that the product can take what the company claims. Therefore, third party confirmation is necessary. In America and Canada there is UL listing, if product is not listed there it is very unlikely that the product has any success in the America or in Canada. Even though there is still cases where there has been products sold without listing.

UL listing also can be made for batch, this way there is no need to pay for X amount of money to upkeep that listing. Though this is only good choice when there is little amount of export to those countries that needs it. UL listing in any means is not required by law, but companies almost always want some reassuring from these types of licensing/standardization companies.

It is also good to know that usually the CE marking does not mean much in the America, even though they recognize it. It is common that they want third party verification of the product.

4 TEST PLANNING

Is important to know what test the product must go through before there is any progress in the actual making of the product. All these things are laid out in the Master test plan. Master test plan is the document that is referred when planning tests, therefore it should tell everything from the bird's eye view about the test plans. It only gives guidelines how to make the test plans.

Master test plan does not comment on test case level, as this is up to the engineer how to make it, but there is good practices that are recommended when doing the test cases.

Such as:

- Keep explanation of the test short, but informative.
- Do not repeat test steps, just refer to them when needed to use them several times.
- Use language that does not take any stand education background. E.g. do not use words that only has meaning to an engineer/operator etc.
- Use pictures as additional explanation when describing a setup. This makes understanding of the scenario much better.

4.1 Master test plan

Master test plan the document that is refer when making test plans. It contains test plans that in them self contains brief description of the standard or requirement that is wanted to achieve. After that there is the test itself that contains what must be made in order to confirm that the criteria of the requirement or standard are met. For every requirement there must be verification even if it is a simple one like "is the product painted red." answer is then "yes or no".

Master test plan also is a collection of tests that confirm if the standards and requirements are met for the product. Master test plan is just a name for the collection of the products test. It could be any name, but in this thesis, we are using the name as its most descriptive name for it.

Master test plan includes:

- List of tests
- Testing levels (software)
- List of all items to be tested
- Test execution cycles (software)
- Test budget
- Testing schedule
- Scope of each item
- Predefined entry, continuation and exit conditions for each test levels
- Risks that are involved with test project
- Management and control of testing

These points are not absolute as they can vary on workplace to workplace basis.

Test list is a list of tests to be committed before the product can enter production. This list can be separated into two different categories, software and hardware. This makes it easier for engineers to go through the master test plans as they find their test that are assigned to them.

Testing levels are used in software testing to prevent overlapping in the testing phases and gather information from the product. There is five different levels that must be completed before software testing can be concluded.

1. **Unit testing** – test that the code is working without any issues and it correlates with user defined specifications. Classes, functions etc. are tested also.
2. **Component / module testing** – here we test the different software modules that has been developed, so that the intended code works as planned.
3. **Integration testing** – Modules are tested together as one whole system. Functionality and behavior are tested to see any errors in the integration.
4. **System testing** – testing the code, performance and compatibility with the integrated system.
5. **Acceptance / verification testing** – ensure that requirements and specification are met.

Test execution cycle defines that in what sequence software test are performed. It systematically tells how, when, where and what order the test are to be committed to conclude satisfactory result.

Predefined entry, continuation and exit conditions for each test levels is required, so that the testing will go smoothly, and we avoid unnecessary decision making when it is not needed.

Testing scope for each item is necessary for to avoid over testing and keep tests on schedule. Deciding scope is done as any other scope definition would be made. Testing scope also can be concluded as “no testing required”. This usually means that the item has been used before in some other product inside the company thus not requiring testing anymore.

Management and control of testing. These people must be written to master test plan as it will be easier to find responsible person when there is need for confirmation, verification, etc.

4.2 Test plan

Test plan – is a plan which the test case is to be committed.

Test plan must contain:

- Objectives
- Scope
- Assumptions
- Risks
- Test approach
- Test environment
- Test schedule

Though this is largely dependent on the workplace. There might be more points that are needed for the test plan.

Objectives are needed to complete before tests can conclude. Objectives are to be written so that they will be according the master test plan. Sometimes objectives cannot be completed, so write uncompleted objectives down when writing the test report and the reason why the objective could not be completed.

Scope is to keep testing creeps happening. It outlines the phases that are absolutely needed to be done to have reasonable understanding about the tests result.

