Master Thesis

Optimizing mechanics and the process of fixing sensor PCB card to optics after active alignment

Erik Nilsson & Theodor Wahlgren

Division of Machine Design • Department of Design Science

Faculty of Engineering LTH • Lund University • 2015

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AXIS COMMUNICATIONS

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Preface

This report is the result of our master thesis within Mechanical Engineering with product development. The thesis was performed at the Division of Machine Design, Department of Design Science within the Faculty of Engineering LTH, Lund University. The project was conducted in collaboration with Axis Communications AB, at the department of Research and Development, Lund.

The purpose of this thesis is to optimize the fixing process of a sensor PCB card to optical equipment after active alignment.

We would like to thank our mentors, Mikael Persson and Carl Oreborg at Axis Communications. They were a continuous source of inspiration and supported us throughout this project. Also, a special thanks to our supervisor Oscar Strand, whose positive attitude encouraged us along the way.

We would also like to thank a number of people at Axis, who has given us both their time and expertise. Special thanks to Sven Svensson and Stig Frohlund, who quickly provided manufactured components, along with Magnus Bergkvist for taking his time to aid us through experimental measuring operations.

Finally, thanks to Per-Erik Andersson, our mentor at Lund University, for supporting us with the academic part of this master thesis and to Neven Ibrakovič who helped us during tests at LTH.

Lund, June 2015

Erik Nilsson & Theodor Wahlgren

Abstract

This report describes the development of a new fixing process when attaching a sensor PCB card to a camera assembly. The thesis focused on cameras which requires calibration to find the optimal position of the sensor PCB card, a process called active alignment.

The development process applied for this thesis was derived from the *Generic Development Process* by Ulrich and Eppinger. Interviewees with project members and experts within Axis Communications AB were the main source of information. From the interviewees' statements, an interpretation into customer needs was performed. Some of the more important identified needs were to simplify production and minimize the sources of error present with the current solutions.

The challenges with the process of fixing the sensor PCB card were broken down to a simpler version, i.e. fixing two arbitrary components. The customer needs were used to evaluate different fixing methods and the most promising methods were selected. A concept generation process was initiated to find possible solutions within each fixing method. The most basic concepts were quickly evaluated through discussion and then later on through a concept scoring, to identify the most promising ideas. Further evaluation of these concepts included more information gathering of the fixing methods and discussions about their implementation into production. Then, the most promising concept was selected.

With this concept, the details of the solution were further optimized. Through further testing, new demands of the concept were found and solved, arriving at the final specifications of the concept. The final design solution was validated through more thorough testing.

The result is a new general process, which uses UV light curable adhesives. By adding a transparent silicone gasket, control over the adhesive is obtained and results in a simplified as well as significantly improved production chain.

Keywords: Active alignment, Adhesive, UV light, Sensor PCB card, Camera, Product development, Axis Communications AB

Sammanfattning

Den här rapporten behandlar utvecklingen av en ny process för att fixera sensor-PCB-kort till optik i kameramonteringsprocessen. Projektet har fokuserat på kameror som kräver en kalibreringsprocess för att hitta den optimala positionen av sensor-PCB-kort, en process som kallas aktiv kalibrering.

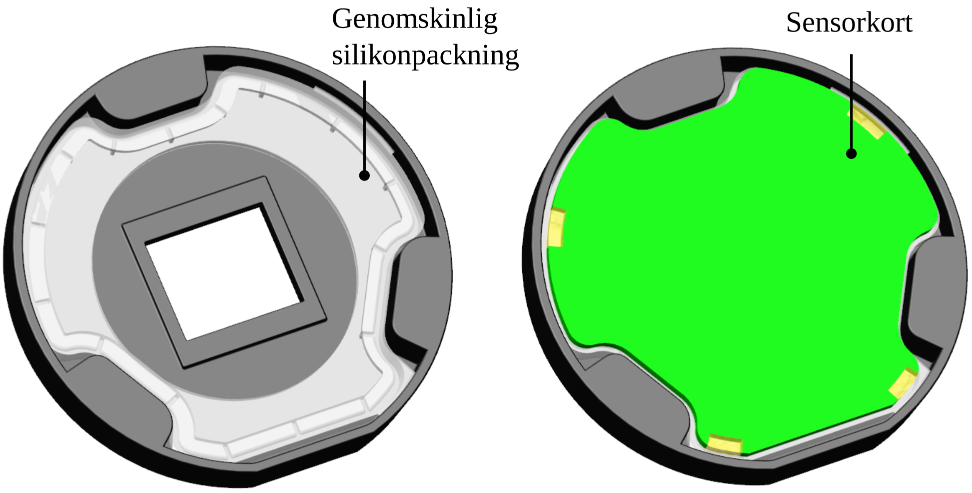
Vid kameratillverkning är sensorkortets position avgörande för att få en högupplöst och god bildkvalitet. För att uppnå detta krävs en vinkelrät position mellan den optiska axeln och kamerans sensor. Även den minsta avvikelse från denna position leder till en försämrad bildkvalitet. Denna position skulle kunna uppnås enbart genom att erhålla små mekaniska toleranser på alla de ingående kamerakomponenterna. Efter senare års förbättringar inom kamerateknologi finns nu kameror med extremt hög upplösning, där det inte längre är rimligt att lita på dessa toleranser. Då används istället aktiv kalibrering för att justera sensor till den optimala positionen. När denna position är funnen måste sensorkortet fixeras. Det här examensarbetet har hanterat hur denna fixering ska ske för att säkerställa en stabil produktion samt erhålla en god fixering av sensorkortet som inte ger bildförsämringar med tiden.

Utvecklingsmetoden som tillämpades för detta projekt är härledd från *Generic Development Process* av Ulrich och Eppinger. Intervjuer med projektmedlemmar och experter inom Axis Communications AB användes som den främsta källan till information, från intervjuerna togs kundkrav fram. Några av de viktigaste kraven var att förenkla produktionen och minimera felen som kan uppstå med de nuvarande lösningarna.

Utmaningen med att fixera ett sensor-PCB-kort bröts ner till ett mer grundläggande problem, att fixera två godtyckliga komponenter med varandra. Kundkraven användes för att utvärdera fixeringsmetoder och de mest lovande metoderna valdes ut. En konceptgeneringsfas påbörjades för att finna möjliga lösningar till problemet inom varje fixeringsmetod. De mest grundläggande koncepten utvärderades snabbt genom diskussioner och senare även genom att poängsätta koncepten. De mest lovande koncepten identifierades och utvärderades ytterligare. Nästa steg innefattade en omfattande undersökning av de olika fixeringsmetoderna och diskussioner behandlade hur de skulle kunna implementeras i produktion. Sedan valdes det mest lovande konceptet ut.

Detta koncept utvärderas ytterligare och en mer detaljerad plan över konceptet togs fram. Genom tester av konceptet upptäcktes nya krav som formade den slutgiltiga lösningen. Denna slutgiltiga lösning genomgick slutligen valideringstester för att säkerställa dess funktionalitet.

Den slutgiltiga lösningen är en generell process som använder sig av UV-härdande lim. Genom att applicera en genomskinlig silikonpackning till kameramonteringsprocessen ges kontroll över limmet, vilket resulterar i en förenklad men även avsevärt förbättrad produktionslina. Den nya fixeringsprocessen klarar de ställda kraven för en lösning som används i kombination med aktiv kalibrering och kan utnyttjas i flertalet av Axis kameror. En illustration av den slutgiltiga lösningen kan ses i Figur 1.



Figur 1. En illustration av den slutgiltiga lösningen.

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1 Introduction

In this chapter the purpose and problem statement of this thesis will be explained. The aims and limitations of the project will be presented along with the adapted methodology and project plan.

1.1 Purpose

Due to later years improvements in camera technology, cameras with a very high resolution is now available. To produce a high quality image with a high resolution sensor, a perpendicular alignment between the optical axis and the image sensor plane is necessary. Even the slightest deviation from this position will result in undesired image quality. This accurate position can be achieved by having very fine mechanical tolerances of the components in the camera assembly. Though, as the resolution improves, it is no longer feasible to only rely on these tolerances to achieve the perpendicular alignment, as components with increasingly fine tolerances become more expensive.

Instead of relying on mechanical tolerances, Axis Communications AB, shortened to Axis throughout this thesis, uses a calibration method. This process finds the optimal position of the sensor with up to five degrees of freedom. The calibration method, called active alignment, will ensure that the sensor is perpendicular to the optical axis even with poor tolerances of the components in the camera assembly. When the optimal position is found, i.e. when the sensor image is of highest possible quality, this position is permanently fixed.

Axis's current method of fixing the sensor in this position is by using adhesive. The adhesive enables a very quick and strong bond without interfering with the active alignment process. However, in addition to uncertainties of a fully cured bond, which can cause low bond strength and outgassing, Axis is facing problems ensuring a stable production. These problems have resulted in adhesive bonds detaching in the camera assembly while handling the camera in production, during transportation and at customers after installation.

Thus, the purpose of this thesis was to develop a more optimized fixing process.

1.2 Project Aims

The project aims of this thesis were derived as:

- Examine current fixing solutions
- Investigate alternative fixing processes
- Propose a new design which ensures a high quality fixing as well as an improved production process

1.3 Limitations

The thesis will be limited to optimizing cameras which require active alignment. Due to the variety of these cameras, it will presumably be challenging to find a general solution that works for all configurations. Hence, the wide variety of actively aligned cameras will not limit a new fixing process which holds good properties for one or a few products.

1.4 Methodology

The methodology used throughout this thesis was Ulrich and Eppinger’s *Product Design and Development* (2008) [1]. Though, some deviations from this process were made to match this specific project.

1.5 Project Plan

This master thesis project began in January 2015 and continued for about 20 weeks, until June 2015. A project plan was made in the first weeks of the project, using a Gantt-scheme because of its quick and perspicuous nature. This preliminary Gantt-scheme can be seen in Appendix A: Preliminary Gantt-Scheme.

2 Methodology

In this chapter the methodology adapted throughout this thesis will be described. The underlying method is the Generic Product Development Process described by Ulrich and Eppinger.

The methodology is divided into two parts. First, a background study is performed in order to understand the problem at hand. The main source of information is internal knowledge within Axis, extracted from previous documentations and informal interviews. Then, the Concept Development Process from Ulrich and Eppinger is applied and explained in further detail. To match the specific project some modifications have been made. These changes will be presented together with that development process.

2.1 Background Study

2.1.1 Interviews

Interviews are conducted with various Axis employees and external experts in the fields of interest. The interviews are kept fairly informal. Thus, the persons interviewed has a chance to ventilate what they believe is relevant for this thesis. A list of the interviewees can be seen in Appendix D: Interviewees, of which some were questioned during the background study.

2.1.2 Documents and Experimental Studies

As the area of the thesis has been examined in the past by Axis, there are some documents containing earlier ideas, experiments and future plans. This data is examined during the background study. When tests are performed on the developed concepts, these are similar to the tests done previously at Axis. This is done to ensure that comparisons between the fixing processes would become reliable.

2.2 Generic Development Process

The Generic Development Process described in Ulrich and Eppinger [1, p. 14] is adapted throughout this thesis. An overview of its included phases can be seen in

Figure 2.1. These six phases stretches from the planning of a product to its final production. This thesis focused upon phase 1, the Concept Development.

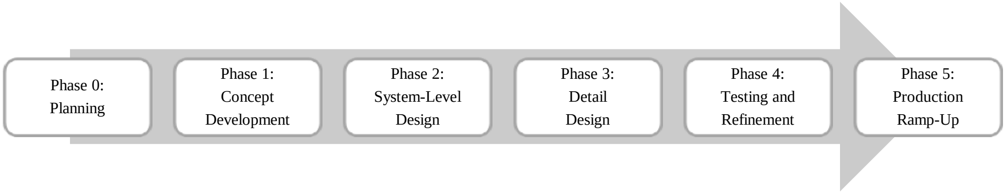


Figure 2.1 The different phases of the generic development process.

2.2.1 Concept Development

The concept development process, derived by Ulrich and Eppinger, is further divided into a: *mission statement, identify customer needs, establish target specifications, generate product concepts, select product concept(s), test product concept(s), set final specifications* and finally *plan downstream development*. An overview of these steps can be seen in Figure 2.2. However, this process rarely proceeds in orderly manner and it should therefore be considered as an iterative process, where reflection is a crucial part of the process [1, p. 16]. The different phases of the concept development process are further presented.

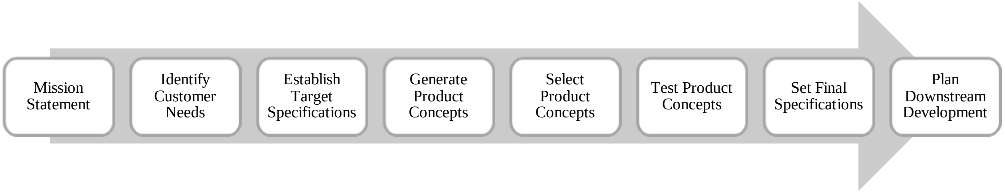


Figure 2.2 The generic concept development process.

2.2.1.1 Mission Statement

The first task of the concept development process is to create a mission statement. This serves as determining the general direction of the project, without specifying the details of reaching the goal [1, p. 55]. The mission statement includes *product description, benefit proposition, key business goals, primary market, assumptions and constraints* and *stakeholders*. Important aspects for some of these categories are further presented.

2.2.1.1.1 Benefit Proposition

The benefit proposition highlights the reasons why a customer would buy the product. This is partially based on a hypothesis, which later becomes validated throughout the concept development [1, p. 48].

2.2.1.1.2 Key Business Goals

The key business goals relate to the goals of the project but also include the corporate strategy surrounding the concept [1, p. 48].

2.2.1.1.3 Assumptions and Constraints

Assumptions and constraints are crucial in order to restrict the range of possible product concepts, resulting in a manageable project scope. However, they must be chosen carefully [1, p. 48].

2.2.1.2 Identifying Customer Needs

By identifying the customer needs, a better understanding of the problem is gained [1, p. 16]. This phase aims to create a direct information channel, linking the customers and the developers. The developers must therefore learn from customers' experiences of using the product in its appropriate environment. Without this knowledge, wrong development decisions are easily made, lowering the prospects of the product [1, p. 54].

Important steps during this phase according to Ulrich and Eppinger are *Gather raw data, Interpret the raw data, Organize the Needs* and *Establish the Relative Importance of the Needs*. During these steps, constant reflection of both the process and the dictions made by the development team is important [1, p. 55].

2.2.1.2.1 Gather Raw Data

Ulrich and Eppinger propose several methods of acquiring the raw data. Some of these methods includes *interviews, focus groups* and *observing the product in use* [1, pp. 56, 57].

2.2.1.2.2 Interpret the Raw Data

The gathered statements form the basis of the customer needs. An interpretation of these statements is required during this process. Ulrich and Eppinger suggest focusing upon:

- Expressing what the product should do and not how it does it.
- Using same level of detail between the raw data and the customer needs.
- Use positive phrasing.
- Express the need as an attribute of the product.
- Avoid using the words *must* and *should.*

When creating a list of all the translated customer needs, some of the needs might not be technically realizable or even be conflict with each other. These issues can be neglected, as the importance lies in documenting all the relevant information [1, pp. 61-63].

2.2.1.2.3 Organize the Needs and Establish Their Relative Importance

The next step is to organize the needs into a hierarchical list, typically with *primary needs* and *secondary needs.* This process is often intuitive and can be done without specific instructions. Further, Ulrich and Eppinger emphasizes that the appropriate weighting of the customer needs in relation to each other is essential in the Concept Development process. Yet, the relative importance of the needs in a hierarchical list is left unspecified. So, their method of achieving this is either by relying on the knowledge of the development team in relations to the customer needs, or by using further survey studies [1, pp. 63-66].

2.2.1.3 Establish Target Specifications

The next step of the generic concept development process is establishing the target specification. The systematic methodology of Ulrich and Eppinger suggests that the customer needs are converted into a list of metrics. This is done in order to objectify the concepts to a greater extent, i.e. by getting a unit of measurement for each metric. The effort of doing this list of metrics can also result in ideal and acceptable target values for the metrics [1, pp. 73, 74].

2.2.1.4 Concept Generation

Concepts are generated as explanations of the product under development. They are not as concrete as a product. Measurements, materials, functions etc. are partially ignored in order to achieve an innovative process when generating concepts. Instead, the concepts should describe how they meet the earlier generated customer needs. Even though this methodology is described as linear, Ulrich and Eppinger emphasizes that the process should be continuously iterative [1, p. 98].

2.2.1.4.1 Clarifying the Problem

To achieve a successful concept generating process, Ulrich and Eppinger propose different methods. The purpose of these methods is to decompose the complexity of the problem, making it easier to identify and solve its most important aspects [1, p. 99].

By clarifying the problem, the complexity of the problem is reduced and smaller sub-problems arise [1, p. 101]. The smaller problems are solved individually and later combined and adapted into the final concept. It is essential that the most critical sub-problems are identified and given most attention [1, pp. 103, 104].

2.2.1.4.2 Information Gathering Process

Exploring and obtaining further knowledge is essential in order to solve these sub-problems. Ulrich and Eppinger divide this information gathering process into an *internal search* and an *external search*. The subcategories of these searches are *Interview lead users, Consult experts, Search Patents and Published Literature, Explore Systematically* and *Benchmarking* [1, pp. 103-118].

2.2.1.5 Concept Selection

The process of concept selection is the evaluation of concepts with respect to the customer needs. The concepts relative strengths and weaknesses are compared in order to guide the selection of the concepts with greatest potential [1, p. 128].

Ulrich and Eppinger recommend a two-stage method for the selection of concepts which involves *concept screening* and *concept scoring* [1, p. 129]. These methods provide structure to the selection process, which assists in maintaining objectivity throughout this critical process [1, pp. 128, 129].

The *concept screening* is used to quickly narrow down the number of concepts and find ways of improvements [1, p. 130]. By using a selection matrix and selecting a reference concept, each concept is relatively scored between “worse than”, “same as” and “better than” this reference concept.

The *concept scoring* is used when many concepts seem promising and finer differentiation between them is needed. This process is more thorough, as it is crucial in deciding the path of further developments [1, p. 134]. Similarly to the screening process, by using a selection matrix and selecting a reference concept, each concept is relatively scored. Though in this process, the details of both the selection matrix and the rating scale is enhanced.

2.2.1.6 Concept Testing

The concept testing phase resembles to concept selection phase in the sense that both methods act to narrow down the amount of concepts under consideration. The tests are done to gather further information from potential customers, regarding possible improvements or to estimate sales potential [1, p. 146]. A vast variety of tests can be performed from surveys, concept communication, and simulations to working prototypes.

2.2.1.7 Set Final Specifications

Within this phase, a final concept is chosen using the results gained from the concept testing. The specifications of the chosen concepts are further established by iterative testing and refinements of the design.

2.2.1.8 Plan Downstream Development

During this phase, the final design is presented. A product plan regarding its implementation into production is presented. Comparisons against other products are made to verify the result of the new product. Finally, the concept is validated thoroughly by tests on its final specifications. With the results of these tests, an evaluation of the concept’s fulfillment of the customer needs is performed.

3 Background Study

In this chapter the theory needed to understand the problem formulation of this thesis is presented. The chapter begins with a brief presentation of Axis Communications AB, followed by some basic camera terminology. Then the process of aligning the sensor to the optical axis is explained. Finally, the basic theory behind the adhesives used by Axis is explained.

3.1 Axis Communications AB

Axis Communications AB is a network based camera surveillance company, founded in 1984, Lund. Today, Axis is a world leading company within camera surveillance, mainly because of its sales model, corporate climate and focus upon innovative solutions.

3.2 Basic Camera Technology

In order to explain the forthcoming sections, a basic camera terminology is necessary.

3.2.1 Camera Lens

A lens element is a transparent object used to bend light. Often the shorter form lens is used instead, which can cause confusion due to its proper definition discussed later. In this report, a lens element means a single piece. When two or more lens elements are assembled, without air in between, they are called a lens group.

The part of a camera, which is collecting light and focusing it onto the sensor, is called a lens. Hence, the lens consists of one or more lens elements. A schematic illustration of this can be seen in Figure 3.1.

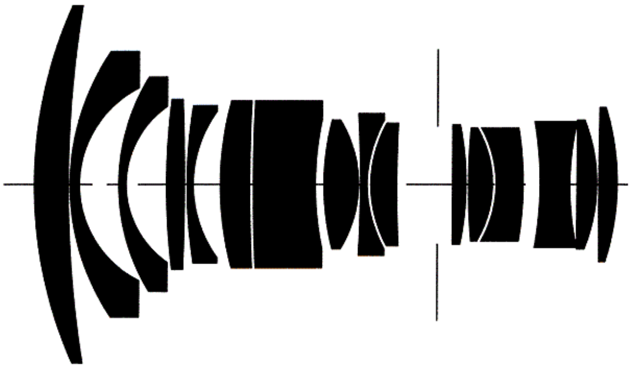


Figure 3.1 Schematic illustration of the arrangement of lens elements in a lens**.**

In Axis's production, lenses are bought from distributors. These lenses include a plastic packaging surrounding it, which could further include, for example, motors that change the focal distance. This assembly is called a lens package throughout this thesis.

3.2.2 Sensor Card

The image sensor is the optical component that converts photons into electrons, which in turn produces an image. The image sensor is placed on a printed circuit board, or PCB card, see Figure 3.2. The PCB card connects the electrical components using copper sheet layers to form conductive tracks, as well as providing mechanical support to these components. A typical PCB card further consists of a laminated fiberglass and epoxy core, with flame resistant capabilities called FR4 [2]. The sensor PCB card will be shortened to PCB card throughout this thesis.

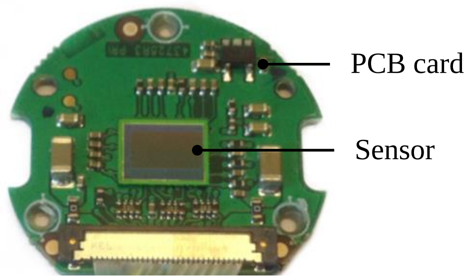


Figure 3.2 PCB card with sensor attached.

3.2.3 Camera Assembly

Axis obtains lens packages to each camera assembly from distributors. This lens package has a reference surface on the opposite side of the outer lens. Axis has tried to order a specific layout of this surface, but this adds too much time in the production phase for the distributor [3]. Thus, Axis produces another plastic part that can be assembled against this reference surface and has an appropriate layout to fit the adhesive joint design. This plastic adapter, from now on referred to as PCB holder, is screwed onto the reference surface of the lens package, see Figure 3.3.

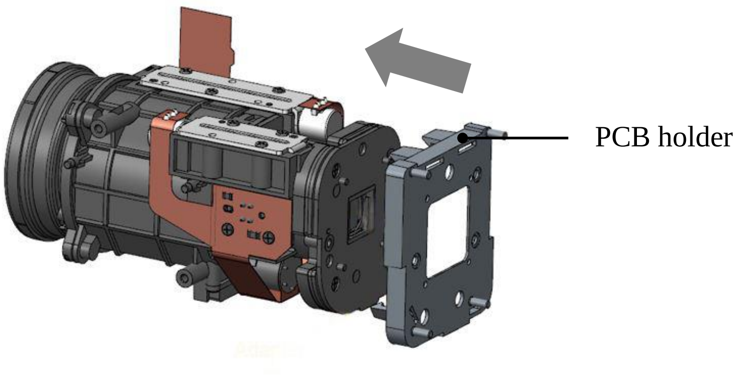


Figure 3.3 Lens package with the plastic adapter.

The next assembling step is adding a sensor glass together with a gasket onto the PCB holder; the sensor glass is held in place by the gasket. Then, UV light curable adhesive is dispensed onto the PCB card. The PCB card and the lens package assembly are mounted separately in Axis's calibration system and brought together for the active alignment process. When the alignment process is performed, UV light guides are activated and the adhesive cures, fixing the position of the PCB card. An overview of this camera assembling process can be seen in Figure 3.4.