Assumptions are guesses about that are expected from the tests results. E.g. we are doing +100°C temp test to heat sensitive material. “The material will likely melt or have some signs of melting”

Risks are effects that have effect outside of the test. Risks should be all listed. In the list there should be the effect when the risk is triggered and the trigger. Also, it is good to order them in the way that the highest risk is first in the list.

Test approach is a way that tests are done. This thesis uses lean. There is also different approaches that can be used in tandem, like exploratory, linear testing or automatic testing.

Test environment is the parts that are needed to complete the test. Like laboratory, pressure chamber or weather environmental chamber.

Test schedule is time required to complete the test. This can go from 1h to 2 weeks depending on the characteristics of the test.

Test plan also might have some beforehand made criteria's like temp over time chart (Fig.6). These criteria's must be considered when making the test plan. Usually decisions about how the test plan is committed is up to the test engineer. Here is a link for some good test plan templates (StrongQA, N/A).

4.3 Test case

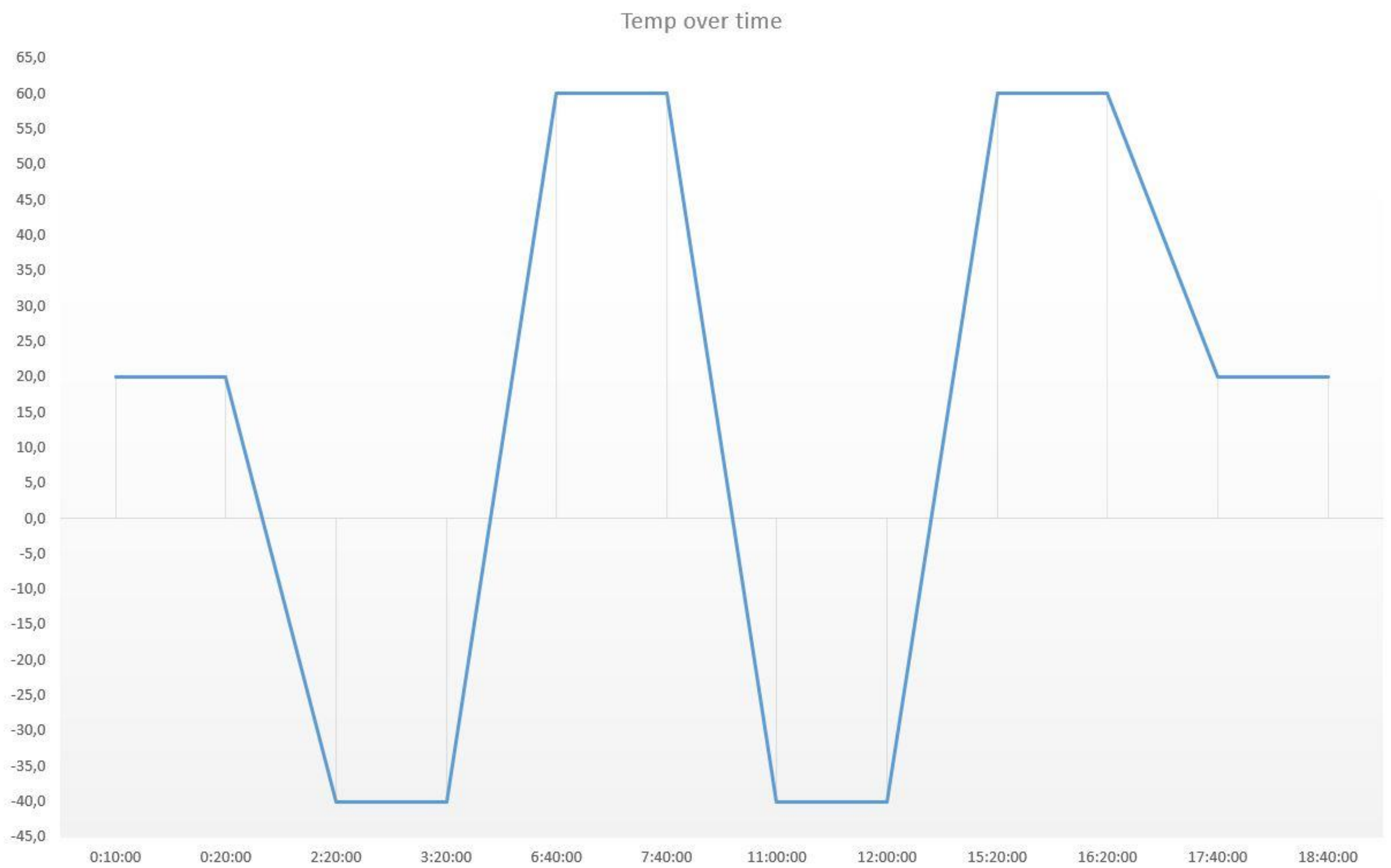

Figure 6 Temp over time

Test case – is single test that refers to a test plan. It is done by the engineer\operator to a single\multiple unit e.g. testing if the unit can be used in +60°C.