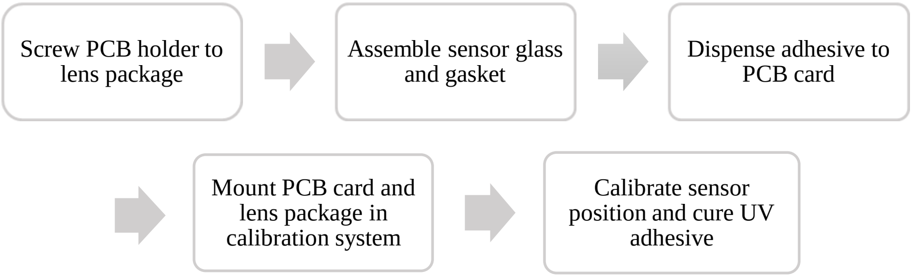


Figure 3.4 Overview of assembly steps.

3.2.4 Optical Alignment

A poor alignment of the sensor will even deteriorate the image quality of a perfect lens [4, p. 1]. Thus, the lens needs to be assembled to the sensor at an optimal position in order to achieve best possible image quality. The optimal position is a perpendicular alignment between optical axis and the sensor's surface, at the correct focal distance. Furthermore, as previously mentioned, higher sensor resolution increases the importance of an accurately positioned sensor to the optical equipment. Due to this, relying on the mechanical tolerances for each part in a camera assembly to achieve this optimal position becomes increasingly difficult and expensive. In addition, Axis’s lens packages manufactures cannot specify the exact position or the focal distance of each lens, because of the individual tolerances of each lens element. Manufacturing errors, such as misalignment of single lens element, differences within the mechanical tolerances or centering errors can lead to a focus deviation. A misalignment can result in a non-centered image, slightly changed focal length, as well as a tilted image plane [5]. When discussing directions in this chapter, the coordinate system applied is seen in Figure 3.5, i.e. x: left/right, y: up/down and z: in/out.

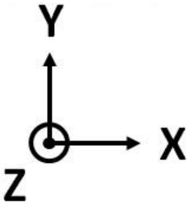


Figure 3.5 Directions used throughout this chapter.

A non-centered sensor will result in black areas on the final image, as the sensor is not fully covered by the incoming light cone see Figure 3.6.

Figure 3.6 Misaligned in a) x-direction b) y-direction.

A misaligned focal length, i.e. z-distance leads to a blurry image, which becomes permanent for cameras without zoom, see Figure 3.7. A camera with zoom can adjust the z-distance; therefore the image will only be blurry at the outer limits of the focal distance.

Figure 3.7 Misaligned in z-direction.

A varying object distance, from a tilted sensor plane, results in varying sharpness of the image, for example one sharp and one blurry side of the image [6, p. 3], see Figure 3.8.

Figure 3.8 Misaligned in vertical tilt.

So, instead of relying on tolerances, Axis calibrates each sensor to each lens package, into the position of optimal image quality. This process is called active alignment.

3.3 Active Alignment

Active alignment is normally a process which requires five to six degrees of freedom, with the sixth degree of freedom being the rotation of the sensor relative to the optics [4, p. 1].

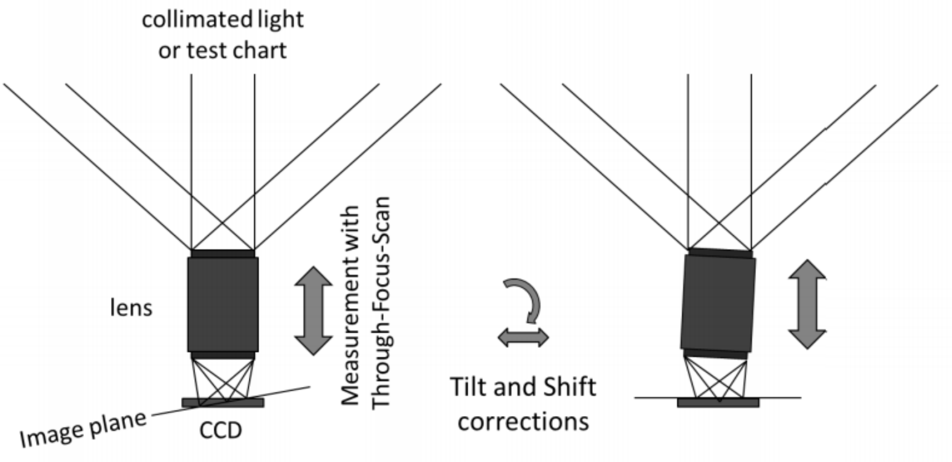


Figure 3.9 Image plane measurement, tilt and shift corrections to achieve an aligned lens.

To determine the correct angle between the sensor and the image plane during the active alignment process, the distance between lens and sensor is varied while evaluating a fixed object or a test chart, see Figure 3.9. The angle of optimal alignment is acquired when a flat image plane on the sensor is achieved.

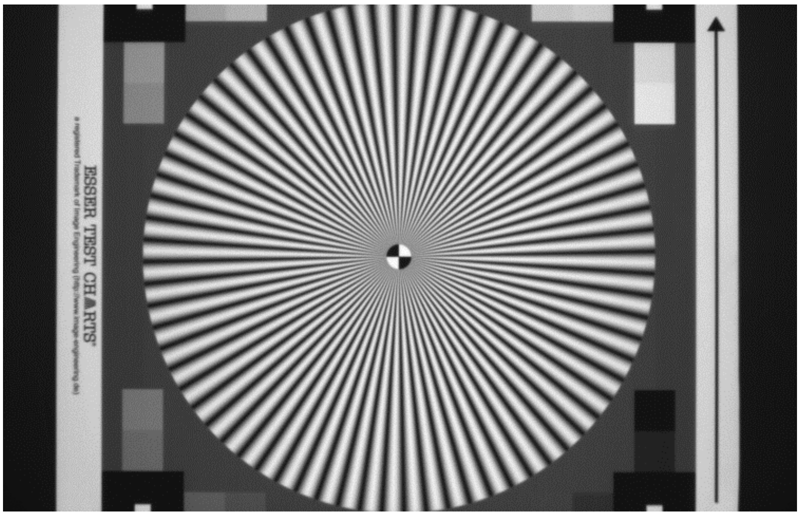
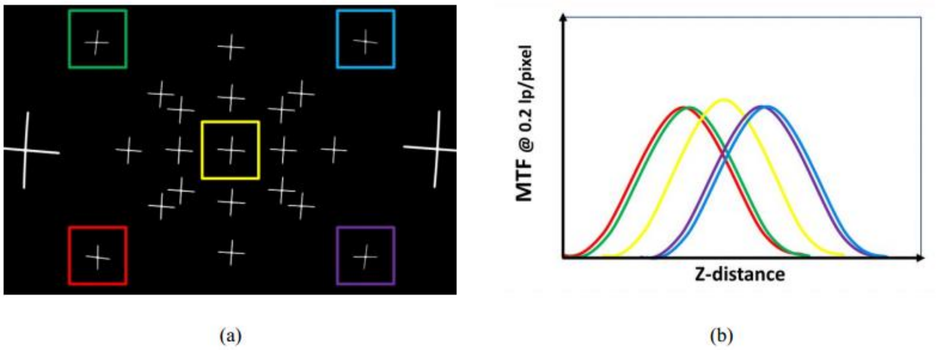


Figure 3.10 Example of pattern for Modulation Transfer Function.

To evaluate the image quality, one common technique is to use test charts and a Modulation Transfer Function (MTF). The MTF is the ratio between the relative image contrast divided by the relative object contrast. This ratio is used to describe the resolution and performance of an optical system [4, pp. 1-3]. An example of a pattern used to calculate MTF can be seen in Figure 3.10.

An illustration of image analysis software can be seen in Figure 3.11. The colored boxes around the crosses denote the search field, or the so-called field positions. The software looks at the test chart within the area of these boxes, which contains various patterns, such as in Figure 3.10. For each field position the focus is calculated using MTF. This is done at a range of lens to sensor distances, called the focal distance, or z-distance. When an optimal focal distance is found, a maximum will appear. This is done for all the search fields and the corresponding curves can be seen in Figure 3.11b).



(a) (b)

Figure 3.11 a) Sensor image of a test chart and search areas for the crosses b) example of output data from a through-focus-scan of non-aligned.

In Figure 3.11, the green/red, yellow and blue/purple areas have different optimal focal distances. However, the red and green, as well as the blue and purple areas have the same optimal distance. This situation represents a tilt in the vertical direction. A perfect sensor lens alignment is given when the maxima of the focus curves coincides [4, pp. 2-4]. In order to achieve this alignment in Figure 3.11, the sensor, or the lens, is tilted horizontally to this position, so that all the colored areas have the same optimal z-distance.

Besides this, other parameters that can be evaluated include: color rendition, white balance, bad pixels and sensitivity. These can also be controlled during the alignment stage [6, pp. 1-3].

The active alignment system Axis uses to calibrate the image sensor’s position is called IBAS, which is short for image based alignment system.

3.4 Fixing the PCB Card after Active Alignment

The current active alignment process at Axis is extremely sensitive to external forces. Even a tiny force can cause vibrations to spread through the alignment equipment. This problem was detected in the manual calibration system earlier used at Axis, which increased calibration time as the vibrating movements needed to disappear before aligning could continue. Therefore IBAS calibrates the sensor, or the PCB card by which the sensor is mounted, automatically using stepper motors. This minimizes the required contact and removes the human interaction.

The time it takes to fix the PCB card’s position, approximately 30 seconds, is a small portion of the entire IBAS process. Unfortunately, this alignment process is a bottleneck in production and every second of the fixing adds to the total assembling time for each camera.

The permanent bond after alignment has to endure external forces, such as removing the newly fixated assembly, unplug cables, vibrations during transportation etc. So, in addition to supply a quick fix, the bond also has to achieve a sufficient handling strength instantly and remain in the desired position throughout the camera lifetime.

The alignment equipment, IBAS, is located in a clean room environment. Hence, particle and gases has to be contained or controlled. The clean room specifications at Axis's Electronic manufacturing sites, EMS, are ISO class 8. These clean room classes are determined by the maximum number of particles, of varying sizes, allowed per cubic meter air, see Appendix C: ISO Class.

The process that is in need of these clean room specifications is the assembling of the PCB card and the lens package. As previously mentioned, during this process a gasket is applied to enclose the sensor. This is done to prevent external light, other than that going through the camera optics, from reaching the sensor. The gasket also acts as a barrier to dust particles. If large enough dust particles are trapped within the sealed air around the sensor, or if external light is present, it would lead to poor image quality.

3.5 Adhesive

Some adhesives have the advantage of being able to form a quick and strong bond, at a time of choosing, without outer forces interfering with the bonding process. Because of this, adhesives are used as the method of fixing the PCB card to the lens package within Axis. The adhesives are UV light curing, which results in a quick contact free bond when the UV light is activated. However, in many applications a fully cured bond cannot be guaranteed and therefore a secondary, more cumbersome curing mechanism is mandatory.

3.5.1 Adhesion & Cohesion

Adhesives use adhesion to bond two substrates. This is the attraction between two different particles or surfaces originating from forces between them. This is different from cohesion, which is another intermolecular attraction between similar molecules that the adhesive use to bond itself. In both adhesion and cohesion, it is mainly van der Waal forces that act as the intermolecular bond [7, p. 4].

There are uncertainties regarding the exact theory behind adhesion between two substrates. The theory is divided into different categories that may solely or in combination with the others be the mechanism that governs adhesion. The main theories are: *adhesion theory*, *mechanical theory, electrostatic theory, diffusion theory* and *weak-boundary-layer theory.*

3.5.1.1 Adhesion Theory

Two materials in contact experience forces of attraction to each other, depending on their chemical structure. Assuming that the adhesive has wetted sufficiently well, forces of attraction is formed. These forces can consist of either primary bonds, such as covalent or hydrogen bonds, or secondary van der Waal bonds, which has a far less dependence upon the chemical structure. In the adhesion theory these bonds are assumed to be forces behind adhesion [7, pp. 12, 15, 17].

3.5.1.2 Mechanical Theory

This theory emphasizes the mechanical bond between the surfaces' of the adhesive and the substrate. Every "smooth" surface is highly rough when examined on a smaller scale. If sufficient wetting is achieved, the adhesive gets into every compartment of the rough surface. This leads to a mechanical interlock as the adhesive hardens, similar to the functionality of a Velcro. In the mechanical theory, this interlocking forms the strongest link of the adhesive bond [7, pp. 12, 20, 21].

3.5.1.3 Electrostatic theory

There is always a difference in electrochemical potential across two materials with surface contact. Hence, free charges try to find equilibrium across this interface, creating an electric double layer. This process resembles two substrates bonded by an adhesive. Thus, when destroying an adhesive bond, there are sometime sparkles formed. In the electrostatic theory, the energy that forms these sparkles is the main force that controls adhesion. However, when the energy levels of this phenomenon have been measured, they have been much lower than the fracture energies of the adhesive bond. This has resulted in less support of this theory, as one of the major mechanism of adhesion [7, pp. 12, 25].

3.5.1.4 Diffusion Theory

With increasing knowledge of polymers, the diffusion theory has evolved to describe polymers adhesion to each other. This is the work of reptation, which is the long polymer-chains entanglement, i.e. how they easily get tangled but not untangled to each other. This theory explains some of the time- and molecular weight dependence that has been seen in different polymers [7, pp. 12, 26, 28].

3.5.1.5 Weak-boundary-layer Theory

The thin surface in contact between the adhesive and the substrates is called a boundary layer. The theory of weak-boundary-layer focuses upon the properties of this layer. If a fracture occurs between two substrates, not within the adhesive but in the boundary layer, the structural strength of this layer becomes essential. Examples of weak boundary layers are thin oxide films covering the surface of the substrates, contaminations, bad wetting (air bubbles), bad mechanical properties etc. Even though weak boundary layers certainly can cause weak adhesive joints, there have been some results contradicting this theory [8].

3.5.2 Adhesive Joint Design

There are five types of stresses that can apply to an adhesive joint: *compressive, tensile, shear, cleavage* and *peel.* An illustration of these stresses can be seen in Figure 3.12.

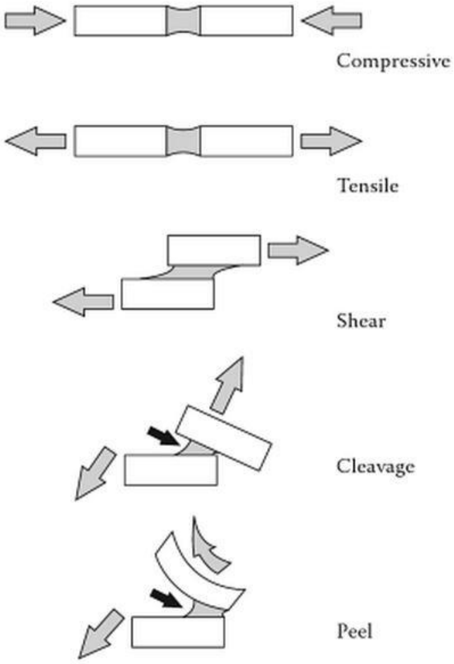


Figure 3.12 An illustration of different stresses that can appear in an adhesive joint.

For an equal bonding area, the length of the adhesive joint under *tension* or *shear* results in increased strength of the bond [10, p. 39].

A good adhesive joint further categorized by the forces acting as *compressive, tensile* or *shearing,* as these forces form fairly uniform stresses. Of these three, the joint strength becomes significantly higher for *Shear* stresses [10, p. 39]. This is because *tension* or *compression* in reality rarely has uniform stress distributions, which might lead to stress concentrations at the boundaries of the bond [9]. These stress concentrations can further result in a crack propagating process if failure occurs. This is similar to the behavior of *Cleavage* and *peeling*, which characterizes the worst adhesive bonds.

3.5.3 Wetting

Good wetting is an important aspect of a well-formed adhesive bond with high strength. The substrates surfaces' and the adhesive properties are important aspects to ensure sufficient wetting. Contaminations or residues could restrain the wetting by acting as a separating layer. By preparation and pretreatment of the components, wetting and strength can be further increased [24, pp. 25, 27-29].

The components must first be prepared by removing greases, oils, lubricants, residues and other foreign substances. It is essential that the cleaners are completely evaporated from the components [24, pp. 25, 56-57]. The cleaners could otherwise reduce adhesion to the substrate.

Additional surface treatments can be applied if higher bond strength is required. Some methods include brushing and grinding, blasting and plasma. These methods results in larger effective bonding area through roughening of the surface and improving its wettability [24, pp. 25, 29-35].

3.5.4 Thermosetting Plastics

The adhesives used at Axis are thermosetting plastics, which is a material that irreversibly cures. Thermosetting materials are typically in liquid, solid or paste forms and consist of three-dimensional cross-linked networks of molecules [7, p. 276]. They cure by forming a cross-linked structure with reactive molecules [7, p. 273]. To initiate and propagate the cross-linking reaction in a thermosetting polymer, free radicals are often used. They are produced by decomposition of a suitable molecule, an initiator. Common initiators are activated thermally, chemically or by irradiation [11, p. 41].

3.5.5 Curing

3.5.5.1 UV Light Curing

The adhesives that cure by light contain photo initiators. These initiators are activated at certain wavelengths [12, p. 10]. They absorb light in order to decompose and create free radicals, see Figure 3.13. The radical chain reaction starts directly as the system is exposed to radiation and stops immediately after the radiation ceases [11, p. 41].

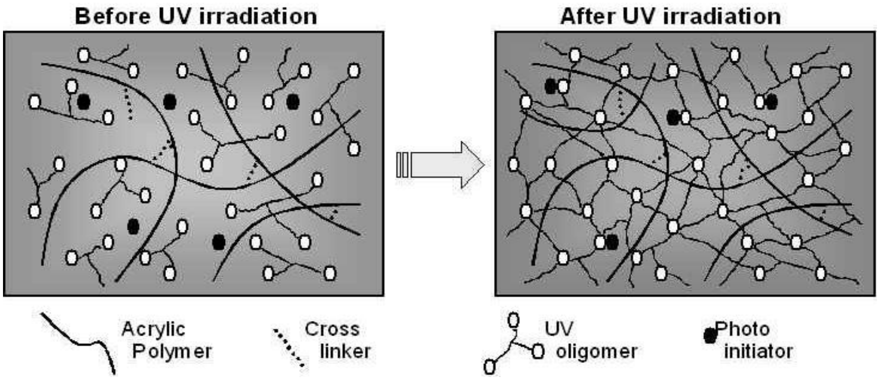


Figure 3.13 UV curing adhesive before and after irradiation.

Different radiation spectra, or specific wavelengths, can be used to cure UV light curable adhesives, depending on the adhesives' composition. The UV-spectrum is present at wavelengths below the human visible spectrum, consisting of UVC, UVB and UVA waves as seen in Figure 3.14. The most common adhesives are cured in the UVA spectra and early visible part of the electromagnetic spectrum. This also applies to the adhesives used at Axis [13].

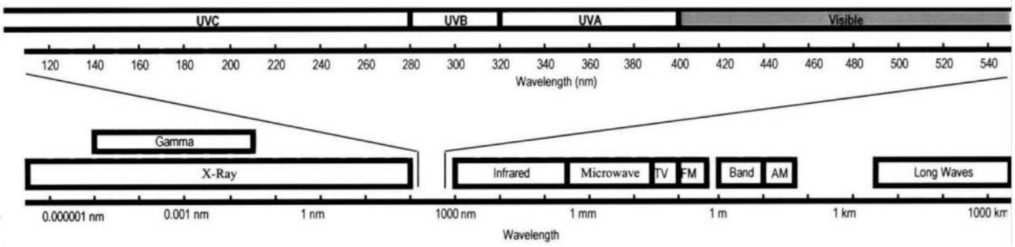


Figure 3.14 Electromagnetic spectrum with a magnification of the typical UV light curing spectrum.

3.5.5.2 Dual-cure

To achieve a fully cured adhesive joint, the adhesive must be exposed to light of the appropriate wavelength, intensity and duration. If for example, the adhesive is located in an area where light cannot reach it, a shadow zone, the adhesive in that area will remain uncured. Adhesive joint designs which contain shadow zones, due to the geometry of the assembly or the position of the light-guides, needs a secondary curing mechanism [12, p. 20]. Some secondary cure mechanisms include: heat, lack of oxygen, moisture, and two part mixtures. The adhesive does not necessarily become stronger after the secondary curing [13].

3.5.6 Determining Complete Cure

The definition of a fully cured adhesive is not absolute. One definition is that an adhesive is cured when it makes a phase transformation from its liquid to solid phase. Another definition is that an adhesive is fully cured when further curing does not enhance its properties [12]. There are some examples of adhesives where the color changes through this transformation, which makes it easier to see if the adhesive is cured all the way through [14]. Without such properties, determining a fully cured bond has to be done by destructible methods. Though even then, experts are often needed to make a correct assessment of the adhesives' complete curing.

3.5.7 Outgassing

When adhesives experience elevated temperatures, they lose some of its mass due to evaporation. This phenomenon is measured as outgassing, and its quantity is determined by weight loss of the adhesive during a time period [13].

For camera assemblies, this might be a complication due to their entrapped nature, causing fogging on optical equipment, i.e. evaporated adhesive condensing. This, in turn leads to an undesirable image quality.

3.5.8 Thermal Expansion

Most materials experience volumetric changes as temperature varies, which sometimes causes problems within mechanical assemblies. In some cases, this material behavior can be approximated by its linear coefficient of thermal expansion. This coefficient differs among materials.

As the temperature changes within Axis's cameras, this phenomenon causes movement between the aligned position of the PCB card and the lens package. For a large enough movement, the image quality becomes unacceptable. Hence, materials with low coefficient of thermal expansion are preferable materials within Axis's cameras.

4 Mission Statement

In this chapter the initial part of the Concept Development Process is described. The process starts with a mission statement deriving an outlined structure of the project, focusing upon the most fundamental parts of the problem. The benefit proposition, key business goals, together with assumptions and constraints are further discussed.

4.1 Mission Statement

The mission statement of this thesis aimed to give the project an appropriate direction, by identifying the basic properties of an optimal fixing process, with corresponding assumptions and limitations within Axis's production. The Mission statement can be seen in Table 4.1.

Table 4.1 Mission statement for the thesis

Mission Statement	
Product Description	• Optimize a design(s) and method to fix a sensor PCB card to camera housing
Benefit proposition	• Guarantees a high quality product
Key business goals	• An optimal process and design for fixing sensor PCB card • Optimize an adhesive solution • Guarantee a stable and strong fix • Easy production
Primary market	• Axis's internal production of cameras
Assumptions and Constrains	• Global mass production • Compatible with active alignment • Fixing is done in a clean room • Not prolong the IBAS process • Humans in production
Stakeholders	• Axis • Axis’s EMS sites • Customers

4.1.1 Benefit Proposition

The uncertainties of the current adhesive process were identified as lowering the overall quality of Axis’s products, since it sometimes results in problems after cameras has been delivered to customers. Thus, the main benefit proposition of a new fixing process had to guarantee a high quality product, increasing the customers’ satisfaction.

4.1.2 Key Business Goals

The key business goal was determined as optimize the fixing process of the PCB card. This optimization was initially categorized by a stable, strong and easy producible fixing.

Since using adhesive is the current fixing process within Axis, another goal of the thesis was to optimize a fixing process using adhesives. Even though adhesives pose some disadvantages, these disadvantages could possibly be eliminated with an optimized adhesive joint design. This would probably also become the most beneficial solution regarding cost, implementation time etc.

4.1.3 Assumptions and Constraints

In this thesis, an assumption was that the fixing process was compatible with the active alignment process used at Axis. This included the necessity of a clean room environment around the fixing process. However, smaller adjustments of the alignment equipment were seen as acceptable. The fixing process should not prolong the IBAS process as this is a bottleneck in the current production.

Furthermore, it was assumed that the method of fixing had to be applicable to mass production and the time of fixing had to be comparable with the current method.

For the adhesive concept, specific assumptions were made regarding production. In order to motivate such a concept, it was concluded that only small changes of the current production were acceptable. Hence, one assumption was that the adhesive dispensing would be kept manual by humans, not relying on automatic dispensing systems for the concepts generated.

5 Identifying Customer Needs

In this chapter the process of identifying customer needs, based upon the mission statement, is presented. The methodology is initiated by gathering raw data and interpreting this data into appropriate customer needs. A hierarchical organization of these needs is later performed, whilst giving the needs a weighted score of relative importance.

In this project, the customer needs were related to the different needs of the departments of Axis. So, the task during this thesis was to gather various needs from all stakeholders and give them appropriate weights of importance, relating to the benefit of Axis.

5.1.1 Gather Raw Data

Interviews were used as the main method of gathering this raw data. This method was chosen due to the nature of the problem, where different persons of different projects were able to share their experience and provide individual preferences. Questions were prepared before the interviews and were used to raise discussions of the subject. The information gathered from these interviews was documented using notes. The interviewees can be seen in Appendix D: Interviewees.

Axis's Electronic Manufacturing Services (EMS) sites are companies that manufacture electronics for Axis. By examining recordings from manufacturing of the products relating to this thesis was also observed during production. By doing this, an overall perspective of the production chain was obtained together with a better understanding of the environmental conditions at the EMS sites.

5.1.2 Interpret the Raw Data

The raw data gathered through the interviews and observations of the products was interpreted into customer needs. Relatively few customer needs were obtained during this process. The derived needs can be seen in Table 5.1.

Table 5.1 Raw data interpreted into customer needs

Interpreted Customer Needs
Fixing the PCB card has a low risk of affecting the alignment
The fix is stable during the cameras lifetime
The fixing process is done in simple steps
The fixing process is quick in production
The fixing solution is space conservative
The fixing process have room for mistakes
A general fixing process would be preferable
The fixing process ensures quality
Components required for the fixing process are easy to manufacture
The fixing process has a low risk of damaging components
The fixing process allows alignment in multiple directions
The fixing process is suitable for mass production
The fixing process is affordable
The fixing process allows for an environmentally sustainable camera

5.1.3 Organize the Needs and Establish Their Relative Importance

The customer needs from Table 5.1 was categorized as primary and secondary needs, which can be seen in Table 5.2. This was done subjectively, relying on the experience and knowledge gained throughout the process.

The weighting took into consideration that different departments of Axis had different priorities. Different projects or even people within the same project, had priorities corresponding to their respective requirements. The primarily identified weighting was iteratively altered throughout the project, as some priorities changed during the different concept development phases. For instance, implementation into production had a low priority during the concept generation phase, to allow a less restricted concept generation process. Though, during later concept selections and even more during the final stages of this thesis, this aspect was regarded as one of the most crucial parts of the design.

The primary needs were differentiated by two labels, necessary needs ***N*** and desirable needs ***D***. A necessary need included crucial requirements of the fixing process, i.e. it would not be feasible otherwise. Thus, others need were instead a desirable feature of the final design. Secondary needs were used to divide some primary needs into further sub-categories. They were then given a relative importance within each primary need.

Table 5.2 Customer needs categorized by primary needs.

Customer Needs: Hierarchical		
N	**The fixing process is suitable for mass production**	
	*	Components required for the fixing process are easy to manufacture
	**	The fixing process is quick in production
	**	The fixing process have room for mistakes
D	**The fixing process allows for alignment in multiple directions**	
N	**The fix is stable during the cameras lifetime**	
N	**The fixing process has few uncertainties**	
	*	The fixing process has a low risk of damaging components
	**	The fixing process is done in simple steps
	***	The fixing process ensures quality
	***	Fixing the PCB card has a low risk of affecting the alignment
D	**The new fix method is easy to implement**	
	*	The fixing process is affordable
	*	A general fixing process would be preferable
	*	The fixing solution is space conservative
D	**The fixing process for an environmentally sustainable camera**	
	**	Ease of recycling
	**	Environmental friendly components

* Less Important ** Important *** Very Important

Since it was important to have a stable fixing process, a necessary need became *The fixing process has few uncertainties*. This need favored knowledge about the fixing process, as new processes might have a vast number features making them impossible to use during active alignment. This need minimized the time spent researching solutions to the many problems which might have occurred with an uncertain fixing process.

Other chosen necessary needs were *The fixing process is suitable for mass production* and *The fix is stable during the cameras lifetime*. One problem found with the current adhesive solutions was that the large variances of the adhesive amount that could occur were not compatible with the small specifications allowed. Hence, a fixing process which provided a wider process window, i.e. allowing more variation in production while still maintaining high quality, was therefore highly demanded. Furthermore, the fix had to be stable through the cameras lifetime, as re-alignment or servicing was not a viable option.

By not choosing *The fixing process allows for alignment in multiple directions* as a necessary need, concept development process with fewer limitations was acquired. Some concepts that only allowed alignment in one or two directions could possibly later be combined with other concepts to enable a solution with full aligning possibilities.

A number of needs were identified as trying to satisfy the aspect of implementation into production. These were given a new primary need called *The new fix method is easy to implement*. As previously stated, this need was regarded as a desirable need in the initial concept generations, since too much focus upon implement ability might have resulted in a less creative process.

The need of an *Environmentally sustainable camera* was further divided into two secondary needs. This was done to further discretize between the different fixing methods, when later investigated. The environmental aspect was considered as desirable since the environmental friendliness of a fixing process would be greatly depending on different materials compatible with each method. Therefore this need was not prioritized during the first concept development cycle. Although, when an applicable concept for the fixing process was found, more effort was spent on the environmental friendliness of the solution.

6 Establishment of Target Specifications

In this chapter the Concept generation process continues with the establishment of target specifications. The fixing processes used at Axis are presented, together with their respective advantages and disadvantages. These processes are later compared through benchmarking. Other companies' methods of assembling lenses to optic components are also examined.

6.1 Establish Target Specifications

The main focus of this thesis was to find and optimize a fixing process that guaranteed the fulfillment of the active alignment requirements. A major part of the identified needs were hard or impossible to quantify into a list of metrics within time of this project as no current data was available. During this phase, an attempt was made to establish these target specifications but ultimately this part of Ulrich and Eppinger's methodology was excluded.

Instead a benchmark of the current fixing methods was conducted. The information gained from this benchmark together with an investigation of competitors' methods was considered as sufficient basis for the later concept generation.

6.2 Description of Currently Used Fixing Methods

6.2.1 Metal Holder with Passive Alignment

When the resolutions of the cameras are slightly lower, the tolerances of a misaligned sensor are higher. The lower resolution makes the imperfections harder to notice. An active alignment in five degrees of freedom is therefore sometimes unnecessary for these cameras. Nonetheless, some accuracy is often required of the focal distance between the PCB card and the lens package.

For these cameras, this more simple alignment process is done within Axis by using a piece of reference, with highly manufactured tolerances. This piece is inserted into a hole of the camera housing, where the lens package is later attached by threads. The PCB card is then placed at a specific position determined by the piece of reference and fixed by using adhesives.

This piece of reference takes into account the individuality of the camera housing and aligns the sensor parallel to the outer surface of this housing. As the lens package is later attached against this same outer surface, a sufficiently accurate position of the focal length is acquired. Finally, the lens package is screwed into place. Due to this process, it is possible to change it if necessary.

Figure 6.1 The metal holder solution.

One example of an assembly that uses this process can be seen in Figure 6.1. In this case, the adhesive is dispensed around the PCB card, fixing it to the metal piece surrounding it. This assembly will be referred to as *Metal Holder* throughout this thesis.

For this assembly, Axis uses an adhesive which primarily cures by UV light. Due to the presence of shadow zones, the adhesive is secondarily cured by heat. This heating process is done at 140 °C for five minutes [15]. In the benchmarking, this adhesive is denoted as *UV & heat 1*.

6.2.2 Pin/hole

The currently most common used technique within Axis when fixating the PCB card after active alignment is using UV light curable adhesives together with a *Pin/hole* design, as seen in Figure 6.2. Similarly to the assembling process described in 3.2.3 Camera , a plastic part, PCB holder, is assembled to the lens package. This PCB holder has pins that are aligned with holes on the PCB card. The diameter of the holes is slightly larger than that of the pins to enable movement during the active alignment. The pins also form a distance between the plastic part and the PCB card, to make room for electrical components, gasket and the sensor glass. The adhesive is dispensed inside the holes of the PCB card, hold in place by the surface tension of the adhesive. As the active alignment takes place, the pins are pushed into the adhesive and later primary cured by using UV light.

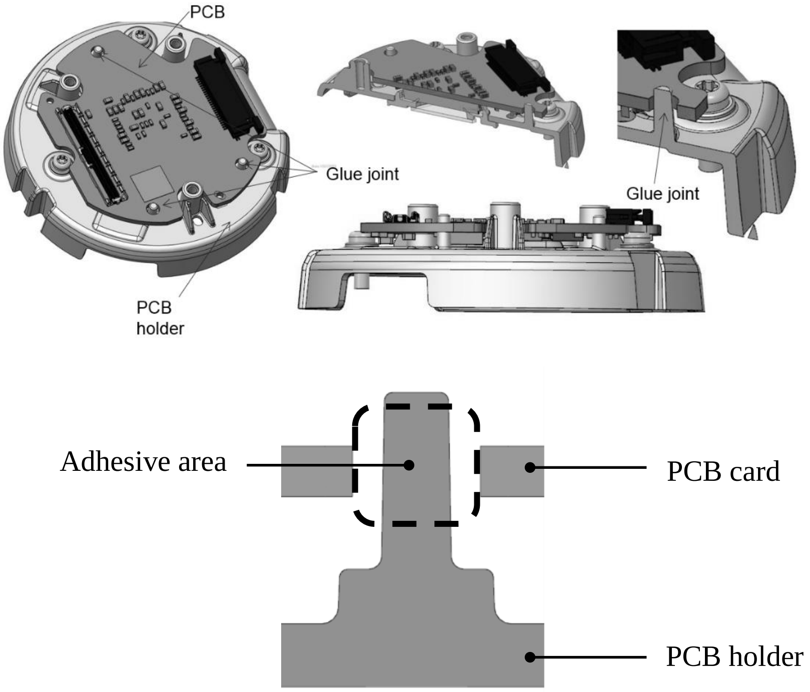


Figure 6.2 Example of the pin/hole solution.

This method is implemented on most of Axis's cameras, due to its efficiency. Although, when the pins are pushed into the adhesive, there is no control over the adhesive, often resulting in some located at the backside of the PCB. The UV light cannot reach this area of the PCB card. Thus, some of the adhesive does not cure and therefore a secondary curing mechanism is necessary.

The adhesive used in this design is a dual curable epoxy resin that primarily cures with UV light and secondarily with heat. The adhesive joints are irradiated by UV light from above. Heat curing takes place at 80°C for an hour. This adhesive is denoted as *UV & heat 2* and has similar properties with *UV & heat 1,* although a lower viscosity.

6.2.3 Pin/hole & UV-transparent Cups

Due to the problem in the *Pin/hole* design with the adhesives in shadowed areas, a similar solution uses tiny UV-transparent plastic cups inside the holes of the PCB card, see Figure 6.3. The attachment of these cups requires a separate dispensing and curing process. Then, for the assembling process, the adhesive is dispensed into the cups. Similarly to the *Pin/hole* configuration, pins are pushed into the holes of the PCB card. Though, the extra volume gained from these cups minimizes the risk of adhesive reaching the backside of the PCB card. When aligned properly, the adhesive is cured by UV light going through the transparent cups. In Figure 6.3 an illustrative assembly of a transparent cup solution is presented.

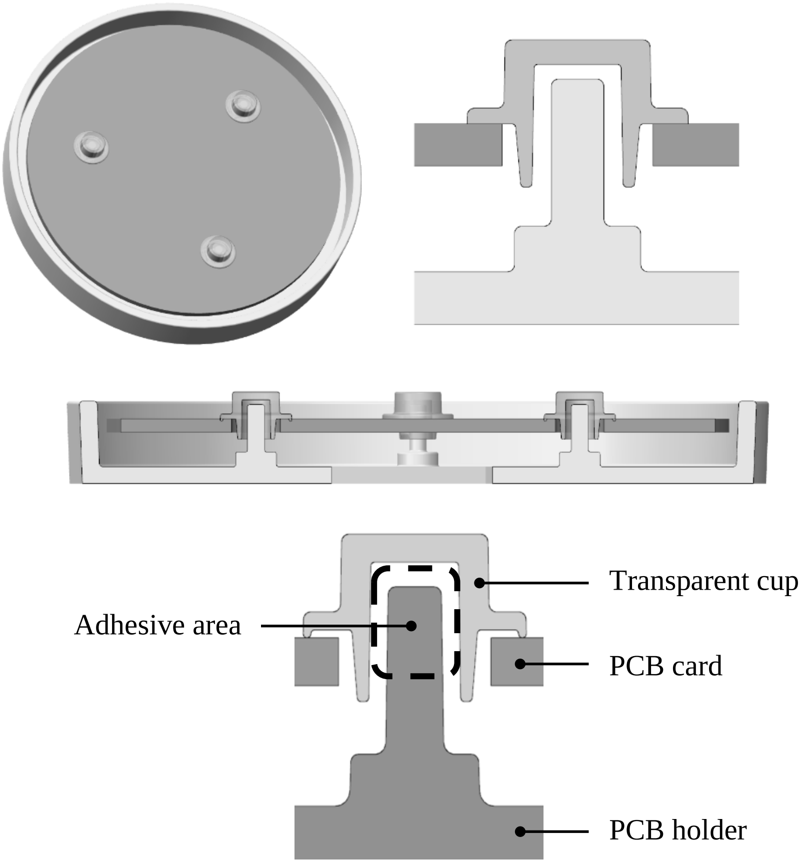


Figure 6.3 An illustrative example of the *pin/hole & UV-transparent cups* solution.

The design, which will be referred to as *Transparent cups* throughout this thesis, makes it possible to use a fully UV light curing adhesive. The same adhesive is used both for attaching the cups and for the fixing of the PCB card to the PCB-holder. In the benchmark this adhesive is denoted as *UV 1*.

6.2.4 Pin/hole & Plastic Mold

Another setup that is used in some of Axis's cameras is to include the transparent cups in a separate double molded plastic part. This part consists of two different plastic materials, one of which is the same as for the transparent cups, see Figure 6.4. This plastic part requires extra space on the front side of the PCB card. During the assembling, the PCB card is screwed onto this part and the adhesive is dispensed into its cavities. Then, the alignment procedure follows similarly to the previous designs. Though now, the adhesive bonds the pins to the double molded plastic part.

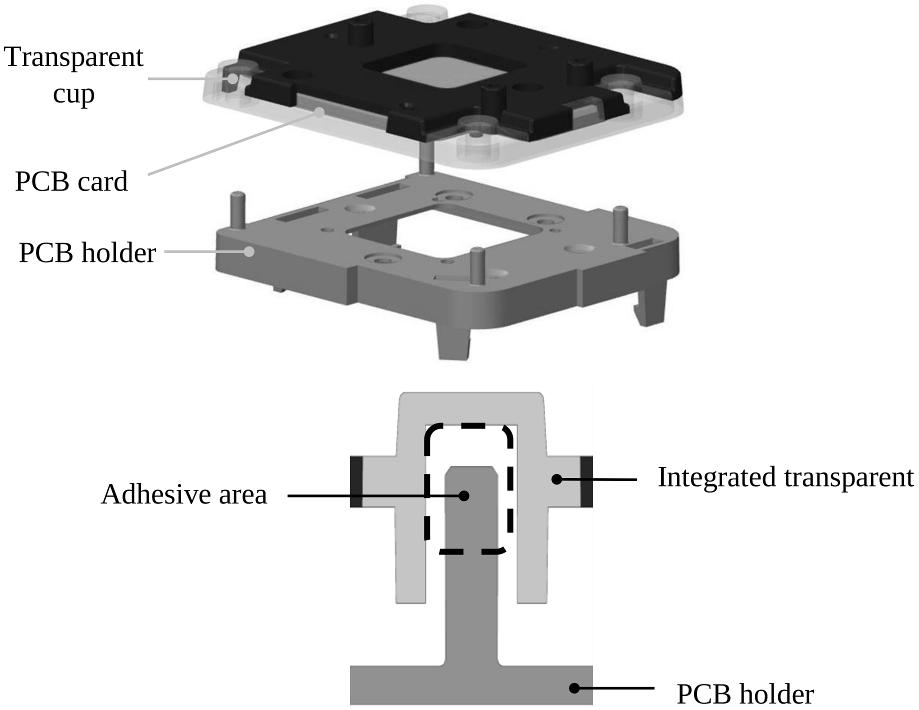


Figure 6.4 Example of the pin/hole & plastic mold solution.

Similarly to the *Transparent cup* design, a fully UV light curable adhesive can be used with this design. Same adhesive as previously is used in this design, i.e. *UV 1*. Throughout the report, this design will be referred to as *Plastic Mold*.

6.2.5 Clamping

There is one of Axis's cameras with active alignment requirements that use a mechanical clamp to fix a PCB card assembly to the lens package.

The custom features of this camera have been favorable of this solution. Firstly, the light cone from its lens is larger than its sensor, which provides some flexibility in the x- and y-direction tolerances. Due to this, there is no need for active alignment in these directions. Further due the quality of its lenses and the level of resolution, the tilting alignment is negligible. Thus, the only active alignment necessary is in the z-direction, i.e. the focus.

The process of alignment begins with fixing the sensor PCB to a plastic holder. This is done by attaching a separate plastic component with screws, which presses the PCB card to this holder, see Figure 6.5. Screwing in this PCB card directly would result in bending forces twisting the optical components. The lens package and this plastic

PCB holder are then joined temporarily while aligning, enclosed by a loosely fitted metal ring. When the alignment is done, the metal ring is pinched, permanently fixing the two components. The impact of the pinching on the alignment is also negligible.

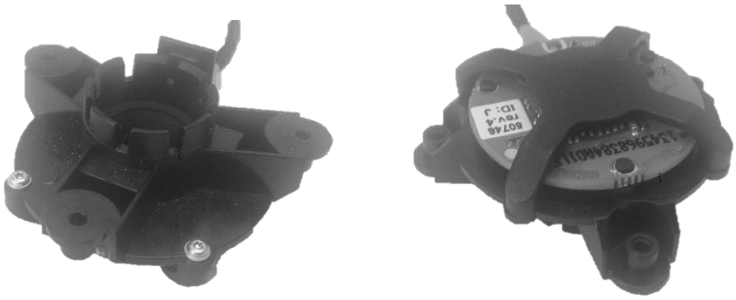


Figure 6.5 The clamping solution.

This method of alignment works very well, with much shorter alignment-time than that of IBAS, using a custom-made alignment setup. However, it is further stressed this design is very dependent upon these project specific features. Due to this, and the fact that this is an adhesive free solution, it was not considered during benchmarking versus the adhesive solutions.

6.3 Benchmark of Current Adhesive Solutions

In this thesis, a benchmarking was done considering Axis’s different design solutions together with their respective adhesives. Because of the continuously iterative improvements of these solutions at Axis and alternative adhesive tests, it was regarded as sufficiently systematic and correct to view these combinations as complete design solutions rather than examining every possible combination. The result of this benchmarking can be seen in Table 6.1.

Table 6.1 Benchmark of current adhesive solutions

Solution **Adhesive used**	Metal holder UV & heat 1	Pin/hole UV & heat 2	Plastic mold UV 1	Transparent cups UV 1
Logistics				
Transport to EMS sites	-	-	+	+
Storage time	+	+	+	+
Production				
Environmental preparation	-	-	-	-
Curing depth	+	+	0	0
Time for the adhesive process	+	+	0	-
Adhesive stickiness	0	0	-	-
Uncertainty in production	0	0	+	+
Adhesive Properties				
Primary curing time.	+	+	+	+
Secondary curing time	-	-	+	+
Shrinkage	0	0	+	+
Thermal expansion	-	+	0	0
Mechanical properties of joint	+	0	+	+
Ease of quality control	0	0	0	0
Total score	**1**	**2**	**5**	**4**

The solutions were benchmarked against each other within each category, i.e. no reference solution was used. Hence, the methodology resembles Ulrich and Eppinger's recommendations of using multiple reference points to avoid "scale comparison", which could be present if the reference concept deviates from the average values, thus compressing the rating scale [1, pp. 135, 136]. The scoring system used consisted of three grades, where "+" was the highest score, "-" was the lowest and "0" was a neutral score, similar to the relative scoring used in Ulrich and Eppinger's *Concept Screening* [1, p. 131]. The grading scale of three different steps was used to minimize the impact of certain categories and instead focus upon the overall superiority of a solution.

6.3.1 Logistics

Both *UV & heat 1* and *UV & heat 2* have to be stored at temperatures below 0 °C. This also applies to the transportation from its distributers to Axis's EMS sites. Sometimes during transportation, these adhesives have gotten stuck in customs, causing melting of the ice used to keep the adhesive at freezing temperatures, i.e. ruining the adhesive. This lowered the scoring for these adhesives. Since *UV 1* can be transported in room temperature it got higher scores.

The storage time for an unopened adhesive container is similar for all three adhesives. They also have similar maximal storage time for about six months.

6.3.2 Production

All three adhesives cure by both UV light and partially by visible light. Due to this, the EMS sites require environmental preparation of the light sources emitting visible light. This is done by introducing extra shielding of the lights in the facilities. All the current adhesives require the same environmental protection and thus received similar scoring.

The dual curing adhesives both have the advantage of having a high curing depth during the secondary heat curing process, which can fully cure adhesive at a range of different thicknesses. This is valuable due to the variations in the adhesive dispensing process, where larger volumes of adhesive might be difficult to fully penetrate with UV light. This is sometimes problematic for the *Plastic mold* and the *Transparent cups* design. This means that sometimes the UV light cannot penetrate the entire adhesive with enough intensity, leaving some uncured adhesive furthest away from the light source.

Both the *Pin/hole* and the *Metal holder* have designs which enable a quick and easy dispensing of the adhesive. Similar properties are also present for the *Plastic mold* and the *Transparent Cups.* However, both the *Plastic Mold* and the *Transparent cups* require an extra assembling step.

At Axis's EMS sites, the adhesive is dispensed using pressure/time dependent equipment. There is a backpressure in the dispensing equipment that constantly needs to be calibrated. This ensures that the adhesive does not drip from the needle after dispensing, although too much backpressure means that less adhesive than specified is dispensed. Due to this, there is always some deviation from what is specified [15]. Concerning the dispensing, operators have found that the high viscosity of *UV 1*, in combination with this pressure/time equipment, often leads to adhesive sticking to the dispensing needle. This adds even larger deviations of the adhesive amount at each adhesive joint.

Furthermore, the adhesives that require heat as a secondary curing mechanism introduces more uncertainties to the fixing process. Some components of the camera assembly cannot handle temperatures above 85 degrees. But the heat curing of the adhesives start at 80°C. This results in the requirements of a highly calibrated and controlled oven. At Axis’s EMS sites, it has sometimes been difficult to keep the oven at such specific requirements, as the temperature is dependent on the position inside the oven [16]. The oven process was therefore regarded as unreliable.

6.3.3 Adhesive Properties

All four solutions use primary UV light curing adhesives, which cure in seconds. Though, both *UV & heat 1* and *UV & heat 2* require additional heat curing to ensure a fully cured bond. This process was regarded as a bottleneck in production, since the oven has to be filled before it starts. A camera cannot be individually taken out and put into the oven since it would compromise stability of the heating process [16].