Test case should be described short, but in a way that it will convey what is the aim of the test. At simplest the answer “PASS” or “FAIL” should be enough to describe the test status. Then there should be “additional information” field where there can describe the error/fault in full detail.

Here is test case templates that we recommend being used as example when making test cases for the first time. (StrongQA, N/A)

Table 1 Test steps

Test steps	Description	PASS or FAIL	Additional information	PASS requirement
1	Is the unit red	PASS	-	Unit is red
2	Is there any visible marks or scratches	FAIL	Unit has scratches on this and this part.	Unit is unscratched and there in no visible dents
Etc.	Etc.	Etc.	Etc.	Etc.

All test case documents are usually done in the same way to prevent confusion when there are multiple testers, but it is almost always up to the engineer to decide what the test case document looks like. However, it should be noted that when there are multiple test case documents, it usually becomes lot more difficult to keep up with them. We would recommend streamlining test cases to reasonable degree.

5 TESTING

When conducting tests, there should always be a little bit over shooting for the test parameters, so that when the official product testing is done it will surely reach the specifications. if e.g. temperature test specifications state that it should handle 60°C then do the test with >65°C to be sure that it will not become unusable when the temperature is on the border of the limits.

When going into the proof of concept phase, there should always be ongoing tests for the prototype / breadboard along the way of the project. This is to ensure that throughout the project we have some type understanding of the strengths and weaknesses in the product. Almost always things do not go as planned, so when testing protos with every step, issues will be solved more efficiently. This also prevent redesign cycles taking place too often. Test changes, even if it is known that new design changes will work in old overall design before implication work starts for new design, this is more efficient if there is issue in new design.

After the final version of the product has been launched there should be one or more units in constant use. This way the company can detect any malfunctions in the product and act before any customer has that issue. Unfortunately, sometimes this does not work because lack of same type environments that customer has, but there still is valuable information in the data that can be gathered even if it is not always the type of data that helps with customer case.

Also, if the product is some type of measuring device there should be few reference tests running all times so that is known if the measurement data start to deviate from the other reference devices. Good practice is that there is third party device as one of the reference devices. This also is to prevent bias from the data.

5.1 Accelerated testing

Accelerated testing is used when testing environmental reliability, electronics, and mechanical etc. properties of the product. Purpose of these accelerated test are to find and know the problems caused by long time usage in the field situations.

Accelerated testing is usually done with overusing some aspects of the unit or accelerating certain types of accumulation test. For example, when testing how many times EEPROM can be written and read. Test plan would consist of test where pc would constantly write to the EEPROM and then try to read it to verify that the write was successful. These types of tests are repeated in different environments so that there is more variety in the tests. As it is hard to demonstrate for example dry place in humid climate.

Testing these kinds of cases can be quite difficult because more than often one might expect that simulated test is not representative enough to simulate real life environment. So, if there is any customer returns that have been in environments that are challenging, these units should be looked at and compare those with the result that was got from the accelerated test to see if those are anything alike. If the wear is like the test result, it shows that the test that was made is simulating real situation in the field. This also means that test plan can be used in the future projects, in a way that it can be expected to simulate the environment to reasonable degree.

In accelerated testing there is always used acceleration factor that tells how many times faster the aging process is going. This is used when there is need to know how many years of wear the product is expected to last in the tested environment. All component there is, has a different acceleration testing done by the manufacturer already, so there is no need to know individual components aging process. Test the whole product, test single components only if absolutely needed.

Calculating the acceleration factor for the product comes first when finding out how many years the unit is expected to be age. Here we are calculating acceleration factor due to change in temperature on electronics. (For.4) (Caswell, N/A)

$$AF = \exp\left[\left(\frac{-\mathrm{Ea}}{\mathrm{k}}\right)\left(\frac{1}{\mathrm{T1}} - \frac{1}{\mathrm{T2}}\right)\right] \tag{4}$$

- Acceleration factor = AF
- Accelerated test temperature = T1
- Practical use temperature = T2
- Activation energy = Ea
- Boltzmann constant = k

Accelerated test temperature is the temperature used to simulate the practical temperature over certain period. Practical temperature is temperature that the product is expected to withstand at most. These both temperatures are given as kelvin.