To retain the alignment of the PCB card while curing, it is preferable if the adhesive have a low curing shrinkage. Otherwise, the PCB card would experience large movement during curing, causing a misalignment. Furthermore, a low thermal expansion of the adhesive results in smaller movements of the PCB card for variances in temperatures. This movement could otherwise cause a temporarily deteriorated image. These two criteria have been evaluated after the adhesive properties and not the design of the adhesive joints.

The mechanical properties for the three adhesives are fairly similar, when evaluated within the design solutions. However, the *Pin/hole* design has uncertainties of the exact amount of adhesive in the joints, which can lead to a weaker bond, hence the lower score.

6.4 Conclusions

Table 6.2 Summary benchmark of adhesive fixing solutions.

Solution	Metal holder	Pin/hole	Plastic mold	Transparent cups
Adhesive used	UV & heat 1	UV & heat 2	UV 1	UV 1
Total score	1	2	5	4
Rank	4	3	1	2

The benchmarking, with summarized results seen in Table 6.2, determined the *Plastic mold* solution as the best current design solution, closely followed by the *Transparent cups*. The main difference between these two designs was the slightly more cumbersome assembling process of the cups during mass production. The adhesive process of the *Plastic mold* was also considerer slightly more controllable, as the areas around the cups are transparent, enabling curing of overfilled cups. Though, one disadvantage was that it uses some extra space on the front side of the PCB card.

Both of the highest scoring designs use *UV 1,* which has an undesirable viscosity. Due to this a new adhesive with a lower viscosity was evaluated, *UV 2*. The result of the tests can be seen in Appendix E: New . *UV 2* was found to have satisfying properties. It could most likely be used in Axis's production, after further project specific validations.

The many uncertainties of the *Pin/hole* design, as well as the requirement for secondary heat curing for both *Pin/hole* and *Metal holder*, are the main reasons for their lower scores.

6.5 Competitors' Methods

Axis's temperature requirements make their alignment process fairly unique in comparison to similar applications [20], thus it was difficult to find suitable competitors' methods.

Though, two other examples of cameras requiring active alignment were found in the automotive industry and mobile phone industry. The alignment process for these cameras, seen in Figure 6.6, includes an adhesive which primarily cures by UV light and secondary by heat. The heat curing mechanism is needed due to the designs risk of uncured adhesive in shadow zones. One advantage which these cameras pose in comparison to Axis is that they are less sensitive to heat. Other examined active alignment applications uses a similar concept with UV curing adhesive and heat curing as a second curing mechanism.

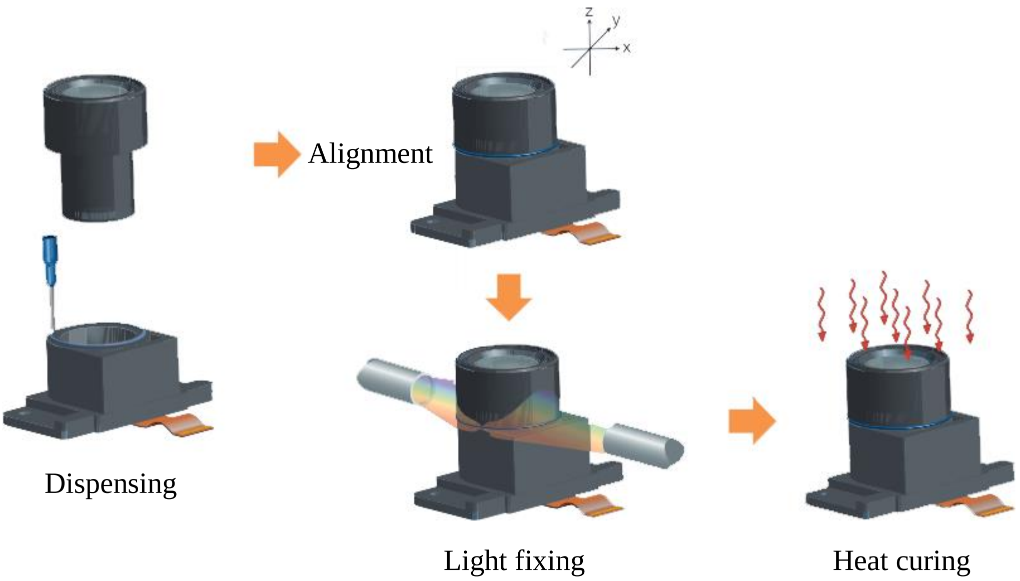


Figure 6.6 Overview of an alignment process used in the automotive camera.

7 Concept Generation – Decomposing the Problem

In this chapter the Concept Generation phase of this project will be presented. First, a clarification of the problem is done in order to find smaller sub-problems of the project. Then, the promising methods of solving these sub-problems are explored systematically.

7.1 Clarifying the Problem

The most fundamental problem of this thesis was determined as fixing the PCB card to the optics. An even wider approach was derived as fixing two arbitrary objects to each other. Different methods of solving these problems were examined. This resulted in smaller sub-problems to arise, as the limitations and assumptions of this thesis were applied.

7.2 Information Gathering Process

Information was gathered both internally within Axis and externally from other companies, experts and patent searches. However, the benchmarking done previously was regarded as sufficient and no external benchmarking was performed, due to time constraints and lack of competitors using active alignment.

Because of the vast diversity of different fixing methods, the information gathering process of this thesis needed structure and the areas of interest required sufficient exploration and focus. Thus, the methodology of *Exploring Systematically* in Ulrich and Eppinger [1, pp. 110-114] by using *Classification trees* was employed to achieve an overview over all possible methods.

After some consideration, methods with less promising properties were discarded due to the time frame of the project, as recommended from Ulrich and Eppinger [1, p. 112]. Examples of these methods include nails, tapes, joinery etc., where the external forces, bond strength, requirement of reference surfaces, among other factors, were seen as evident problems.

Furthermore, as advised from Ulrich and Eppinger [1, p. 112], various possibilities within each promising method were explored and their prospects were quickly evaluated, focusing upon those with best potential. The most promising alternatives were further branched out, evaluated and used as inspiration when generating concepts. The less promising branches were pruned due the lack of time of the master thesis project.

The more promising fixing methods: *adhesives, melting, screws* and *clamping,* can be seen in Figure 7.1. These methods were further analyzed, which is presented in the forthcoming sections.

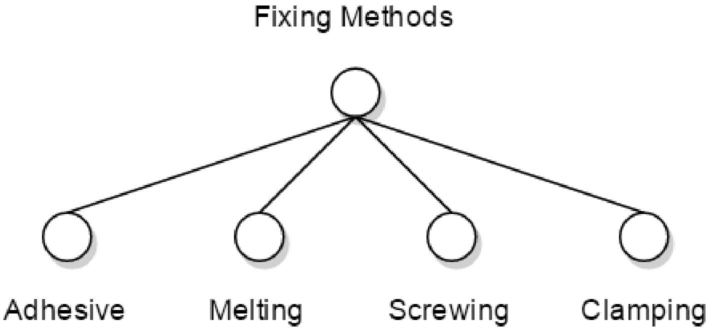


Figure 7.1 Concept classification tree of different fixing methods.

Moreover, the process of exploring the different fixing methods and concept generating within these methods were done simultaneously. Therefore, inspirational combinations between concepts of different fixing methods were found continuously. Thus, the methodology of using *concept combination tables*, as advised by Ulrich and Eppinger [1, p. 144], was neglected.

7.2.1 Adhesives and Curing Methods

There are a vast number of adhesives and curing methods. Many adhesives have the advantage that no disturbing contact needs to be present during fixing. Some also have the possibility of fixing two components in seconds and forming a strong bond. However, they might also have different grades of curing, which introduce uncertainties into the fixing process. For Axis's product assemblies, the adhesives must always be fully cured. Otherwise there can be problems with outgassing, damaging components, bad bonds, unstable processes etc.

There are mainly three groups of adhesives: *physically hardening, chemically curing* and *pressure sensitive*.

- Physically hardening adhesives are already acquired in their final chemical state and thus must be liquefied in order for wetting and adhesion to occur. The four main groups within this category are *hot melts, organic solvents, plastisols and water-based adhesives* [17].

- Chemically curing adhesives can either be single-component or two-component. Single-component adhesives are already mixed in their final proportions but chemically blocked. The curing of the adhesive is activated by some surrounding circumstance, corresponding to the specific curing system of the adhesive. There are four main groups of single-component adhesives based on differences in curing: *anaerobic curing, heat curing, moisture curing,* and *radiation curing.* For two-component adhesives, the curing process is initiated by the mixing of these two components [18].

- Pressure sensitive adhesives, unlike the other adhesives, do not solidify when cured. Instead, they remain viscous. An example of these adhesives is pressure sensitive adhesive tape, which remains tacky even after the removal of the tape. Due to this, their strength is fairly low in relation to both physically hardening and chemically curing adhesives. Their strength weakens in the presence of heat and they also have a tendency to creep while under static loads [19]. These were not desired properties in the bonding process of the PCB card. Thus, pressure sensitive adhesives were not further examined.

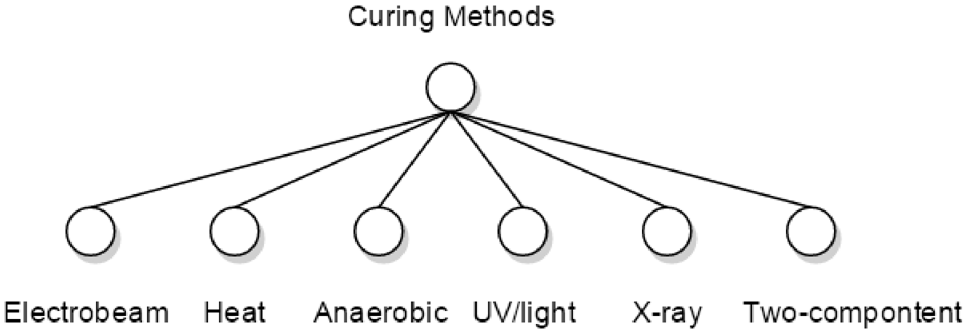


Figure 7.2 Adhesive curing methods.

7.2.1.1 Primary Curing Alternatives

The current primary UV light curing process takes up to 30 seconds. Therefore, any primary curing mechanism longer than a minute was assumed to be too long to motivate its implementation.

Moreover, the assumption of human controlled dispensing of the adhesive requires that the adhesive is dispensed before the alignment is completed. Otherwise, there is always the possibility of the interaction disturbing the alignment process. Due to this assumption, instant curing adhesives such as "anaerobic super-glues" cannot be used.

In other words, it is crucial that the curing of the adhesive starts instantaneously as the alignment process is done and that the curing process is as fast as possible. The only primary curing systems with these properties were chemically radiation curing adhesives, which cure either by UV light, visible light or electron beam radiation.

7.2.1.1.1 UV and Light Curing

One important aspect of the curing by UV light is the rate of light energy intensity per time unit that reaches the adhesive's surface, measured in W/cm^2. The intensity of a UV light source decreases with the distance to the adhesive's surface. There can also be huge differences of the intensity between the center of a UV light beam and its proximity. Generally the curing process is faster with higher intensity, although too much intensity can cause problems with the penetration depth of the UV light through the adhesive [20]. Additionally, materials absorb light, which also affects adhesives. Therefore as the intensity drops throughout the adhesive, there is a limited depth of curing [12, p. 15].

One of the main advantages with UV- and light curable adhesives is that it requires a fairly affordable radiation source.

7.2.1.1.2 Electron Beam Curing

Accelerated electrons can be sent to collide with adhesive, by using an electron cloud created in a vacuum chamber. During this collision, the electrons ionize the adhesive. This process creates free radicals that induce crosslinking, i.e. curing the adhesive [22]. Because of this, there is no need for a photo initiator, as needed in UV- and light curable adhesives.

One advantage in comparison with UV- and light curing is that there are no degrees of curing when using electron beam radiation. The adhesive is either cured or not [21]. Electron beams can also partially penetrate opaque materials, reducing the problem with "shadow zones". As an example, for a typical composite lamination application using appropriate equipment, opaque penetration around two centimeters is possible [22, pp. 310, 311].

Although during the process of using electron beams, X-ray radiation is created. Thus, appropriate shielding of the equipment is required. There is also a need of reducing the oxygen levels in the air were the electrons travel, in order to increase curing efficiency and avoid generating of ozone. The most common method of doing this is by increasing the amount of nitrogen in the surrounding air [22].

7.2.1.1.3 Conclusion

Using electron beam curing adhesives would potentially solve the problems with uncured adhesive within Axis's production. However, there are many uncertainties of whether this process is compatible with the active alignment process. Huge amount of effort, investments and further restrictions would also be needed to implement this technology at Axis's EMS sites. As there currently are solutions within Axis, enabling fully UV light curable adhesives, this implementation could not be motivated. Therefore, this method was not further investigated as an alternative.

7.2.1.2 Secondary Curing Alternatives

As the UV- and light curable adhesive were seen as the best alternative for an adhesive curing system, the concept generation was based on a design that fitted the requirements of such an adhesive. In other words, there could be no shadow zones, or too thick adhesive joints.

These two issues could either be solved by specially designing the components to be bonded so the problems could not occur, or by using a secondary curing mechanism that could ensure a fully cured bond. Secondary curing mechanisms compatible with the UV- and light curable adhesives were examined. The different secondary curing alternatives were *anaerobic*, *heat*, *moisture* and *two-component* [13].

7.2.1.2.1 Anaerobic Curing

For anaerobic adhesives, curing is initiated and proceeds by the absence of oxygen and the catalytic influence of metal ions. Thus, the outer boundary of the adhesive must be free of oxygen in order for the curing process to start. These adhesives reach their initial strength after a few minutes. The reaction can be accelerated by using heat or activators [24, p. 80].

Hence, UV- and light could initially cure the outer boundary. This would leave the rest of the adhesive enclosed and with absence of oxygen, which would activate the secondary curing mechanism [13].

Due to the curing conditions of anaerobic adhesives, they must be stored in half filled air-permeable bottles to prevent premature curing. Precautions must also be taken when dispensing the adhesive [24, pp. 44, 45].

7.2.1.2.2 Heat Curing

Heat curing adhesives need an elevated temperature for a specific amount of time in order to cure. Curing temperatures for these adhesives range from 60 °C to 180 °C [24, p. 75]. This curing process also needs to be proceed for about 15-75 minutes, with faster curing times for higher temperatures [13].

7.2.1.2.3 Moisture Curing

Moisture curing is mainly initiated by OH^- ions in air humidity or in the humidity of a component’s surface. The ideal curing conditions are 40-70% relative humidity, with accelerated curing for levels. A too low relative humidity decelerates the curing process or even weakens the bond [24, p. 82]. A moisture curing adhesive needs at least 20% relative humidity to cure [20]. Final curing is achieved after 20 hours [24, p. 82].

7.2.1.2.4 Two-component Curing

Two-component adhesives consist of two different parts, a resin and a hardener. The adhesive cures as the two parts are mixed together. The specified mixing ratio needs to be met with a 95% precision in order to cure. This can be controlled by using special dispensing equipment [24, pp. 78, 46, 47]. An example of the mixing process inside an adhesive dispenser can be seen in Figure 7.3. The initial cure of the adhesive is developed after six hours in room temperature [24, pp. 78, 79].

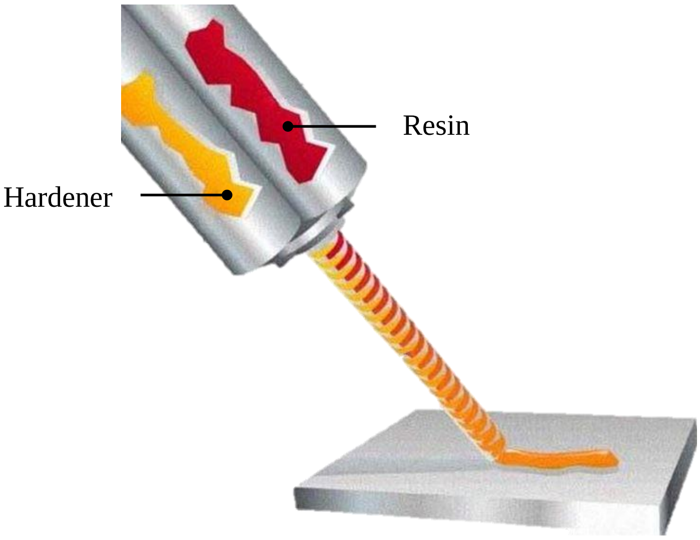


Figure 7.3 Illustration of two-component adhesive dispenser.

7.2.1.3 Further Discussion

The development team had discussions with employees at Axis, regarding using a secondary curing mechanism. The conclusions were:

- **Anaerobic** – This secondary curing mechanism was regarded too complicated, due to the need of special adhesive storing and certain atmospheric conditions while dispensing.

- **Heat -** This is already implemented at Axis. These adhesives cure at a minimum of 80 °C. Even though adhesives capable of curing at lower temperatures exist, they are not suitable for Axis's application [20]. Though, as earlier mentioned, the heating process is difficult to control, as the temperature needs to be kept close to the minimal requirement of the adhesive to not damage optical components.

- **Moisture** - Secondary moisture curing needs less control, as the curing process would continue at room temperature. With fewer requirements on control, the long curing time could become a smaller problem. The cameras that have been primarily fixed could be temporarily stored while the secondary curing takes place. Yet, various conditions at the different EMS sites regarding the humidity levels would still require further investigation of each site. At sites were the humidity levels are low, humidity chambers could become necessary.

- **Two-component** – These systems can guarantee a fully cured bond, without any control parameters such as temperature or humidity levels. Though, it would require new dispensing systems at each dispensing unit in order to mix the adhesive. It was also difficult to find a commercial product with primary UV curing and secondary two-component curing, although a prototype adhesive could most likely be provided by one of Axis' adhesive distributors [20].

7.2.1.3.1 Conclusion

All of these secondary curing mechanisms could probably solve the current problems within Axis's production. Despite this, if a new secondary curing system was to be implemented, there would still be a vast amount of validation needed for these new adhesives, regarding bond strength, dispensing, outgassing etc. It was decided that proceeding with these validations could not compete with a design that could guarantee a fully cured adhesive using only UV light. Therefore, further concept generations focused upon designs without the need of a secondary curing mechanism.

7.2.2 Melting and Heating Methods

Different methods for joining two components through melting were examined, see Figure 7.4. How these different methods could be varied by using different heating techniques or materials was however not initially considered. All melting methods originated from joining two materials by melting one or more materials to create a bond. In some applications, a filler material could be added. A wide range of energy sources for these melting applications were later examined.

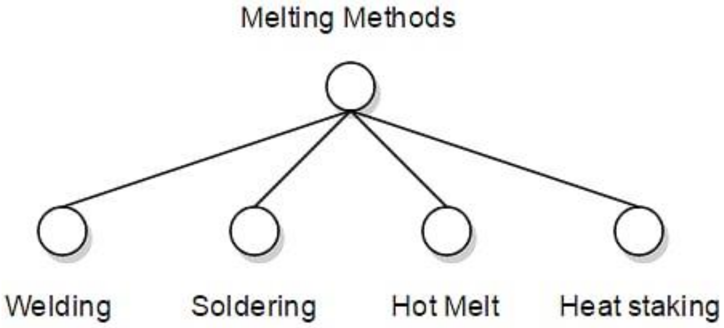


Figure 7.4 Melting fixing methods.

7.2.2.1 Soldering & Welding

Soldering is a joining process where a filler material is melted and added to a joint, in order to bond two or more components. In soldering, heat is applied to the work pieces, which causes the solder to melt. Thus, the filler material has a lower melting point than the adjoining materials. The melted solder wets the surfaces' of the work pieces and while the assembly is kept still, the solder solidifies. The difference between soldering and adhesives is that the filler material forms an alloy with the work pieces at the junction.

Soldering with low temperatures is called soft soldering. When the filler material has a higher melting temperature, it is instead called brazing, but the work piece materials still remain solid in both methods. The distinction between soldering and brazing is based on the filler material having a melting point below approximately 450 °C [26, chapter 43 p. 35, chapter 43 p. 39].

Soldering is a very flexible method, due to filler materials being available in many different configurations, matching different applications. Final strength of the bond is also dependent on the filler material used. Soft soldering generally produces a joint not suitable for mechanical load-bearing applications. However, this can be overcome in most applications by proper joint designs, filler metals and soldering procedures [26, chapter 43 p. 39].

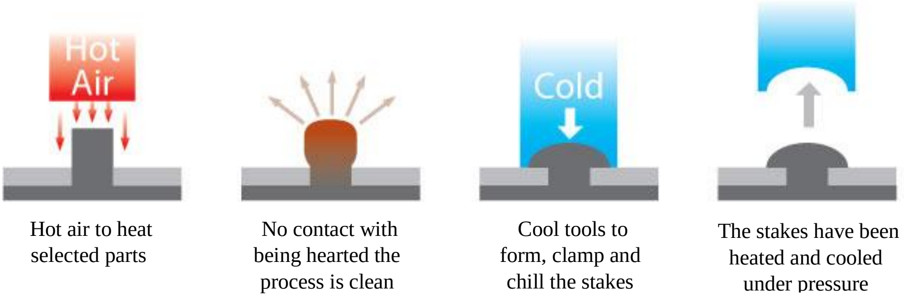
Welding compared to soldering, further includes melting the work pieces. Just as with soldering, welding often includes an added filler material. The melted work pieces and the filler material forms a combined molten pool, which solidifies and forms a strong joint, called coalescence. Sometimes pressure is used to complement the heat when producing the weld.

7.2.2.2 Hot Melt

A hot melt is essentially a melted plastic used to bond components. Not all plastics have adhesive properties and do not easily bond with plastics other than themselves when melted; in addition during this process pressure needs to be applied [27]. A risk is also that these plastics are charred rather than liquefied. A melted plastic which possess adhesive properties is called a hot melt. These plastics liquefy when heated and forms a bond when cooled.

7.2.2.3 Heat Staking

Heat staking is joining two components by creating a mechanical lock, achieved by friction between the two parts, a so-called interference fit. The most common method is by fitting a stud from one component through a hole in the other. Then, a staking probe is used to deform the stud, forming the interference fit, see Figure 7.5. Unlike welding, heat staking has the possibility to join two dissimilar materials such as plastic and metal, or two dissimilar plastics [28, p. 135].



Hot air to heat selected parts

No contact with being hearted the process is clean

Cool tools to form, clamp and chill the stakes

The stakes have been heated and cooled under pressure

Figure 7.5 Illustration of heat staking.

7.2.2.4 Possible Heating Methods

The more promising heating methods that can be used for soldering, welding or hot melts can be seen in Figure 7.6.

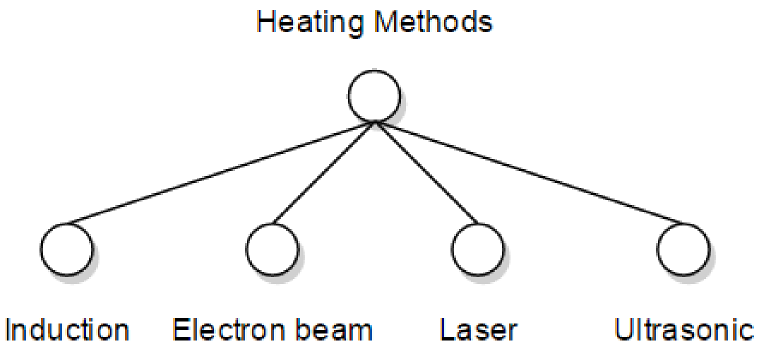


Figure 7.6 Possible heating methods for soldering & welding.

7.2.2.4.1 Electron Beam

An electron beam can be used as a heat source for both welding and soldering. The kinetic energy of the electrons transforms into heat upon impact. This has the advantage of being a non-contact method. The process often requires vacuum to prevent the electron beam from dissipating.

7.2.2.4.2 Ultrasonic

Ultrasonic energy can be used to either solder or weld two components together. When welding, the ultrasonic energy melts the interface between the two components while soldering heats a filler material. During the process of ultrasonic soldering and welding, pressure is required between the two work pieces.

7.2.2.4.3 Laser

To either weld or solder using laser as a heat source produces a local heating, without requiring contact. The laser system is generally more expensive for higher temperature requirements [31]. However, a laser system needs to be automated.

7.2.2.4.4 Induction

To heat a soldering material through induction is another contact-free method. Induction heating limits the design to electrically conductive base metals [26, chapter 43, p. 40]. An alternative is to infuse other materials such as non-conductive metals or plastics with a conductive metal. The design also has to allow for an induction tool to surround the joint.

7.2.2.5 Conclusion

To use a non-contact heating process was seen as highly preferable. Both ultrasonic welding and heat staking requires pressure between the components to join. Similar to earlier discussions regarding interference during the alignment, the effort of further developing a concept based on such methods was seen as too complicated.

Laser, electron beam and induction all provided a contact-free heating method. However, the electron beam required vacuum to ensure a stable process. This would be inconvenient in production. Hence induction and laser was seen as the two most viable heating methods.

Hot melts as an adhesive was earlier dismissed due to the limitation of adhesive dispensing before the active alignment process. Though when regarded as a material in a melting method, the hot melt could be applied before the active alignment starts and later re-melted as the alignment is performed.

7.2.3 Screwing

A screw is a fastener characterized by a thread wrapped around a cylinder, used to bond two different materials. The underlying force retaining the screw is friction, both between its head and the material, but also within the threads. In order to achieve a good strength of a screw bond, i.e. high friction force, it is crucial to apply sufficient normal force. For further strength, bolts can be used on the opposite side of the material, which further increases the friction surface available.

Screws have the advantage of being easy to handle in the production. There is room for mistakes since it can easily be disassembled and even automated. Screws can either be the common *fix screw*, or an adjustable version called a *set screw*.

If a screw is used to fix, or adjust the position of the PCB card, there would most likely be disturbance during the active alignment process. This disturbing contact was sufficient to discard some of the adhesive solutions, were dispensing had to be done after the alignment. Despite this, the advantages of a fully functional screw design were considered enough to partially ignore this risk during the concept generation process.

7.2.4 Clamping

Clamping requires two surfaces being parallel to each in order to achieve a stable fix. The method poses some similar advantages to screws as being easy in production and enables simple disassembling properties. As clamping relies on mechanical deformation, there is a high risk of affecting the alignment as the clamp is being deformed. However, for the current project using clamping, this disturbance was negligible. Therefore, it was further examined through the concept generation process.

7.2.5 Summary of the Possible Fixing Method

The methods chosen for further examination can be seen in Table 7.1.

Table 7.1 Summary of the possible fixing methods.

Adhesive	Melt	Screw	Clamp
UV curable	Soldering	Set Screw	Mechanical Clamp
	Welding	Fix Screw	
	Hot Melt		

8 Concept Generation – Brief Descriptions of the Concepts

In this chapter the most promising generated concepts categories will be briefly presented. The concepts are divided into the different most promising fixing methods derived in Chapter 7, i.e. adhesive, melting, screwing and clamping.

8.1 Description of the Concepts

The details of the concepts categories were kept fairly undefined, with lots of possible designs within each category. This way, the emphasis was the potential of the concepts rather than the details of the design solutions. The concepts categories are presented together with their corresponding fixing method, which are *adhesive, melting, screws* and *clamping.*

8.1.1 Adhesive

- **Walls -** Plastic walls arising from the PCB-holder, to which the PCB card would be fixed. The walls could be placed under, around or over the PCB card. Additionally, all of, or parts of the walls could be transparent to fully cure adhesive.

- **PCB-connector -** A plastic component attached to the PCB, similar to the plastic mold used in some current projects. The connector on the plastic component would join connectors to the PCB-holder, similarly to the *Pin/hole* design. The connectors could be the standard pin/hole configuration or have more advanced connectors such as rounded shapes and spherical cups.

- **Control adhesive -** By using gaskets, tracks or added parts to control the adhesive, its movement would be limited. When applying pressure to the adhesive area it would not end up in undesirable regions such as shadow zones.

- **Mirrors -** The UV-lamps from the set-up have movement and placement restrictions. By using mirrors, the light could be guided to shaded areas, for instance the back side of the PCB card.

- **Redirect light -** Similar to the mirrors concept, the restrictions of the UV-lamps was examined a bit further. By using fiber optics or other ways to redirect the light to shaded areas, a fully cured bond could be achieved.

- **Glue module -** Normally, the PCB is aligned against the camera modulus and PCB-holder. The idea behind this concept was to split the alignment process to a rough alignment and another alignment for fine tuning. Then different joints could fixate the PCB card in different degrees of freedom. Another alternative was to align the PCB card to a separate part that would be used as a reference surface, parallel to the PCB-holder, similar to the passive alignment of the *Metal holder*. This separate part could be fixed to the PCB card with adhesive, using UV light sources on both sides of the PCB card. This new modulus could then later easily be attached to the camera modulus.

- **Spider –** A plate is attached to the PCB holder by four spider arms. This plate would be placed above the PCB card and function as a new PCB holder. Adhesive would be placed in a cup on the top side of the PCB card and form a connection between the spider plate and PCB card.

- **Removable wall -** By using removable walls, with a surface that the adhesive cannot adhere to, the adhesive could be kept at certain areas. By restricting the adhesive’s movement, it would be prevented from reaching shadow zones. After fixing of the PCB card the walls would be removed. The non-adhere surface of the wall could make it re-usable.

8.1.2 Melting

- **Ball –** The PCB holder would be modified with three open cylinders. The PCB card would be shaped to fit within the three cylinders. A ball placed on top of the PCB card would follow the movement of the active alignment, while still maintaining contact. When an optimal alignment is found, the balls would be heated above melting temperature to form a bond between PCB card and the PCB holder.

- **Ring -** This concept was very similar to the current *Pin/hole* solution. When the pins are positioned in the holes of the PCB card, a preformed solder in the shape of a ring, could be placed around the pin. This ring would melt and form a bond between pin and the PCB card. The solder material used could be altered; another promising alternative was using a solder paste. This would then mimic the adhesive *Pin/hole* solution, though with a solder paste instead of an adhesive.

- **Melting walls -** Walls attached to the PCB card containing material that is melted during the alignment. When the alignment is completed, the pool of melted walls would be quickly cooled, fixing the PCB card.

8.1.3 Screwing

- **Jointed screws -** A screw could be used to align the PCB card in z-direction. With a jointed head the screw could also follow the tilting movement. If the screw head is larger than the hole it would also allow alignment in the x/y-direction.

- **Set screws –** Different screws controlling different degrees of freedom during the alignment are used. When a sufficient alignment is found the screws could simply be left in their position and nothing more needs to be done.

- **Fix screws -** By having a track on either the PCB card or PCB holder and a screw on the other the component, the screw could be used to fixate the surfaces to each other in the direction of the track. This fix process would be limited to one alignment direction.

- **Rocket screw -** A separate part with rounded end could be used as a reference surface, with adhesive bonding on the central back-position of the PCB. The rounded shape would make it possible to tilt the PCB while x/y-alignment is done by moving the PCB. The separate part would contain a screw that could move it in z-direction in order to ensure that there is always contact between the surfaces to adhere.

- **Adhesive set plate -** Instead of interfering with the PCB card with screws that could disrupt the alignment, the position of a separate plate could be controlled by set screws. When an optimal alignment position of the PCB card is found, the screws on the separate plate could place the plate as close as possible to the PCB card. Then a very good adhesive bond could be made between the PCB card and plate. It would also be possible to perform the x/y-alignment in the adhesive bonding between the plate and PCB.

8.1.4 Clamping

- **Spherical holder –** An additional holder is attached to the PCB card and then placed in the PCB holder. To enable full alignment, the additional holder would be spherical. To fix the additional holder to the PCB holder a pinch clamp would be used to connect the two holders, very similar to the clamping solution in section 6.2.1 Metal Holder with Passive Alignment.

- **Wall clamp -** Walls arising from the PCB-holder enclose the PCB card, some elasticity should exist within these walls. When proper alignment is found, a mechanical clamp is pinched around the walls. The elasticity would enable the tilt alignment, by minimizing the risk of movement after the clamp had been pinched. This elasticity could be produced by a rubber component placed around the outside of the PCB card.

- **Jointed pin -** By having a jointed pin fully attached to the PCB card, the aligning movements could be followed. The pin would be placed in a cylindrical pipe to allow movement in z direction. When the optimal sensor position is found, a clamp could be pinched around the pipe to fix jointed pin and thereby the PCB card.

9 Concept Selection

In this chapter the prospects of the generated concepts is evaluated in order to narrow down the amount of concepts that should be tested. The evaluation process is done by using the customer needs derived in Chapter 5 through a Concept Scoring within each of the different fix methods. The result is a numerical value of comparison between the different concepts. The final selections and combinations of concepts are presented at the end.

9.1 Concept Selection

In this thesis, the concept screening process was replaced by discussion around the prospects of the different concepts. Although it might be very difficult to state that a concept will not work, its risk of failure during further development was quickly evaluated. With this methodology, some concepts could be quickly discarded, although their strengths were recorded. Due to this, the amount of concepts could be narrowed down and combined from fifty to about twenty, which corresponds to the described concept categories earlier. Within these remaining concept categories, there were several different design ideas.

There were ideas coming from each of the four fixation methods derived earlier. Hence, the concept scoring process was divided into four different eliminations.

9.2 Concept Scoring

9.2.1 Description and Motivation of the Concept Scoring Process

A list of criteria was made for the concept scoring process. These criteria were formed from the customer needs. The primary needs' label along with their secondary needs' relative importance was used as guideline for the weighting process. All primary needs were given roughly the same amount of weighting. The secondary needs were used to divide the weighting of a primary need into simpler categories. This was done in order to gain a more accurate reflection of the whole process. The same criteria were used for all four fixing methods.

A reference solution to the fixing process was chosen as the *Transparent cup* design, since this is the solution currently implemented by new projects. This method of fixating the PCB card has many advantages, though some drawbacks mentioned earlier do exist.

Due to the complexity of the problem, and the many specific improvements that could be done to each concept, an iterative methodology of the concept scoring was applied. So, during this process, the concepts were subjectively scored by their potential and the details of the solutions were kept vague. The better a concept could handle obvious problems, the higher score it was given. This way, some concepts that had prospects but were not as detailed as others could get a chance of further exploration. According to Ulrich and Eppinger this includes some risk, but the project team decided that this method seemed most suitable for this project.

Moreover, sensitivity analyses were conducted as recommended by Ulrich and Eppinger. The weighted score of the different criteria's were altered to find and evaluate the concepts sensitivity to certain criteria's [1, pp. 136, 137]. This was done by the project team, considering the opinions of the interviewees. In this report, these sensitivity analyses are not presented and the final concept scoring matrices are presented, in Appendix F-I.

9.2.2 Description and Motivation to the Different Criteria

9.2.2.1 Suitable for Mass Production

The suitability for mass production of a concept was covered by the following criteria: ease of manufacturing the required components, time in production and if mistakes can be made in production while maintaining the quality. The reference solution was seen as moderately easy to manufacture. It needed transparent cups for each of the holes. If a concept needed a more advanced plastic component or additional components, it generally got a lower score. The ease of manufacturing was one of the transparent cup solution's strengths and it was strong in this category compared to many other concepts.

When considering the time in production, the reference had to attach the transparent cups onto the PCB card and filling the holes with adhesive. If a concept needed additional steps, it got a lower score than the reference. If a concept’s process ended up as a bottleneck, it also got a lower score.

There are always parameters in production that are hard to control. It might be the surroundings, operators doing mistakes while fixing the PCB card to the lens housing etc. If a concept ensured quality even though some mistakes were made, a higher score was received. One of the advantages of the reference solution was that there was a designated area for the adhesive and this minimizes/eliminates the risk of uncured adhesive. Many of the concepts focused upon these two aspects and therefore received the same or a higher score than the reference.

9.2.2.2 Degrees of Alignment

The capability of handling all degrees of alignment was a very important aspect. The reference solution has full alignment possibilities. Hence, concepts with the same properties got similar score; a higher score could not be received. Some concepts only handled one or two degrees and thus got a lower score. Since a new design preferably should be applicable to a range of current projects, it was hard to motivate development of concepts that received a low score in this category. Nevertheless, they could very well be used in combination with other concepts.

9.2.2.3 Good Fix

A good fix corresponds to a bond that is stable during the cameras entire lifetime. For the *Transparent cups* solution the bond is between the cups' inside and the pins. For adhesive concepts, a solution with a large bonding surface generally got a higher score. Using a higher amount of adhesive was not considered negative in this category. Properties of the bond, such as strength and stability, were approximated.

9.2.2.4 Risk

Comparing concepts which have been tested to a varying degree could result in an imbalanced concept scoring. A more tested method might have known problems whereas an untested method might have several unknown limitations. To deal with this, a risk criterion was added to the scoring. This handled concerns such as the risk of damaging components, low bond strength, method affecting the alignment etc. If a concept involved a low risk, it received a high score. When comparing adhesive concepts to the reference, a concept that moved the adhesive area away from the PCB card's components generally got a better score. For some screwing and clamping concepts, there might be a risk of damaging or bending the PCB card or its components. With soldering, generally a higher score was given due to this method currently being used to solder components to PCB card.

Another important aspect within this category was the repeatability of the fixing process. An optimal solution would result in identical bonds each time. The transparent cup solution leads to a very low variation of the bond. However, in extreme cases adhesive can end up on the bottom side of the PCB, in a shadow zone. A stable fixing process must guarantee the behavior of the final bond. For adhesive and melting solutions this might include a designated area for the adhesive or added material. The ease of quality control, and if this was necessary or could be integrated with a concept, was also considered within this category. The optimal option would have been a very stable process where quality control is redundant. Concepts that had no clear method of ensuring a stable fixing process, such as a few screwing and clamping concepts, generally got a lower score.

Finally, the risk of the concepts fixing process affecting the alignment was considered. If contact with the PCB card was necessary for the fixing process this could lead to an interference with the alignment. Thus, lower scores were received for concepts and processes were this was considered to be a problem.

9.2.2.5 Implementation

This criterion evaluated how the concept was going to be implemented into production. Factors under consideration were the generality of the concepts i.e. how many of the existing Axis products that the solution could be implemented into. The more products it includes, the higher the score. Space conservative concepts were also favored due to this. Moreover, concepts that could be used with the current alignment system, with minor modifications, received a higher score. This also affected the additional criterion of investments. Concepts in need of larger implementation costs, such as the requirement of new machines were scored lower; a laser source was example of this. Though, minor investments such as tools, additional EMS site training etc. were ignored.

9.2.2.6 Environment

The environmental aspects of a production process are always important. As earlier mentioned, Axis has a vision of sustainability including ease of recycling and disassembling, as well as using environmental friendly products [29], if disassembling is possible, repairs and replacement of components are easier, which results in a more sustainable product. Concepts that enabled these features were therefore given a higher score.

9.2.3 Results

9.2.3.1 Adhesive

Table 9.1 Summary of the adhesive concept scoring, concept for further development are marked gray.

Concept	**Total score**
Wall + Control Adhesive	3,48
Control Adhesive	3,45
PCB-connector	3,28
Glue Module	3,23
Mirrors	3,05
Redirect Light	3,05
Spider	3,03
Wall	3,00
Removable Wall	2,95

The results from the scoring of adhesive concepts can be seen in Table 9.1 and with further details in Appendix F. The vast knowledge and testing already done with adhesives became clear within the risk category where high scores were received, i.e. the risks were minimal. Degrees of alignment were unchanged from the reference, as well as environmental effects, for all concepts. Most concepts had bonds that were considered just as good as the reference. With the wall concept, an adhesive joint could be placed around the entire wall; leading to higher strength. Implementation should become fairly easy for all concepts, since the equipment is already present, though some new parts could still be required. Hence, suitability of mass production also seemed favorable.

To generalize, the concepts *Walls* received low scores due to the poorly controlled adhesive. *Redirect light* and *Mirrors* had some advantages, but they only solved problems with already poorly designed adhesive joints. The *Spider* concept involved many plastic parts and was space consuming. Moreover, *Removable wall* did not pose enough advantages compared to other concepts. Thus these concepts will not be further examined in their current configuration.

Though, a combination opportunity was seen between *Walls* and *Control Adhesive*. The result was a wall with a gasket controlling the adhesive, which provided a much higher reliability. The score of the combined concept can also be seen in Table 9.1.

PCB-connector, *Glue Module* and *Walls + Control Adhesive* did all pose very advantageous properties in production and was therefore further evaluated. *Walls + Control Adhesive* will be referred to as *Wall & Gasket* through the rest of the thesis.

9.2.3.2 Melting

Table 9.2 Summary of the melting concept scoring. Concept for further development is marked gray.

Concepts	Total score
Ring	3,45
Ball	3,05
Melting Walls	2,45

The results from the scoring of melting concepts can be seen in Table 9.2 and with further details in Appendix G. Similar scores were received in the mass production, degrees of alignment and environmental categories compared to the reference; though with somewhat higher scoring in specific areas. A melted fix was seen as better than using adhesives. However, investments in melting equipment would become necessary. There were also some uncertainties of the melting process and its ability to ensure a stable bonding solution.

To generalize, *Melting Walls* was considered hard to implement as the melted material had to be liquidized during the alignment process. The *Ball* concept did not pose enough benefits compared to the reference solution. Thus these two concepts were not further evaluated.

The *Ring* concept posed the advantageous properties of a stable production process. It was more general and space conservative than the other melting concepts. Therefore *Ring* was further evaluated.

9.2.3.3 Screwing

Table 9.3 Summary of the screwing concept scoring.

Concepts	Total score
Adhesive Set Plate	2,85
Rocket Screw	2,8
Jointed Screw	2,7
Fix Screw	2,55
Set Screw	2,35

The results from the scoring of screw concepts can be seen in Table 9.3 and with further details in Appendix H. Due to a high risk and requirements of many complex parts; all concepts received fairly low scoring in both mass production and risk analysis. The possible degrees of alignment for the concepts were altering. Small movements and the high strength of a screw fix made the scoring of some categories similar to the adhesives. The implementation challenges were seen as fairly small and the environmental aspects better than that of adhesives.

To generalize, the concepts developed for *Set screws* and *Fix screws* did not provide active alignment in as many degrees of freedom as the reference solution, which was seen as a step backwards when examined as a full concept. *Jointed screw* would involve too complex parts compared to the concepts advantages. *Rocket screw* and *Adhesive Set plate* did simplify the adhesive bonding process, though complicating the fixing process overall. Because of this, none of the screw concepts were further evaluated.

9.2.3.4 Clamping

Table 9.4 Summary of the clamping concept scoring.

Concepts	Total score
Jointed Pin	2,83
Spherical Clamp	2,73
Wall Clamp	2,60

The results from the scoring of clamping concepts can be seen in Table 9.4 and with further details in Appendix I. There were great environmental benefits of clamping.

Mass production seemed fairly easy, as well as implementation and degrees of alignment. However, due to concerns regarding both the quality of the fix and how it would affect the alignment, all concepts received fairly low scoring in these categories. Because of this, none of the clamping concepts were further evaluated.

9.3 Reflection upon the Results

To summarize, the highest scoring concepts that were further evaluated were *Wall & Gasket, PCB-connector, Glue-module* and *Ring*. These moved on for further evaluation. Concerning the *Ring* concept, the most preferable method of melting the ring was also further evaluated.

A screw or a clamping solution could pose great advantages if further developed, but the risk of failure was considered too high. Thus these concepts did no proceed for further development. An overview of the highest scoring concepts can be seen in Table 9.5.

Table 9.5 Concepts with the highest scoring. Concepts for further development are marked gray.

Concepts	**Total score**
Wall + Control Adhesive	3,48
Control Adhesive	3,45
Ring	3,45
PCB-connector	3,28
Glue Module	3,23
Mirrors	3,05
Redirect Light	3,05
Ball	3,05
Spider	3,03
Wall	3,00

10 Evaluation of Concepts

In this chapter the concepts that were chosen during the Concept Scoring: Glue Module, PCB-connector, Wall & gasket and Ring, will be further described and evaluated. Further examinations of their corresponding fixing methods will also be presented. Both possibilities and possible problems will be discussed.

10.1 Evaluation of the Adhesive Concepts

The method of fixing an aligned PCB card with an UV curing adhesive is well known and documented at Axis. Therefore the focus of these concepts could be more upon the details of the solutions and less upon the chosen fixing method.

The methodology of evaluating the different concepts and fixing methods were primarily performed through discussions within the development team and by consulting experts. Some simpler tests were also performed.

10.1.1 Glue Module

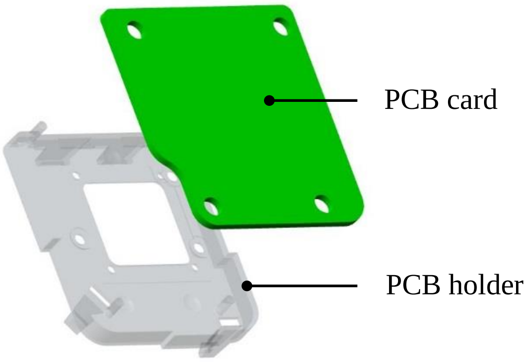


Figure 10.1 An illustration of the *Glue Module* concept. The transparent part is the PCB holder, with UV light penetrable properties, and the darker part is the PCB card.

The *Glue Module* concept required two separate bonding processes. The first bond between the transparent plastic part, the *Glue module,* and the PCB card should be performed by using adhesives, due to its ability to handle large different possible positions of the bond. This bond would be fixed after the alignment process. The great advantage of this adhesive bond was that its design could be fairly arbitrary, as UV light would shine from two different directions. This would require increasing the amount of UV light sources, or possibly illuminating one side at a time, i.e. increasing the total illumination time. Despite this, after further investigations the most suitable design of the bond was still considered to be some pin/hole design or walls around the PCB card, with transparent plastic parts. The main reason for this had to do with the limited amount of opportunity in designing the joint on the PCB card.

After this first bond had been made, the second bond between the *Glue Module* and the lens package would have had a small to none tolerance diversion. Then other bonds such as screws could possibly be utilized, with advantages described earlier such as disassembly, easy of handling etc. However, there were concerns whether this second bond would be sufficiently accurate to guarantee that the alignment was preserved. Though, this process would be fairly similar to the current passive alignment process and therefore it was assumed possible.

For the adhesive bonding, it would be preferable with transparent plastic sections at the joints. Thus, the *Glue Module* could be made in an entirely transparent material, such as Polymethyl methacrylate, or PMMA. Though, it is not recommended to screw in PMMA due to the risk of cracking, which limited the second attachment of the *Glue Module* to the lens package [30]. To solve this problem, it could be possible to produce a double molded part, similar to the current design. Another material that could be a more suitable option was transparent Polycarbonate, or PC. This material has less risk of cracking and it is possible to screw through this material. However, its transparence properties are slightly worse than those of PMMA.

Despite the fact that *Glue Module* solves the problem with uncured adhesive, its design was not optimized but rather based on the current designs. It was concluded that a more optimal design would not need illumination from two sides. Hence, this concept was not further evaluated.

10.1.2 PCB-connector

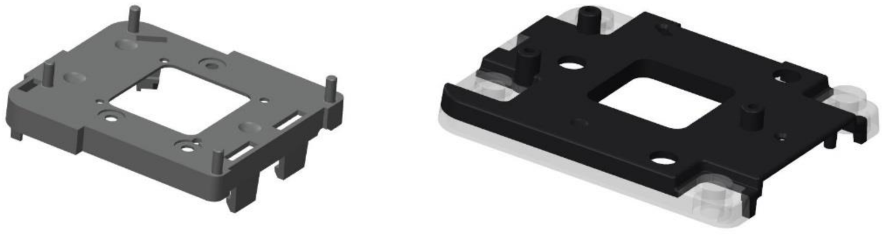


Figure 10.2 Parts from an already existing product within Axis, which illustrates the idea behind the PCB-connector.