Activation energy is the minimum amount of energy required to activate a temperature-accelerated failure mechanism. This activation energy is different for every failure mechanism and different materials. (Tab.2) In this case we are using activation energy as 0.7eV. This represents typical activation energy for the electronics (Aeroflex, 2006).

Table 2 Typical Failure Mechanisms (Aeroflex, 2006)

Failure Mechanism	Activation Energy	Screening and Testing	Control
Oxide Defects	0.3 – 0.5 eV	High Temperature Operating Life (HTOL) and voltage stress	Statistical Process Control of oxide parameters, defect density control and voltage stress testing
Silicon Defects (Bulk)	0.3 – 0.5 eV	HTOL and voltage stress	Vendor statistical Quality Control and Statistical Process Control on thermal process
Corrosion	0.45 eV	Highly Accelerated Stress Testing (HAST)	Passivation dopant control, hermetic mold compounds and product handling
Assembly Defects	0.5 – 0.7 eV	Temperature cycling, temp/ mechanical shock and environmental stressing	Vendor statistical Quality Control and Statistical Process Control of assembly process
Electromigration Al line Contact/Via	 0.6 eV 0.9 eV	Test vehicle characterizations at highly elevated temperatures	Design process ground rules to match measured data, statistical control of metals, photoresist and passivation
No failure	1.0 eV	Nonoccurrence of a failure during life testing.	Default

Unknown failure	0.7 eV	Unknown failure mechanism during the manufacturing process	

The Boltzmann constant (8.62×10^{-5}) $(eV \times K^{-1})$ is physical constant that puts into perspective temperature energy per molecule.

Example if we want to know how many years our temperature simulation represents, then we can use the formula shown before (For.4) to calculate acceleration factor.

In this case we are going to use following values

- T1 = 100°c or 373.15°K
- T2 = 40°c or 313.15°K
- Ea = 0.7eV
- k = 8.62×10^{-5}

$$\exp\left[\left(-\frac{0.7}{8.62 \times 10^{-5}}\right)\left(\frac{1}{373.15} - \frac{1}{313.15}\right)\right] = \sim 64.70$$

After the AF is known, the years to simulate aging can be found. In this example let us use 500h simulation time. If our acceleration factor is ~64.70, then the 500h hour simulation will be same as ~3.70 years in real time. (For.5)

$$Simulated\ time\ in\ years = \frac{\frac{h*AF}{24}}{365} \qquad (5)$$

Even though there is way to calculate how many years the product will last in the tested temperature, it will not mean that it is absolute truth. Simulations rarely represent real life environments as absolute. The simulated years are good approximation, but as rule usually the incorrectness of the calculation is ±1 year.

There is more accurate way to know how long the product lasts in the field, but this method can be used only after establishing another product before that has similar usage, material etc. E.g. if we have had product out for 10 years and we know the failure rate of that product, we can use that products failure rate as basis to find out simulation parameters. Basis for this method is just trial and error, but it is still effective as it can compared its effect to real field situation. Let us say that 1 out of 10 units has failure, then we have failure rate 10%. So, when we are testing this new product, the result of accelerated testing should be 10% of failure. The closer we get to that 10%, more inline the test is with the previous products data. (Ruohola, 2019)

5.2 Test validation

Test validator in most cases is the same person who makes the test case themselves. When making tests cases we also must think how we can validate those tests as a proof that tests represent the scenario that we are going to use them. E.g. if it is wanted to validate that the product is certain color. Then we just look at it and say:" Yes, its red" and move on. Or if we want to check if the product will work under water then the best validating method is to put it under water and validate if it works underwater. (Ruohola, 2019)

Test validation is quite simple as can be seen. Of course, if the test is complex and the validation is hard, have a different person making the test validation as it makes mistakes less likely when more people are involved in the test process.

Operator – is person who does the tests and builds the product when the product is in manufacturing.

5.3 Issue found

When issue has been found, in testing first thing that should be done is to consider the impact of the issue. E.g. is this going to cause the release to be late or is this something can be fixed easily. After the estimate has been done, the redesign phase can start.