The inspiration of the *PCB-connector* came from Axis’s own design solution seen in Figure 10.2. Similarly to the *Glue Module*, the design of this concept could be made fairly arbitrary. The adhesive joints of the *PCB-connector* could be further optimized as both the PCB holder and the double molded plastic part had designing opportunities. However, the main concern during these design iterations was space conservation.

The designs evaluated had one male connecter and one female connector, similar to a *Pin/hole* (male/female). The male/female connectors could either be placed on the PCB holder or the plastic mold. Different concepts were developed for both configurations.

One aspect of the *PCB-connector* was to focus upon the bond of the connector and the PCB card. Either a whole part, as the plastic mold, or certain components could be attached. These components would have to endure some fixing process, when attached to the PCB card, preferably screws or soldering combined with the attachment of the electrical components of the PCB card. The material of these connectors could either be some transparent material, which would allow easier joint designs, or some opaque material used in conjunction with an appropriate angle of the UV light guides.

However, it was found that this concept heavily relied on some transparent plastic to enable a fully cured adhesive bond. This would most likely have to be dual-molded with PC and PMMA, or just transparent PC, to ensure a simple attachment to the PCB card. However, in some projects plastic manufacturers cannot produce a dually molded plastic holder [31]. Furthermore, a transparent PC part could pose problems with thermal expansion, as the fiber glass enforcements that are otherwise used to minimize this expansion, prevents the transparent properties.

The different designs of the *PCB-connector* solved the problems with shadowed areas, guaranteeing fully cured adhesive joints. They could also fairly easily be assembled in production and the risk of further evaluating these designs were seen as low. Though, the concept was limited to larger assemblies. On many of the smaller PCB cards, it would be difficult to design the adhesive joints, fitting the *PCB-connector* into the assemblies. Thus, this concept was not further evaluated.

10.1.3 Wall & Gasket

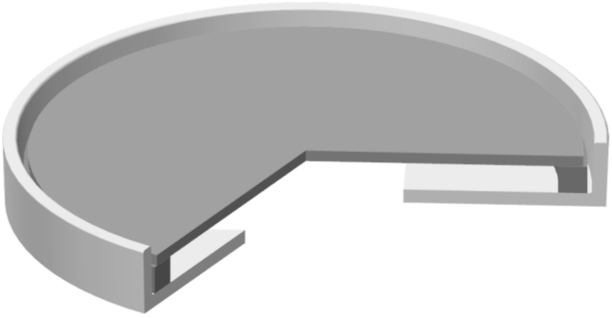


Figure 10.3 Illustration of the *Wall & Gasket* concept, where a section has been cut out to further illustrate the assembly.

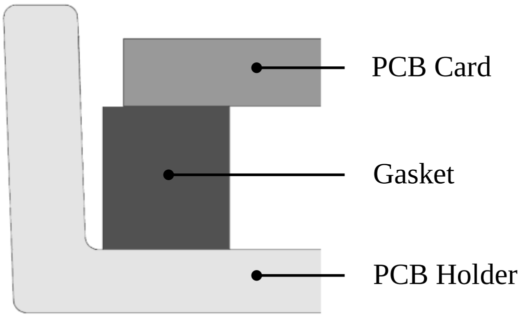


Figure 10.4 Cross section of the *Wall & Gasket* concept.

As earlier mentioned, one of the drawbacks with the first wall concept was that there was no designated area to dispense and control adhesive. The adhesive could therefore end up in shadowed areas. With a gasket placed between the PCB card and the plastic wall, these two issues could be solved. A basic illustration of the *Wall & Gasket* design can be seen in Figure 10.3 and Figure 10.4.

Additionally, this design enabled the performance of simple tests. In this way, the advantages of this design could be thoroughly evaluated and possible problems identified.

This concept was very general and could possibly be implemented on most cameras. Its greatest advantages were seen in the smaller camera assemblies, as the solution would be fairly space conserving. The main concern of the *Wall & Gasket* concept was to find an appropriate material for the gasket, which would allow full movement during the alignment. Though, as gaskets already existed within all Axis cameras, this was a minor concern. Hence, this concept was further evaluated.

10.2 Evaluation of the Melting Concept

Using soldering or welding to fixate the PCB card after active alignment was a completely new possible fixing process for Axis's camera assemblies. Therefore, the fixing concept *Ring* was kept fairly simple and the further evaluation of this concept focused upon examining the possibility to use its fixing method after active alignment.

10.2.1 Ring

The conceptual design of the ring concept was very similar to the current adhesive *Pin/hole* design, see Figure 10.5. The main difference was that in order for the *Ring* concept to become a contact free method, the soldering material had to be present already during alignment. As it would be cumbersome to keep the solder liquidized at its melting temperature during the entire alignment process, the solder had to be in its solid state. However, the solid solder still needed to provide sufficient movement for alignment process.

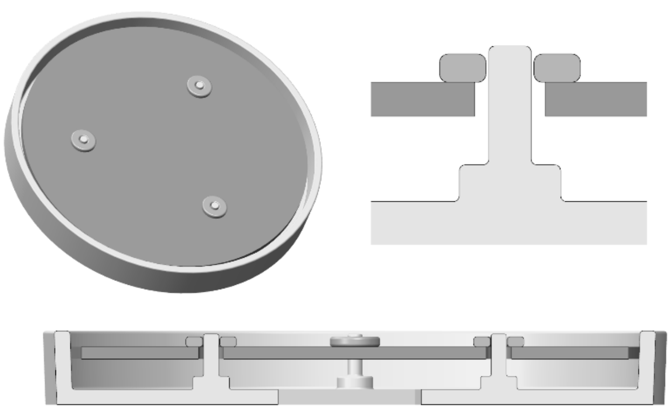


Figure 10.5 Illustration of the ring soldering assembly.

By using a ring that is in close contact with the pin, freely positioned on the surface of the PCB card, alignment in all directions would be possible. The angular alignment could be obtained by having enough room for the ring to angularly move along the pin. After the alignment process, the solder ring would be melted to form a bond between the PCB card and the pin, see Figure 10.6.

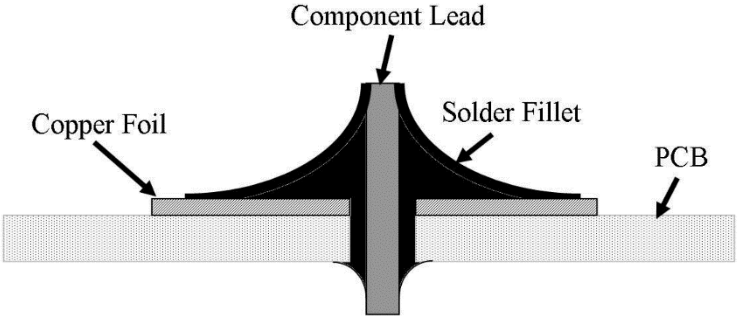


Figure 10.6 Example of Pin/hole soldering with the ring concept.

Solders generally do not wet a PCB coating and thus metal plating is commonly used. In Figure 10.6, a copper foil is used to provide this metal plating. To provide a good wetting between the solder and the pin, the pin would also have to consist of metal or have an outer metal coated layer. Moreover, the pin, the plated area, the surrounding PCB card as well as its components would have to endure the required soldering temperature.

10.2.1.1 Heating Method

A laser source's required output power, when used as a heating method, is directly connected to the required temperature. A higher temperature and thereby output power leads to a higher cost for the laser system [31].

When soldering, a laser source with power ranging from 10-40 W was recommended. The output of the laser sources could be varied to match the required temperature of the solder. When welding, the power required increased dramatically, as the required temperatures were higher. For example, in order to weld two 1 mm thick stainless steel plates, a 1 kW laser was recommended. The price range was approximately 30,000 € for a 50 W laser system and 80,000 € for a 1 kW laser system. This price includes the laser source, a deliver fiber cable and processing optics [31].

An induction heating system would include an inductor used to heat a specific area. The inductor design could be varied to concentrate the generated heat to the pins. By doing this, the risk of damaging components could be minimized. No specific price range was acquired for a customized inductor but with enough time it would be possible to build one [33]. Due to this possibility it was considered significantly cheaper than a laser system.

10.2.1.2 Filler Material

Different filler materials were considered when fixing two components with soldering or welding. The ones which were focused upon were plastics, metals and alloys.

When using melted plastic for welding applications, pressure is required between the parts to be bonded, to ensure that the melted plastics mixes with the parts and forms a good bond [34]. However, finding a design which could provide pressure between the PCB card and pins, while simultaneously allowing full movement of the active alignment, was seen as very difficult and hard to further evaluate.

Soldering with plastics by using hot melts was further examined. It was found that the hot melts had bad thermal properties, mainly regarding large coefficients of thermal expansion. This method and material was therefore not further evaluated.

A wide variety of metals and alloys could be used for both welding soldering. This variation made it possible to match the filler material for the intended application. In addition, the filler materials could come in different forms; paste, solid preform, wire etc.

10.2.1.3 Heat Spread

When considering soldering and welding, the heat spread of the two methods was of great importance. If heat spreads to nearby components it could potentially damage them. To minimize the heat spread, it would be preferable if the heating was local and instantaneous.

With induction heating, the nearby components would most likely also be affected by the induction field and thereby heating them directly. This could however be minimized by shielding the components [33].

Welding required a higher temperature; to minimize the heat spread of this method a laser source would be the most viable heating options. This would provide a rapid local heating. The lower temperature requirements of soldering enable the usage of both laser and induction as a heating method. With induction the temperature would build up during a longer time, leading to more spread heat.

10.2.1.4 Conclusion

Welding would most likely require a laser source in providing the heating. This would be more expensive than laser soldering. The main advantage with welding in comparison to soldering was the increased strength. After simple soldering tests it was concluded that the bond strength of a solder joint would be satisfactory. The increased strength of a weld could therefore not motivate the higher price range for a laser welding system.

When further evaluating soldering, both laser or induction heating seemed like viable options, producing similar bond properties. The drawback with induction soldering was the heat spread. With the option of shielding, this problem was not regarded as crucial. However, due to the simplicity of induction heating, the added cost of a laser system and requirement of guidance system, the most preferable option was considered as induction soldering.

As induction heating is limited to electrically conductive base metals, it could not be used to directly heat plastics [26, chapter 43, p. 40]. One option could be to have a conductive metal core inside a plastic ring. However, due to the bad thermal properties of plastics it was not further evaluated as a filler material. Induction soldering with a metal or alloy solder was therefore the most viable option.

10.3 Summary

A summary of the concept evaluation can be seen in Table 10.1.

Table 10.1 Summary of the concept evaluation.

	Glue Module	**PCB-connector**	**Wall & Gasket**	**Ring**
Continue?	No	No	Yes	Yes

11 Further Development and Concept Testing

In this chapter the concept testing phase of this thesis will be described. This will involve further examination of the concepts chosen in the previous chapter. Detailed solutions of the concepts and their fixing methods will be explained, and their functionality with different modifications is evaluated.

11.1 Testing Methodology

The main part of the testing methodology of this thesis aimed at evaluating the feasibility of the fixing methods and corresponding design solutions with the active alignment process. In order to simplify the tests, it was decided that sufficient representation of the active alignment process could be achieved by simulating its movements manually. Furthermore, as focus was on the feasibility of the concepts, there was no need of testing on an external population.

Hence, the testing methodology of this thesis did diverge from the methodology described by Ulrich and Eppinger, where more focus is upon the customers' opinion [1, p. 145-159]. Though, these steps were still somewhat theoretically included when experts were consulted during the testing phase.

11.2 Specifications of the Required Movement

Initial data regarding the required movement of the PCB card during active alignment for Axis's cameras was achieved by examining distances of the nominal positions in CAD-assemblies for some camera models. The specifications were chosen from the largest model examined, the *Transparent Cups*, as it for many smaller models were smaller distances. Thus, if the final concept could handle these larger movements, it was thought that smaller assemblies with smaller requirements would also manage. The chosen positioning tolerances were measured as the distance between a pin and a cup, seen in Figure 11.1. The angular displacement was left unspecified.

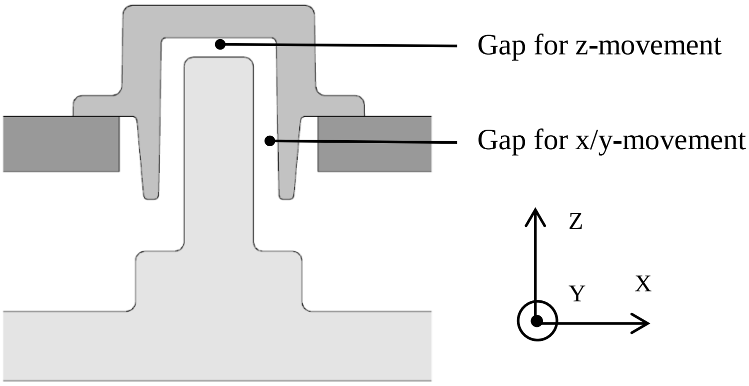


Figure 11.1 Overview of the section where the required movement distances were acquired.

The measured distances before interference between the pin and the transparent cups were:

- 0.5 mm in the x-direction.
- 0.5 mm in the y-direction, (axial symmetry).
- 0.6 mm in the z-direction.
- Additional small angular movement within these distances.

These distances therefore represented the maximal movement between the pins of the PCB holder and the transparent cups, before interference occurred; measured from every parts nominal position. Hence, the required movement of the PCB card was in both positive and negative direction regarding these x/y- and z-directions. Thus the total movement required from a nominal position was set as:

- +/- 0.5 mm in the x/y-direction.
- +/- 0.6 mm in the z-direction.
- Additional small angular movement within these distances.

11.3 Wall & Gasket

In order to test the *Wall & Gasket* concept in a more realistic configuration, with Polypropylene plastic as material, two different Axis camera solutions were selected. The *Transparent cup* design was the first to be selected, mainly because of the shape of the PCB-holder already containing a wall-like structure. This enabled fast testing by just ordering slightly larger PCB cards and custom made gaskets. The large size of its PCB card was also one reason, with easier handling and rate of success. However, in contrast to this, one of the smallest PCB card assemblies (roughly the design of *Metal holder*) was also chosen. With a lathing operation, the same wall-like structure could be quickly achieved in this PCB holder. Thus, if the testing was successful on both these sizes, the PCB card assemblies with sizes in between were considered as manageable.

11.3.1 Design, Distances, Tolerances

The distance between the PCB card and the wall had to be large enough to enable movement in the x/y-direction, see Figure 11.2. Though, the larger the distance, the more adhesive would be needed to form the bond. By simple testing it was found that a longer joint with more adhesive seemed to provide a weaker bond than a shorter joint with less adhesive.

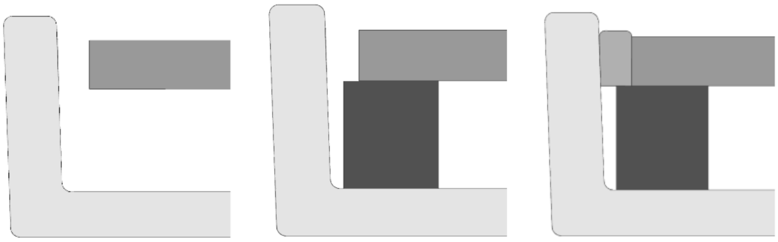


Figure 11.2 Basic design with gasket and dispensed adhesive.

11.3.2 Gasket

11.3.2.1 Shore Hardness

The hardness of a gasket is generally measured by its shore hardness. There are several different scales of shore hardness, but the most widely used in gasket references is the Shore A scale. The Shore A scale goes from 0 to 100 and covers very soft rubber to plastics [35]. Some examples of different shore hardness's of different products can be seen in Figure 11.3.

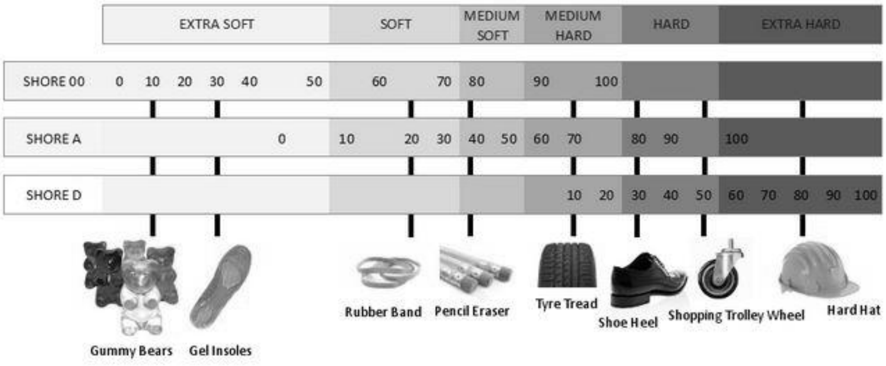


Figure 11.3 Different shore hardness scales and product examples.

11.3.2.2 Material

There are a vast number of different gasket materials. However, many of these do not comply with the desired behavior of the *Wall & Gasket* concept. They could also cause problems in a camera assemblies due to outgassing, particle dust etc. In order to narrow down the possible choices and limiting the amount of required testing, i.e. maximizing the chances of success, the materials examined were those that are already present in Axis’s camera assemblies. These materials are *Poron* and *silicone.*

11.3.2.2.1 Poron

Poron, seen in Figure 11.4, is a common material used for gaskets and sealing electronics. For optical assemblies, Poron possesses very good features, such as low outgassing and low required compression force. The material will not become brittle and crumble to particles leading to dust contamination [36]. Manufacturing methods of Poron include die-cutting, water jet cutting and laser cutting among others.

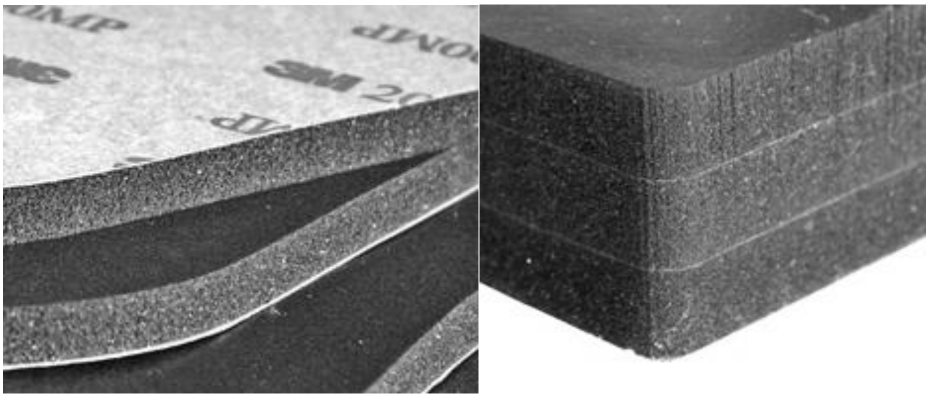


Figure 11.4 A Poron gasket material.

With the assumption of mass production in mind, die-cutting was seen the most viable option. This has the drawback of only being able to produce simple parts where the 2D cross-section consists of straight lines [37].

11.3.2.2.2 Silicone

Silicone has great properties regarding the application at hand. In general it can handle operating temperature range from -50 °C to + 220 °C and a wide range of shore A hardness between 3-90. It can be produced in a variety of colors, or left transparent [38, p. 17]. Examples of silicone gaskets can be seen in Figure 11.5.

Figure 11.5 Examples of silicone gaskets.

Silicone comes in two different forms: *solid silicone rubber* (SSR) and *liquid silicone rubber* (LSR). SSR consists of higher molecular weight than LSR and comes premixed when imported from supplier. LSR, on the other hand, consists of two different components when attained [38, p. 9]. Due to this higher molecular weight, SSR is generally slightly harder than LSR.

There are many different processing techniques for making the raw silicone into desired shapes, for example extrusion, injection molding and low-pressure filling [38, p. 40]. However, within Axis, the process technique used is compression molding, see Figure 11.6. Though, this technique is only compatible with SSR. Hence, this will be examined instead of LSR.

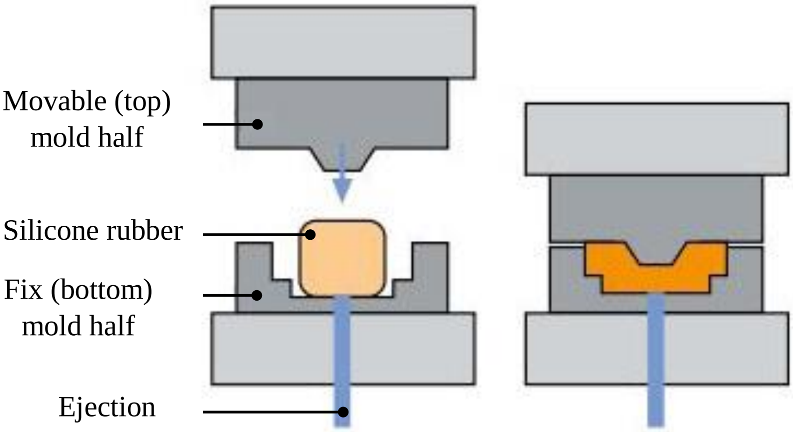


Figure 11.6 Illustration of compression molding.

11.3.3 Further Development of the Design

11.3.3.1 Adhesive under the PCB Card or Gasket While Aligning In the x/y-direction

Because the adhesive is dispensed manually, before the active alignment, the adhesive wets the surfaces' where it has been in contact. If a gasket was to move along a surface already wetted by adhesive, the adhesive would end up underneath the gasket. Same reasoning applies for moving the PCB along a wetted gasket surface. Two possible solutions to this problem were examined:

- Using adhesive tape on both sides of the gasket, preventing the adhesive from finding its way between these surfaces, see Figure 11.7. This was assumed possible, mainly regarding outgassing properties, as adhesive tape is used in some of Axis's camera assemblies. The difficulties with this approach were fitting the gasket into a hole with very small tolerances. During this process, the adhesive tape might easily get stuck onto the walls. Another problem with this approach was that the gasket would create its own shadow. As the top and bottom surface of the gasket would be fixed, but still in need of x- and y-alignment, the gasket became angled at the ends, producing its own shadow zones.

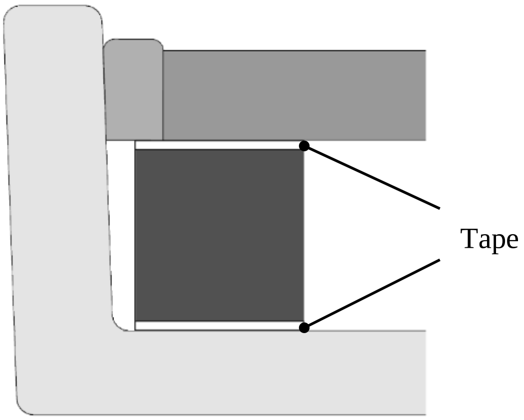


Figure 11.7 Basic gasket design with adhesive and tape.

- Adhesive dispensing after alignment. The difficulties with this approach were that the dispensing has to be done with automation due to the interference with the IBAS system. As earlier mentioned, the smallest external force interacting with IBAS if done manually will interrupt the alignment. As this violated the assumption made at the initial stage of the project, this approach was not further examined.

11.3.3.2 Glue between Gasket and Wall

As the gasket had to be flexible, there might be adhesive coming into the area between the gasket and the wall. An example of this can be seen in Figure 11.8, where the perpendicular angle versus the draft angle of the PCB-holder/walls leaved a compartment where the adhesive was compressed into. This hypothetical area, where the adhesive might end up after alignment, has been illustrated as a striped area. The concern was not that this area would be filled with adhesive but rather it containing a film or drop of adhesive. If the gasket later closed this gap due to compression forces, this would entrap uncured adhesive.