Other solution that has been used, is not to fix the issue if the product can work with the issue. There is one exception to this, safety. If the issue in anyway make the product unsafe it should be fixed. In these types of cases the release is likely postponed. If the issue is let unfixed the issue is just going to get spotted by third party audits. To claim that the product is safe when it is not, is going to be fined heavily if the product reaches customers when it is potential hazard.

Most common issues types in the testing are issues involving design, test environment or test setup. These are what we call main issue types. There is many subcategories that describes the issue in more meaningful way found under the main issue types.

Issues are usually managed in some type of ticket system inside the company. These tickets should be put in order that the most critical issues is at the top. This prevents clutter happening since there could be list thousands of tickets coming and sorting those in right order is vital. Also, daily tracking of those tickets is also recommended as it makes decision making for the management much easier.

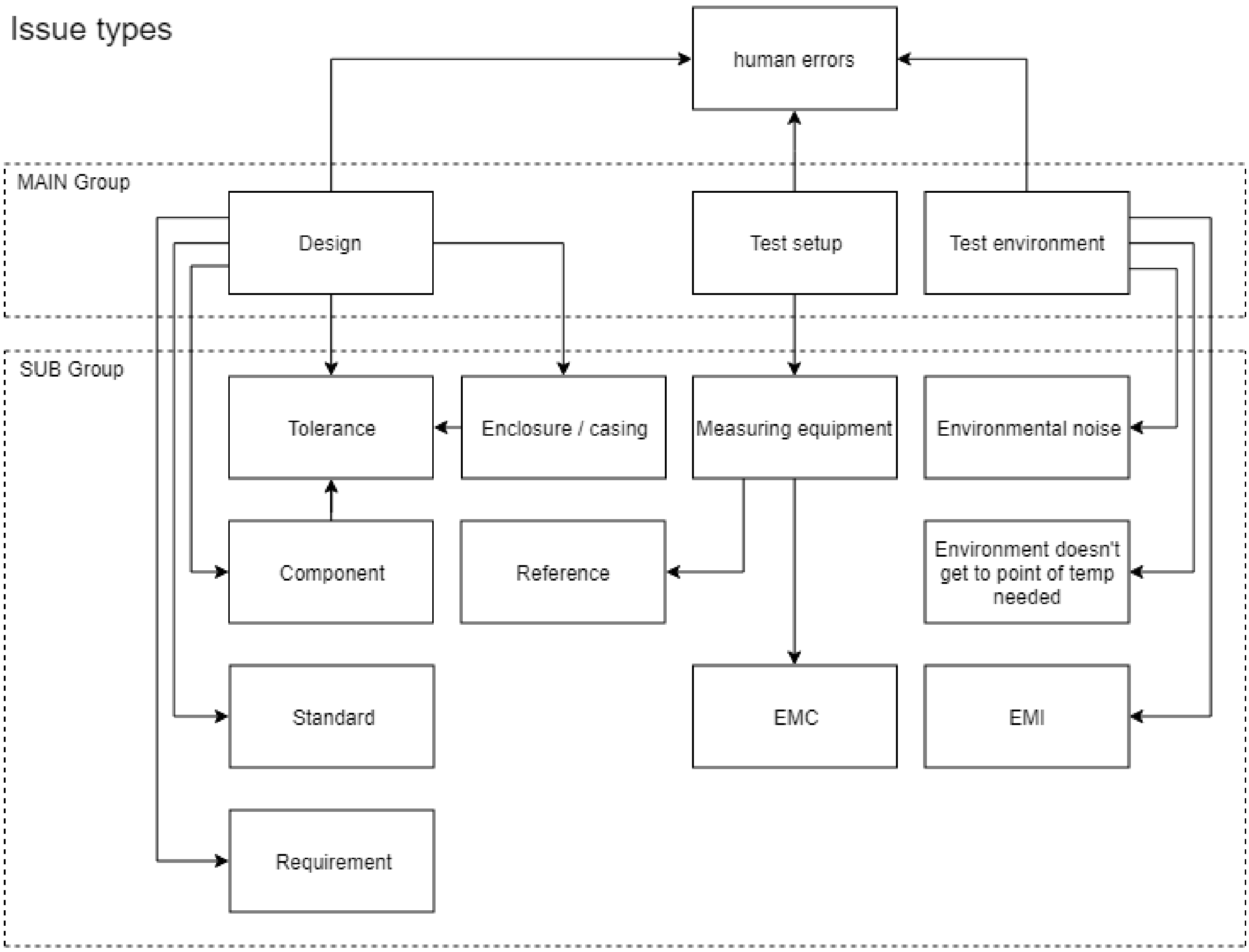

Figure 7 Issue types - The issue type categorization table was developed as a part of this thesis.