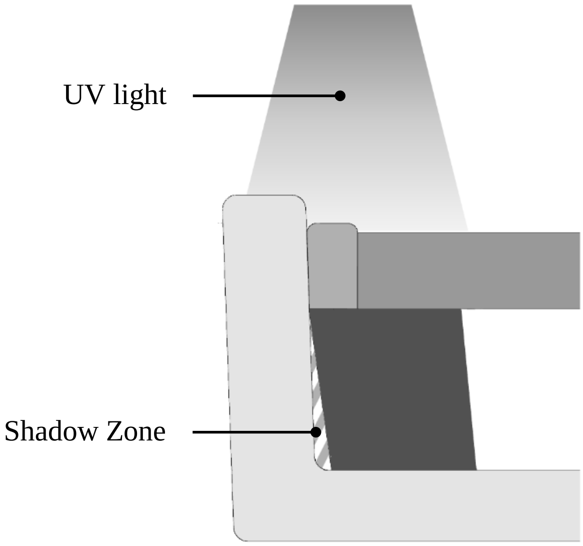


Figure 11.8 Illustration of adhesive trapped in a shadow zone seen as a striped area.

To solve this problem a couple concepts were developed. The goal was to guarantee a fully cured adhesive. The concepts were categorized as *Transparent wall, Angled wall*, *Transparent gasket* and *Angled gasket.*

11.3.3.2.1 Transparent Wall

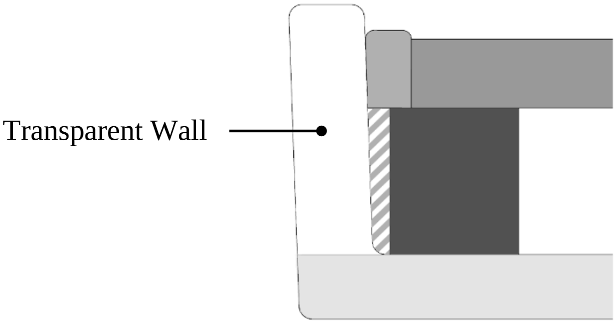


Figure 11.9 Illustration of the transparent wall design.

With a transparent wall, UV light from the side could reach trapped adhesive and thereby curing it, see Figure 11.9. The plastic holder could be fully made from a transparent material or it could be dually molded; only having transparent areas at the adhesive joint. With this design a gasket made of either Poron or silicone could be used. The discussions about these material choices follow the discussions of the *PCB-connector* in section 10.1.2 PCB-connector.

This design was evaluated by continuing the discussions with projects that already tried similar ideas in different applications before.

11.3.3.2.2 Angled Wall

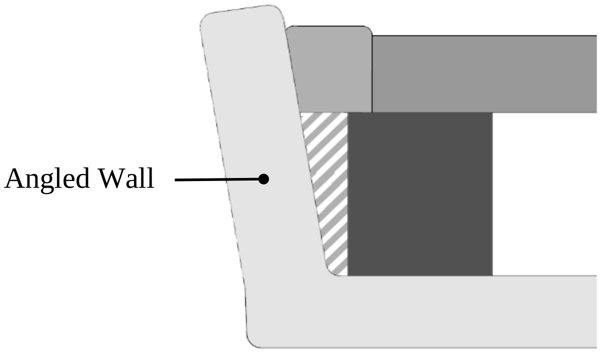


Figure 11.10 Illustration of the angled wall design.

The concerns about the *Angled wall* were that after alignment, the gasket would be at an angled position and thereby shadowing adhesive. With a sufficiently big angle, i.e. bigger than the maximum angle of the gasket, there would always be space for the UV light to reach adhesive, if light guides were set an appropriate angle, see Figure 11.10. A drawback with this design was that it would require a higher amount of adhesive and a larger adhesive joint.

Prototypes were made to evaluate the design. The goal was to test the general impression of the design, as well as the adhesive joint. The prototype was made from aluminum see Figure 11.11. Since the goal was to test the general impression of design instead of joint strength, the material choice was no concern.

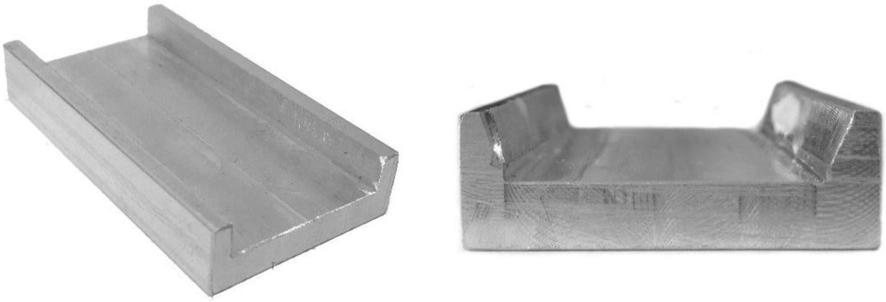


Figure 11.11 Aluminum prototype of the angled wall concept.

11.3.3.2.3 Transparent Gasket

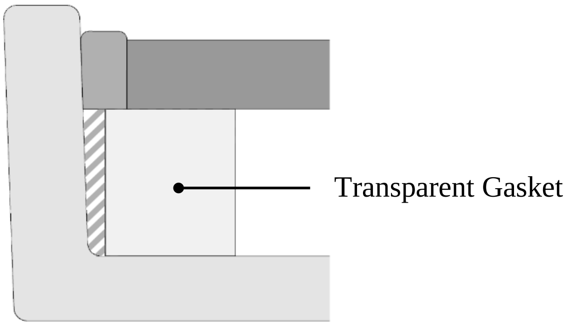


Figure 11.12 Illustration of the transparent gasket design.

With a transparent gasket UV light would be transmitted through the gasket and cure adhesive trapped between the wall and the gasket, see Figure 11.12. Poron is an opaque material, which limited the gasket material to transparent silicone, seen in Figure 11.13. Many silicones are made UV-resistant; meaning that they will not be yellowed by UV light. This is often achieved by having a high UV transmittance.

Figure 11.13 Example of a transparent silicone gasket.

The design of the *Transparent Gasket* was evaluated by investigating UV transmittance for silicone. In Figure 11.14 the transmittance for different silicone gaskets can be seen by the blue lines. The others represent silicone with coloring additives, but as high transmittance was necessary, these were not examined and are left without labels. The two silicones without additives have a transmittance of 60% at the curing wavelength 365 nm, which is the wavelength used at Axis EMS sites.

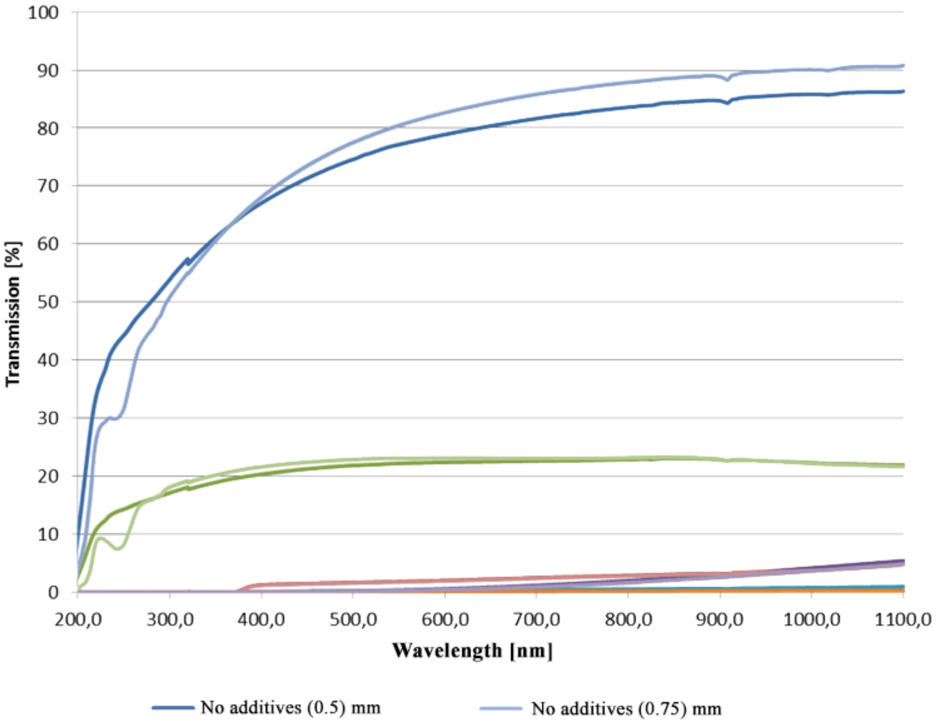


Figure 11.14 Transmittance for silicone with or without fillers. The blue lines represent silicone without additives, for coloring etc.

Tests were also performed with a couple typical transparent silicones, obtained from one of Axis distributors. A silicone sheet was placed between adhesive and a UV light guide. The adhesive was easily cured, even though a sheet of 4 mm thickness was obstructing the adhesive.

11.3.3.2.4 Angled Gasket

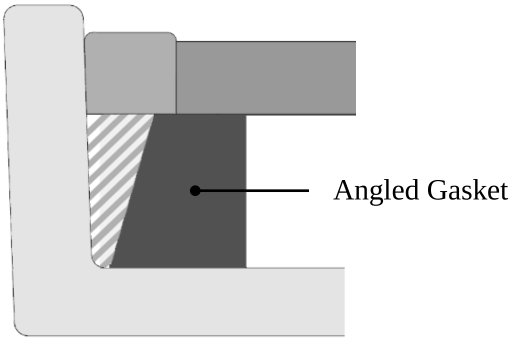


Figure 11.15 Illustration of the angled gasket design

A gasket with an angle would not cause any shadow zones after alignment, if this angle matched the maximum angle of the alignment, see Figure 11.15. For this application, only silicone could be used since Poron needs 2D cross sections with vertical cuts to enable mass production through die-cutting. Tests of this concept were performed using a specially cut Poron gasket. Here the goal was to test the general impression of the concept and confirm the behavior of an angled gasket.

11.4 Ring

11.4.1 Design, Distances, Tolerances

As the similarities with the *Pin/hole* concept were evident, the same tolerances and distances could be transferred to this concept. Thus the total movement required from a nominal position was set as:

- +/- 0.5 mm in the x/y-direction.
- +/- 0.6 mm in the z-direction.
- Additional small angular movement within these distances.

What these tolerances refer to can be seen in Figure 11.16.

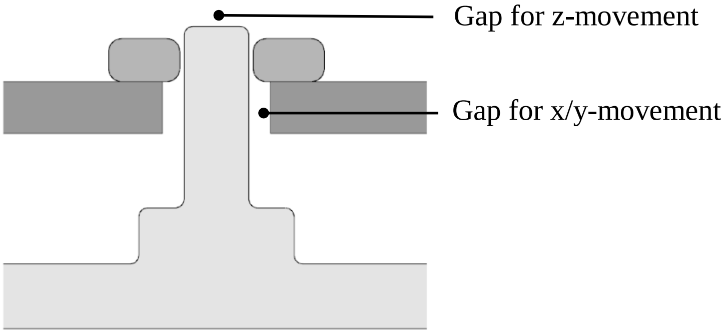


Figure 11.16 Cross section view of pin, hole and solder ring.

11.4.2 Further Development of the Design

Unknown factors that could be fatal for the success of this concept, such as solidification shrinkage, heat distribution etc., could mainly be examined by discussions with experts and further information gathering, due to both time and financial limitations.

11.4.2.1.1 Solder Placement

The solder ring would be required to stay in place during the active alignment procedure. Three possible solutions to this were examined:

- By changing the IBAS system from a horizontal to a vertical set-up the solder ring would be kept in place by gravity. This design change would be possible for newer versions of the IBAS system [39]. Gravity would allow the solder ring to follow the movement of the PCB card when aligning.

- Another possibility was to pre-attach the solder ring to the PCB card, when the electrical components were attached. This would require a bigger x/y-movement gap between pin and ring as the ring would not be able to move. The solder ring would require a higher melting temperature than that of the solder used to attach the components to the PCB card.

- By using a solder paste instead of a solid preform, the paste could be dispensed before the active alignment process. In resemblance to an adhesive, the paste would maintain contact between PCB card and pin while enabling full movement from active alignment.

11.4.2.2 Inductor Design

The inductor system design is crucial to minimize the heat spread and thereby the risk of damaging components. Two main designs were under consideration: a system consisting of one inductor per pin and a continuous inductor system, see Figure 11.17. A continuous inductor would cover more area and thereby affecting more components. Thus, a system consisting of one inductor per pin was presumably most applicable.

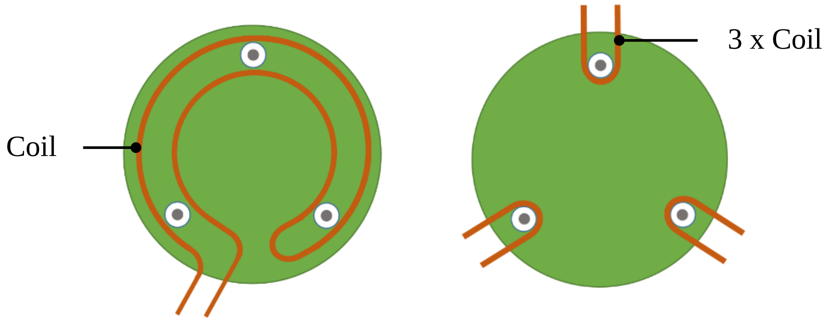


Figure 11.17 Illustration of different inductor designs seen from above: a) continuous inductor b) one inductor per pin.

11.4.2.3 Oxidization & Flux

Wetting of solder materials differs with a varying degree of oxidization, since this act as a coating. The oxidization prevents a good wetting between solder and the oxidized material, in this case the plating and the pin. If oxidization would be a problem and how it could be solved was therefore examined.

To remove the oxidation, a cleaning agent called flux is used. For the intended application flux can however be a problem. The temperature needs to be controlled to ensure that the right amount of heat is induced since excessive heat would cause the flux to sputter. Too little heat will on the other hand not melt the solder material [40, p. 3]. Flux on the PCB card backside needs to be removed. The flux's sticky nature attracts dirt which can cause short-circuiting. This does not necessarily occur immediately but rather weeks or even years afterwards, when a sufficient amount of dirt has been built up. To remove the remaining flux, alcohol is used. The cleaning process is time-consuming and a flux solution thus seemed non-viable for the application [40, p. 12].

Due to the drawbacks with flux, alternative methods were investigated. The first step towards successfully creating a fluxless solder joint is to eliminate all surface contamination, such as oxides, and protect the surface from oxidization through the heating cycle. Such methods generally include non-oxidizable coatings of the components to join. In practice, only gold or platinum can provide sufficiently clean and solderable surfaces. The solderable shelf life provided by gold coatings is dependent on the surface roughness, the coating thickness and the coating application method. If a technique called sputtering is used, a 0.5 µm thick gold layer can maintain an excellent solderability for several months. While electron plating with the same gold layer thickness only protects for a couple of days. Gold-coated surfaces also constraint the types of solder material that can be used. Tin-based solders require a thin gold coating; else the tin will dissolve in the gold and form a brittle bond. If thicker gold coating is used either high gold percentage solders or indium-base solders needs to be used [41, p. 35-36].

Another alternative is to use flux coated preforms. This eliminates the need of manual fluxing and eliminates excessive flux residue [42].

11.4.2.4 Soldering Material

Different solder materials were evaluated for implementation in a fluxless soldering process. In addition to using several different solders with the possibility of flux coated preforms, alternative solders which would not require a flux coating were evaluated. Additionally the most optimal solder with regards to low movement was investigated.

The most commonly used base solder is tin. When a tin-based solder is used in combination with gold coated plating either the coating had to be thin or the solder have a high gold percentage. Tin solder should have sufficient strength and have reasonably good thermal properties, such as low melting point, shrinkage and thermal expansion. Similar properties could be gained from an indium-based solder.

When prioritizing minimal movement of the solder, both during the joining process and afterwards solder manufacturers recommended Bismuth 48/52 [43]. This solder consists of 48 % bismuth and 52 % tin and has very good thermal properties. Bismuth containing solders generally wet and spread less well on gold coated surfaces than tin-lead alloys.

11.4.2.5 Bond Strength

In most literature, soldering is regarded as a bad method of mechanically bonding parts [26, chapter 43 p. 39]. This was regarded as statements referring to more rigid mechanical joints. The mechanical joints regarded in this project, should endure some forces, but perhaps of magnitudes within the range of soldering as the bonding method.

Thus, to get an indication of how mechanically stable a solder joint was in this application, a simplified pin fix was tested. The pin from a resistor was joined with a plated area. To break the joint, a significant force was needed. Hence, the mechanical properties of soldering as a fixing process were no longer seen as a concern.

11.4.2.6 Shrinkage

Soldering is a commonly used method for attaching components to a PCB cards but introducing it as a fix method after active alignment results in a range of new difficulties. One major uncertainty with soldering is how the filler material behaves when melting and solidifying again. If the shrinkage is too high or introduces stress on the PCB card it could lead to an unaligned card.

11.4.2.6.1 Solidification Shrinkage

Solidification shrinkage is the shrinkage that appears when the solder material makes a phase transformation from liquid to solid. An illustration of this can be seen in Figure 11.18.

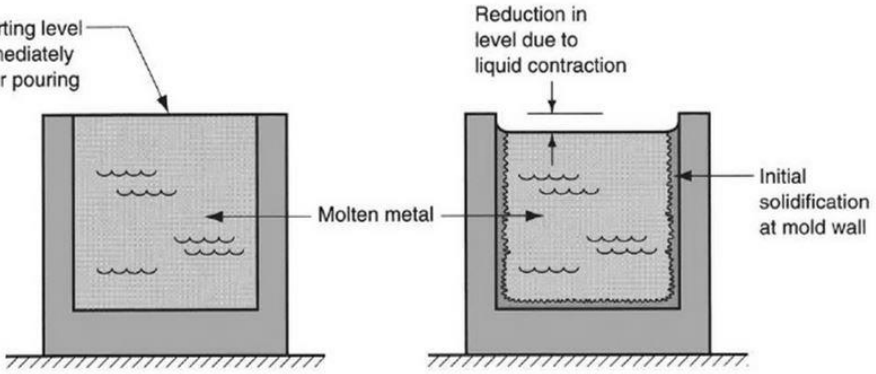


Figure 11.18 Illustration of solidification shrinkage.

For the tin solder it could be reasonable to assume solidification shrinkage of 2.1- 4 % [45, p. 218], [46, p. 107]. For the Bismuth 48/52, the solidification shrinkage is only 0.77 % [47, p. 1019].

This is roughly the same values as the curing shrinkage of *UV & heat 2* that are used as an adhesive today [48]. Hence, it was assumed that this shrinkage would be in the range of acceptable values. It might also be possible to find solders with even less solidification shrinkage, minimizing this problem even further.

11.4.2.6.2 Thermal Contraction

The secondary shrinkage that needed to be considered was the thermal contraction of the solder when cooling down to room temperature, after the phase change from liquid to solid, see Figure 11.19.

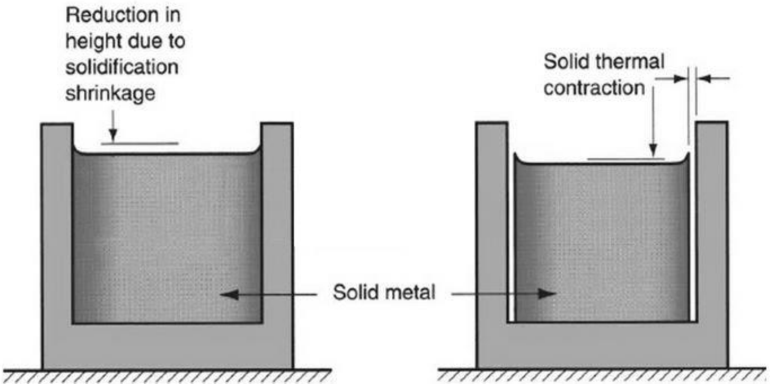


Figure 11.19 Illustration of thermal contraction.

This contraction is often approximated, with varying accuracy, by its linear coefficient of thermal expansion. The linear expansion is given by

$$\frac{\Delta L}{L} = \alpha \, \Delta T$$

where α is the thermal expansion, ΔT the change in temperature, L is the start length and ΔL the change in length. This will give the percentile change in length as a result of a changing temperature.

If an example similar to the previous is adapted with tin solder, the linear coefficient of thermal expansion is $\alpha = 23.8 \cdot 10^{-6}/°C$ and the melting point is at 232 °C [49]. With a room temperature reference at 23 °C, the thermal shrinkage becomes

$$23.8 \cdot 10^{-6} \cdot (232\text{-}23) \approx 0.05\ \%$$

If Bismuth 48/52 is used in the same example it has a melting point of 138 °C, and a linear coefficient of thermal expansion of $13.8 \cdot 10^{-6}/°C$ [50], [51]. With a room temperature reference at 23 °C, the thermal shrinkage becomes

$$23.8 \cdot 10^{-6} \cdot (138\text{-}23) \approx 0.016\ \%$$

11.4.2.7 Outgassing

The fixing process is done right after IBAS, which is placed in a clean room. Due to this, the method needs to be clean. There is a risk that soldering will produce particles or outgassing problems. One way of solving this is to have a fume extractor activated while the soldering process is ongoing.

12 Final Specification

In this chapter the selection of the final concept, along with its final specifications, is presented. First, the two concepts, Wall & Gasket and Ring, are compared and evaluated. This is followed by examination, testing and evaluations of the details around the selected concept, regarding the choices of material and possible design solutions. Finally, more realistic distances of the required movement during the active alignment process is presented.

12.1 Selection of Final Concept - Walls vs Ring

The adhesive concept *Wall & Gasket* was chosen over the soldering concept *Ring* for further development. This was motivated by the many uncertainties of the soldering process after active alignment, which would require more advanced testing. Furthermore, while roughly the same amount of time had been spent on developing these two concepts, the possibility of using soldering as a method of fixing after active alignment required extensive research. This left less time for the refinement of the design of the *Ring* concept. Regarding the *Wall & Gasket*, some research around appropriate gaskets was required, though far more time could be spent on refining the conceptual design. Hence, when comparing the two concepts, there were far greater chances of success associated with further development of the *Wall & Gasket* concept.

12.2 Evaluation of Gasket Material

As previously stated, the softest material of a SSR silicone that was found, from one of Axis's known distributors, had a shore A hardness of 10. However, by some simple testing, it was assumed that shore A 10 would still be too hard for a completely solid geometry. When deforming the gasket during active alignment a solid geometry could result in a too great force against the PCB card. A large force could both lead to bending forces on the PCB card and possibly creeping forces after the adhesive has cured; as the compressed gasket wants to return to its original shape.

Due to this, investigations led to further concept generations around more complex deformable geometries of the silicone. The idea was to construct a geometry with controllable deformation structure. With silicone, fairly complex geometries could be compression molded, including undercuts etc., without any larger costs. The compression tool only has to be produced once, and then the cost per manufactured part would not differ with complexity.

For simple applications a Poron gasket could be used. One advantage of this material is that it could be made considerable softer than silicone. The movement from active alignment could be fully achieved by deforming a solid Poron gasket due to its soft properties.

Moreover, the gasket material choice is highly dependent on the gasket's design and was evaluated further with the design concepts. An overview of material choices for the different designs can be seen in Table 12.1.

Table 12.1 Overview design and gasket selection.

	Transparent Wall	Dually Molded Wall	Angled Wall	Transparent Gasket	Angled Gasket
Silicone	Yes	Yes	Yes	Yes	Yes
Poron	Yes	Yes	Yes	No	No

12.3 Selection of Design

A fully transparent wall in PC with a gasket of silicone or Poron would most likely provide a shadow free design. But since some uncertainties existed regarding strength and rigidness it is not viable to fully rely on this concept. Some projects at Axis have very low tolerances in regards to thermal expansion. A transparent PC holder would have more movement than the current designs. For designs which do not require a very low thermal expansion the concept might still be viable.