5.4 Test case repeatability

The test cases should be easy to follow by any person working on that field. The test should be maid so that operator / engineer can repeat the test by just following the test case steps.

It is up to the maker of the test how the test guide is made, but the most efficient guides are step by step guides. First only write what is necessary to complete the steps and then have separate field where can be written the aim of the step or explanation. This makes it easy to understand and the operators do not have to find the steps from the text. Most important tip that can be given is to keep the guides simple as possible / KISS.

Also, when making the tests it is good to think how efficiently someone can replicate the test. Meaning that if there is need for special tools these should be eliminated, as these special tools introduces more variables to test. Because if these special tools are not made exactly same, they will have their own variation to the results. If there is need for special tools, streamline and have tight tolerance for the tools needed in the test. This will lessen the variables that the special tools introduce.

5.5 **Casing / Enclosure**

Almost every time its designers own experience that decides what kind casing to the product would be the best, but typically the casing is well ventilated thus making it more difficult for a dew point to form. As in almost all types of products that are in humid condition or outside have good chance forming dew point inside of the unit.

Water forming inside of the unit is bad when considering it from safety or reliability point of view. Usually this is prevented with Gore Tex vent as it does not allow water inside and equalize the under pressure that would from to the unit if it would be in changing temperature. Rapid changes in temperature will cause under pressure inside unit, this will make the product suck water inside even from the tiniest holes.

Making the casing completely airtight is not usually the wisest thing as it does not in most of cases work, but there is other ways to make the casing so that it does not take water in such as making the casing hermetic seal with nitrogen. This makes sure that there is no possibility of dew point to form, as the nitrogen keeps the unit at known humidity levels.

5.6 **Final verification test**

When the product is at the end of development there will be “Final verification test” or “Release test”. The purpose of this test is to check if the product can pass those tests within acceptable limits that has been set by the test plans in question.

Test plans general direction are determined in the Master test plan.

Stepping in this phase, there should be 99.99% chance that it will pass the tests that are described in the master test plan. The reason for it being that if there is need to fix something in the product in this phase it will be difficult and time consuming.

6 ENDING PROJECT

After the development loop has been concluded and final verification tests has been done, then follows the phase where the product is reviewed, so that the management can make decisions about the release and product freeze. There also starts the training of the staff, so that they can provide support to the customers for this new product. Of course, there are multiple situations going on at the background that are unrelated to the development, but still necessary.

6.1 Design freeze

In this thesis project this part was not a major concern, but we decided to include this to give some context to the development phases surrounding the testing process that our thesis mainly consists of.

Freezing the project means not making any further improvements to the board. This is because there must be an end to the development so that it can be offered to the customer.

The only exception to this rule is if there is a bug in the software or in the hardware. Remember that it is for fixing only, do not improve it. This is because the product should be streamlined at some point. If there is a need to improve it, a new product version should be considered based on the previous. This way all kinds of issues can be avoided occurring down the line of this unit is life cycle.

Ending the development is not so straightforward an issue as one might think. First and most obvious issue is to check that all requirements were met for the product that were set in the design and standards. Almost always there is some type of a review where different types of developers and executive staff gather to discuss product freeze.

If there are any major bugs or issues in the device product freezing is not possible at this point, but if the issue or bug is manageable this is not an obstacle for the project freezing although it is preferable to fix these issues before the release.

6.2 After release fixing

After the product has been released and when issues in the product are found, there is usually an urge to fix them, but one might think that fixing means that the fix needs to make the product better, but this is not so in most cases. When starting the fixing process, one should not try to make the product necessarily better, the problem just needs fixing. This is to prevent the fixing process taking too long and preventing unnecessary testing.

When fixing the product try to avoid any changes to the product that would require tests to be done again. This is because retesting is expensive and when needed to make some tests again it usually requires that other tests must be also conducted again because these tests might be linked to each other.

If there is no way to avoid changes that would require retesting of the product, just consider that it makes the fix implementation process much longer and a new certification test is usually needed if the test is part of a standard that requires it.

7 CONCLUSION

The test phase division and issue categorization were developed and refined based on work experience in this field. I hope the results presented in this thesis will help newcomers in the field of test engineering.

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