A dually molded transparent wall with either a Poron or silicone gasket would most likely also ensure a shadow free design as well providing a fully cured bond. But since newer project have had problems finding a manufacturer able to produce dual molded plastic it was not feasible to fully rely on this concept. Therefore it was kept as a design choice if the opportunity with a dually molded plastic holder is possible.

Furthermore, some Axis projects requires a metal PCB holder instead of plastic to further reduce the heat sensitivity by thermal expansion. For these projects it is not possible to have a transparent wall.

With the angled wall design it seems possible that a sufficiently angled wall would theoretically prevent shadow zones. But this would be at the cost of a big adhesive joint. The general impression with an angled wall after the test with prototypes was that the adhesive joint was too big. If a non-transparent gasket is used the adhesive might still end up in shadow zones caused by the gasket. Another aspect is that the adhesive joint will shift while aligning in z-direction. This was not a big concern but there might be problems with finding the right design which allows alignment in x/y-direction, z-direction and which does not cause shadow zones. The conclusion was that the design still had uncertainties regarding a fully cured bond and was therefore not further evaluated.

With an angled gasket, silicone is the only choice of material. To enable full alignment movement a deformation structure would have to be used, as mentioned previously. To ensure a fully cured bond transparent silicone is the most viable option since it could cure adhesive where an opaque gasket would otherwise shadow. The concept would thus be very similar to the *transparent gasket* design. To be limited an angled designed is therefore not a viable option. The main focus for further development will be a transparent gasket with a deformation structure which enables the full movement of alignment.

12.4 Development of Selected Design

The focus of the final design was a general solution which could be implemented in a multitude of different projects and camera designs. With this in mind a simple design was prioritized over more advanced which might have more uncertainties.

After discussions, simple adhesive tests and some design iteration, a couple of goals with the proposed design and gasket were developed:

- Deformable in x/y- and z-direction
- Rigid and retains its shape
- Easy to assemble to PCB card and plastic holder
- Not use excessive amount adhesive
- Intuitive area for adhesive dispensing

In an attempt to meet these demands, different deformation structures combined with different shore hardness's were tested by using 3D-printed prototypes. The material used was chosen to mimic the properties of silicone.

12.4.1 Deformation Structure

The force which the gasket affects the PCB card with cannot be too high. A guideline when designing sensor gaskets is 5 N in its nominal position. [52] The aim of the final gasket design was thus to not exceed this value in its nominal position.

With a minimum tolerance gap between the wall and gasket of 0.4 mm the x/y-alignment of 0.5 mm was almost fulfilled. If the gasket is assembled wrong there would still be a gap left allowing some deformation. Additionally, the silicone gasket would also allow some deformation by itself. The x/y-alignment was therefore assumed to be fulfilled regardless of deformation structure. Furthermore, a softer gasket material would allow more deformation by itself.

Therefore, the deformation structure focused on the deformation in z-direction. A number of different design ideas were evaluated. In Figure 12.1 are three designs which categorize many of the others:

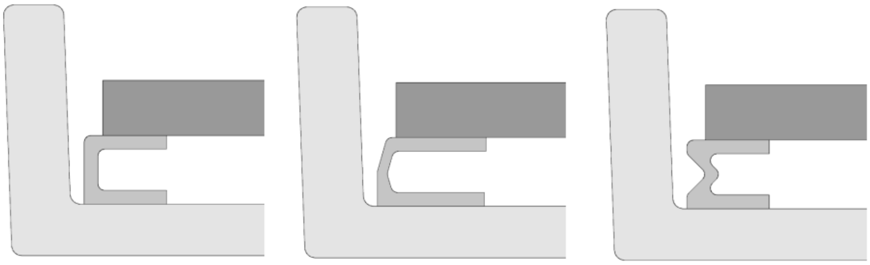


Figure 12.1 Different designs for a deformable structure, from the left a) square, b) iron, c) bellow.

a) **Square -** This was the most basic design, derived from a completely solid gasket profile with a deformable core structure, seen in Figure 12.1a). The design was very simple and provided a sharp edge on which the adhesive could be dispensed.

b) **Iron -** With the deformation indicators as seen in Figure 12.1b), along with a more rounded structure, the deformation of the gasket would probably be more uniform. The ledge seen in Figure 12.1a) was removed to minimize the material between PCB card and wall during compression of the gasket.

c) **Bellow -** Larger and symmetrically placed deformation indicators are used in Figure 12.1c), to provide an even more uniformly deformable structure.

One concern with the *squared* design was that the gasket could be too stiff in the solid part, compared to the rest of the structure. This part could therefore end up between the PCB card and the wall when the gasket is compressed and thereby minimizing the adhesive joint.

An attempt to solve this was tested with the *iron* design. This would however result in a more diffuse dispensing area. There was also a larger risk that the adhesive needle could be pressed down the wedge-formed path to the bottom of the PCB holder.

With the *bellow* design an even more deformable structure was acquired. But there could be a problem if the adhesive ends up within the bellowed structure, as this could end up in a shadow zone of the PCB card.

Although there seemed to be lots of designing opportunities within this area, the small changes almost disappeared when the proper size of the designs are evaluated. During testing, it was seen that the ledge of Figure 12.1a) was enough to prevent the dispensing needle to reach the gap between the gasket and the wall of the PCB holder. Hence, the most basic design, Figure 12.1a), was selected.

12.4.2 Rigid Shape

With an increasingly deformable structure, the rigidness of the gasket was compromised. An example of this was that with earlier iterations the gasket lacked stability and the top part would collapse. This is not preferable, as the gasket would become more vulnerable, harder to handle in production and would also have negative effects on the quality impression. So, different design ideas, in combination with the deformable structure to improve the rigidness, were subjectively evaluated.

In all categories, the idea was to add material at certain places to stiffen the structure. However, the distance between the PCB card and the bottom of the PCB holder is limited. A number of different design ideas were evaluated. In Figure 12.2 are three ideas which categorize many of the others:

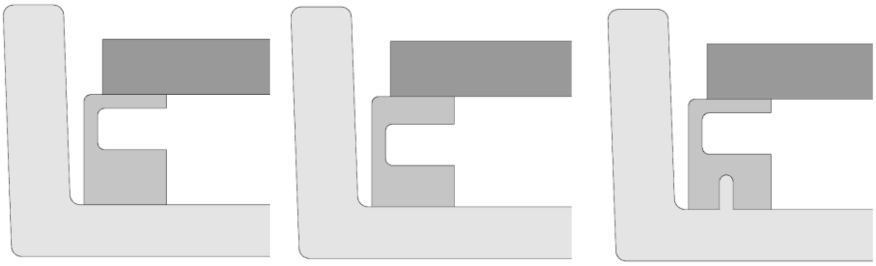


Figure 12.2 Different designs for a rigid structure, from the left a) base, b) up & down, c) trail.

a) **Base -** A solid base platform would become the rigid part of the gasket, as seen in Figure 12.2a). This platform would also make assembling easier.

b) **Up & down -** Both a solid base platform and a solid upper platform forms the rigid part of the gasket, see Figure 12.2b). The thickness of these platforms becomes thinner than the thickness of the base platform in Figure 12.2a), so that the total height is preserved.

c) **Trail -** An inner wall on the PCB holder on which the gasket could be placed would enhance the rigidness of the gasket, especially when assembled, as seen in Figure 12.2c).

Initially, the solid base platform from Figure 12.2a) was evaluated. The platform had satisfactory properties, though the upper part was too unstable. Thus, a design between Figure 12.2a) and b) was seen as most preferable, and further tested. The design of Figure 12.2c) was still seen as an alternative, but the extra effort of design complexity could not motivate further development when compared to Figure 12.2a) and b) as the design had an satisfactorily rigidness. In addition to the proposed designs above, additional ridges was tested. These ridges consisted of solid material placed between the top and bottom part to give additional rigidness and keeping the top part from collapsing.

12.4.3 Minimize Adhesive Amount

Another focus with the design was to minimize the required adhesive. This is partly due to there always being a minimum tolerance gap of 0.4 mm in which adhesive needs to be filled, see Figure 12.3. The general impression when performing tests was that a smaller joint would provide a stronger bond. Furthermore, a too small joint could always be made bigger by simply increasing the distance between PCB card and wall. But a design which requires a big joint will be challenging to optimize to the preferred size.

Figure 12.3 Example tolerance gap a) top view, b) top view with adhesive c) side view with adhesive.

To minimize the amount of adhesive used, press fit designs were tested. Prototypes were made by 3D-printing gaskets in a soft material which would be as close to transparent silicone as possible. The general problem for all press fit designs was that the gasket was deformed. In what way it was deformed varied between the different assemblies. This variance is an added uncertainty. It also gave a less impressive impression of the product. The idea of press fit solutions was therefore to concentrate the deformation area of the press fit; not the whole gasket. In Figure 12.4 are different attempts at a press fit design.

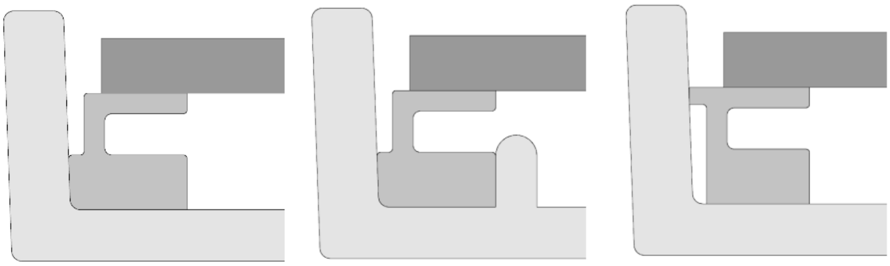


Figure 12.4 Different designs for minimizing the adhesive amount, from the left a) typical press fit, b) inner wall, c) ledge.

a) **Typical press fit -** A slightly bigger gasket will minimize the adhesive required by press fitting between wall and gasket.

b) **Inner wall -** One way of minimizing the deformation caused by a press fit is to have an inner wall. The gasket would be press fit between the inner and outer wall; compressing the gasket instead of deforming it.

c) **Ledge -** Another approach was to use a ledge to minimize the area filled to some degree. This could also work as an indication of where to dispense adhesive. A small ledge in comparison to the overall gasket structure would not deform the gasket structure in the same extent.

The typical press fit design from Figure 12.4a) was first evaluated, and even though only small areas were press fitted the whole shape of the gasket was irregularly deformed. This problem would probably be acceptable with the inner wall design, seen in Figure 12.4b), as this would hopefully compress the gasket instead of deforming it. However, the actual gain of the press fit design was questioned after some design iterations. Tests were carried out on the basic square design; the dispensing needle was not able to penetrate the gap between wall and gasket. Due to this and the problems with deformation of a press fit design it was not further evaluated.

The ledge design from Figure 12.4c) was also tested early on with promising results. As the ledge was much thinner than the rest of the deformation structure, almost all press fit deformation ended up pressing this ledge up against the wall instead of deforming the overall structure. The benefit was a greater overview of the adhesive joint area, where instead of a deep narrow gap, there was now a ledge covering the whole area of adhesive dispensing. Thus, this design was further developed with even longer flies to ensure press fit for all assembling tolerances.

12.4.4 Intuitive Area for Adhesive Dispensing

The first idea of the *Wall & Gasket* concept was that the adhesive would be dispensed all the way around the PCB card. This was recommended by the adhesive consultant at Axis with advantages both regarding shrinkage properties and bond strength [20]. However, it would require very high amount of adhesives, especially for larger PCB cards. It could also result in a problem with trapped air inside sealed compartments between the adhesive, the wall and the gasket might also pose problems during temperature changes, as the air needs to be able to expand. Furthermore, the UV light guides used for curing would have to be replaced at Axis's EMS sites in order to cure the bond all around the cards.

Thus, it was decided that certain areas for adhesive dispensing should be present. As three to four UV light guides are used in each IBAS set up today, it was decided that the adhesive bonding should be represented by four adhesive joints. The basic design derived earlier can be seen in Figure 12.5. The gap between gasket and wall is the minimum tolerance gap of 0.4 mm. The gap between PCB card and wall is 1 mm. This distance will not give shadow zones and is assumed to give a good adhesion joint.

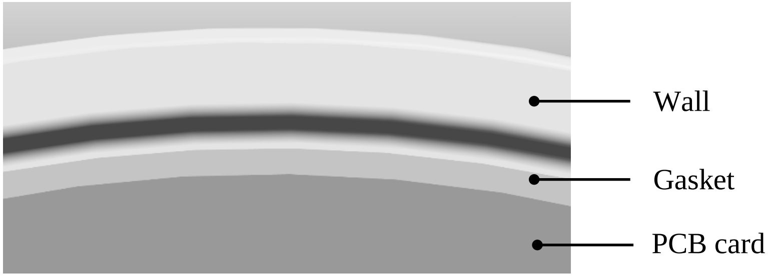


Figure 12.5 Top view of PCB holder, gasket and PCB card.

In order to minimize confusion and possible problems with operators in production, the area for adhesive dispensing had to be intuitive. Different designs of this were evaluated. When dispensing adhesive a needle is used. The adhesive will always be placed between PCB card and wall.

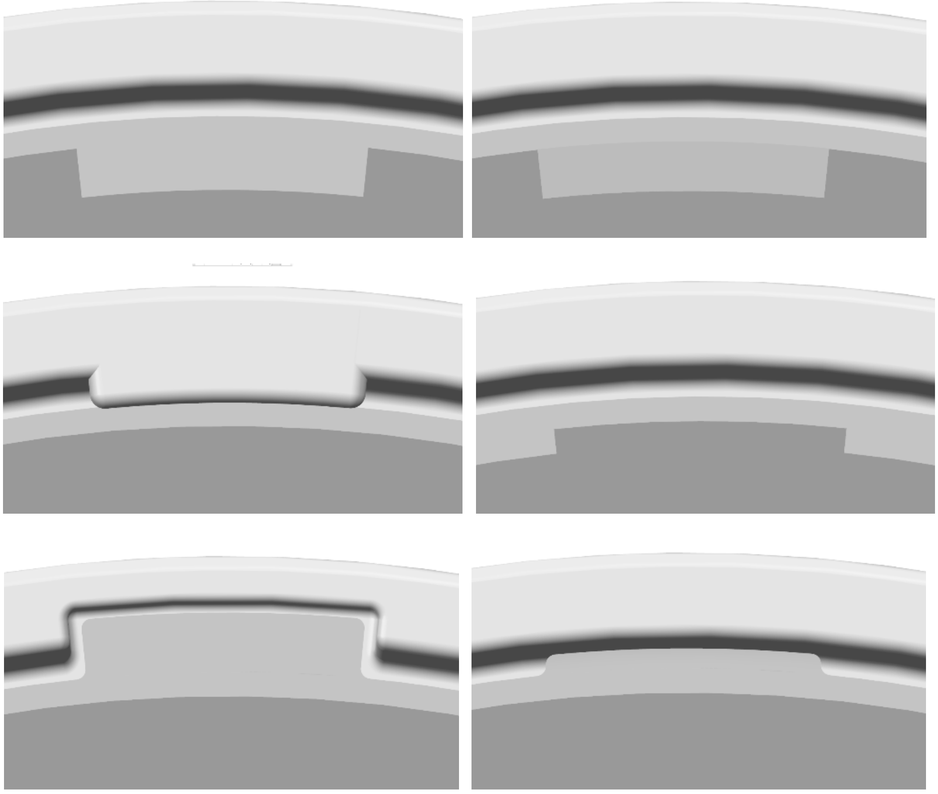


Figure 12.6 Different designs for an adhesive dispensing area, from the upper left to the lower right: a) PCB indicator, b) translucent PCB area, c) extra wall, d) protruding PCB, e) wall indicator, f) ledge.

a) **PCB indicator -** An indicator on the PCB will require a bigger adhesive joint which could be a problem in some smaller applications. With this design tolerances between the wall and gasket can be kept as in the basic design. The design gives a visual as well as physical indication of where to place the needle.

b) **Translucent PCB area -** A transparent PCB at the area of dispensing will provide a visual indication of where dispense adhesive. An added benefit with a slightly transparent PCB area is that this will provide extra UV light for a better curing of the joint.

c) **Extra wall -** One concern with the basic gasket design is the gap between wall and gasket created by tolerances might give a bad impression while dispensing adhesive. One way to minimize this gap is to let a wall close this gap creating a press fit. The adhesive would be dispensed between the extra wall and PCB.

d) **Protruding PCB -** An indicator can be created by letting the PCB card have a protruding area where the adhesive should be dispensed. The gap between wall and PCB card would still have to be the minimum tolerance gap. With this design the area around the indicator would have to be made smaller than the basic design to keep this minimum tolerance distance.

e) **Wall indicator -** By cutting an area of the wall an indicator would be created. The gasket would still need to follow this area to ensure no shadow zones. The tolerance gap between wall and gasket would be kept even in this indicator.

f) **Ledge** – With a ledge a slight visual indication was given. An added benefit with this design was that the dispensed adhesive would more likely stay in place. The ledge could be made so thin that the press fit would not cause a deformation on the overall gasket structure. The ledge gave a better impression when dispensing because the gap between gasket and wall was closed so there was no dark area shadowed where an operator could dispense adhesive.

The designs were evaluated by themselves as well as in combination with each other. Many of the combinations ended up with the same adhesive joint but with different indicators. A protruding PCB with a wall indicator will provide the same adhesive joint as the basic design due to the required tolerances. For most of the designs press fit could be used. The general impression was that most press fit designs would be too unreliable to safely focus on them.

With the goal of minimizing the adhesive joint and simplicity in mind an indication with translucent PCB area was the most favorable. The added benefit with extra UV light to minimize shadow zones at the bottom of the PCB was also favorable. This is combination with a ledge at the adhesive joint was chosen as the design to further develop and evaluate.

12.4.5 Final Specifications of the Required Movement

As many different Axis cameras were under consideration when developing this concept, it was necessary to allow large movement during alignment if the concept was to work on all cameras. When the maximal alignment was set to the maximal distance before interference with the included parts of the assembly, it was well known that these distances were a bit exaggerated for the camera examined. So even though the chosen concept would be able to align within these distances, improvements and higher chance of success during the proof of concept phase would be possible if more accurate numbers were used.

Thus, the tolerance calculations for three different Axis cameras, of varying sizes, were examined further. All of these set of distances were more than half the tolerance width of the required movement used earlier. Therefore, the final specifications of the required movement for the *Wall & Gasket* design were set to:

- +/- 0.3 mm in the x-direction.
- +/- 0.3 mm in the y-direction.
- +/- 0.3 mm in the z-direction.
- +/- 1.5 degrees as the maximal angle of the plane of the PCB.

These distances should still correspond to the maximum required movements of all Axis's cameras, to ensure the concepts general nature. However, even though these distances are used while designing for manufacturing, it is only a fraction of cameras that requires the boundary values of these tolerances.

The final specification of the required movement was used to enable optimization of the adhesive joints. This included minimizing the joint to an appropriate size so that a good strength could be achieved, as well as guarantee assemblies without shadow zones for every possible assembly.

13 Final Design and Plan Downstream Development

In this chapter the final result of this thesis will be presented, as a development proposal. Initially, the design is presented followed by aspects of implementation into production. The proposal is validated through proof of concept tests, which are presented along with its results. A cost analysis of the proposal is performed, comparing it to the other current solutions within Axis. Finally, the final design is evaluated against the customer needs derived earlier in this report.

13.1 Final Design Proposal

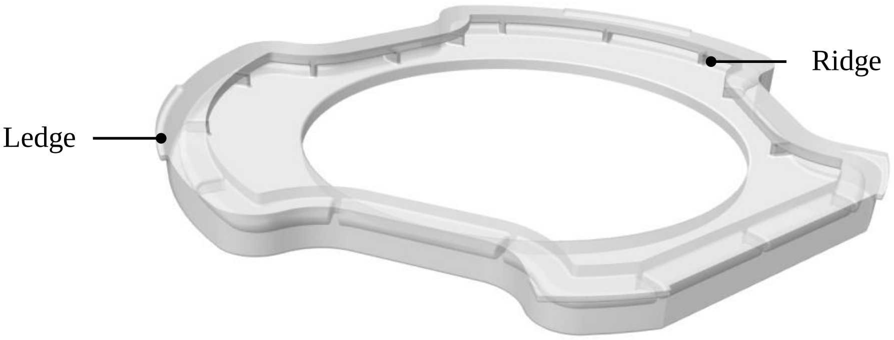


Figure 13.1 Final design of the transparent silicone gasket.

The final design of the gasket can be seen in Figure 13.1. In addition to the ledges and the deformation structure, additional ridges have been added to further add stability. An illustration of the PCB holder and a PCB card with the translucent areas can be seen in Figure 13.2.

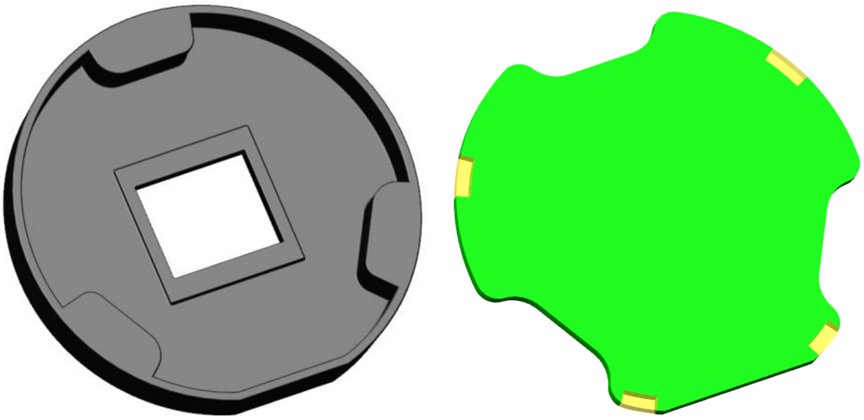


Figure 13.2 Illustration of the PCB holder and PCB card.

The gasket will be delivered from manufacturers with a double sided adhesive tape on its upper side, already assembled. This tape will prevent the UV light curable adhesive from ending up on the backside of the PCB card, in the shadowed area between the card and the gasket. It also allows the gasket to follow the movement of the card while aligning.

13.2 Proposal for Implementation into Production

13.2.1 The Adhesive Assembling Process

The assembling process of the final design solution becomes fairly similar to the current product assemblies within Axis. Some changes are however necessary and a suggestion of the assembling process are presented next. A proposal to the assembly process can be seen in Figure 13.3.

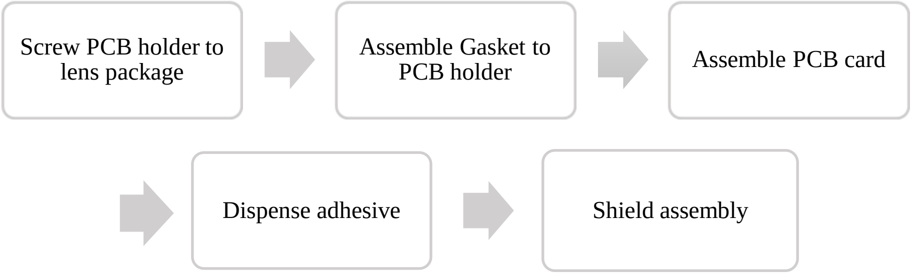


Figure 13.3 Overview of the assembly steps.

The process begins with attaining the PCB holder with the wall structure. This part is screwed onto the backside of the lens package, similarly to the current assembling operations.

Next, the gasket is assembled into the PCB holder, see Figure 13.4. The properties of the gasket, with interference fitting ledges, structure and choice of material makes it possible to perform this assembling process manually. The gasket becomes sufficiently centered during this process. It stays in place, without the need of extra fixing, even if the assembly is turned upside-down.

Then, the sensor glass and the sensor gasket are assembled, as with the current solutions. Next, the PCB card is placed into a fixture, which relates to the geometry of the PCB holder. The protective tape of the double sided adhesive tape, on the upper part of the gasket, is removed and the PCB card becomes accurately assembled into the PCB holder. This process has to be performed under clean room conditions, due to the gasket’s dust sealing.

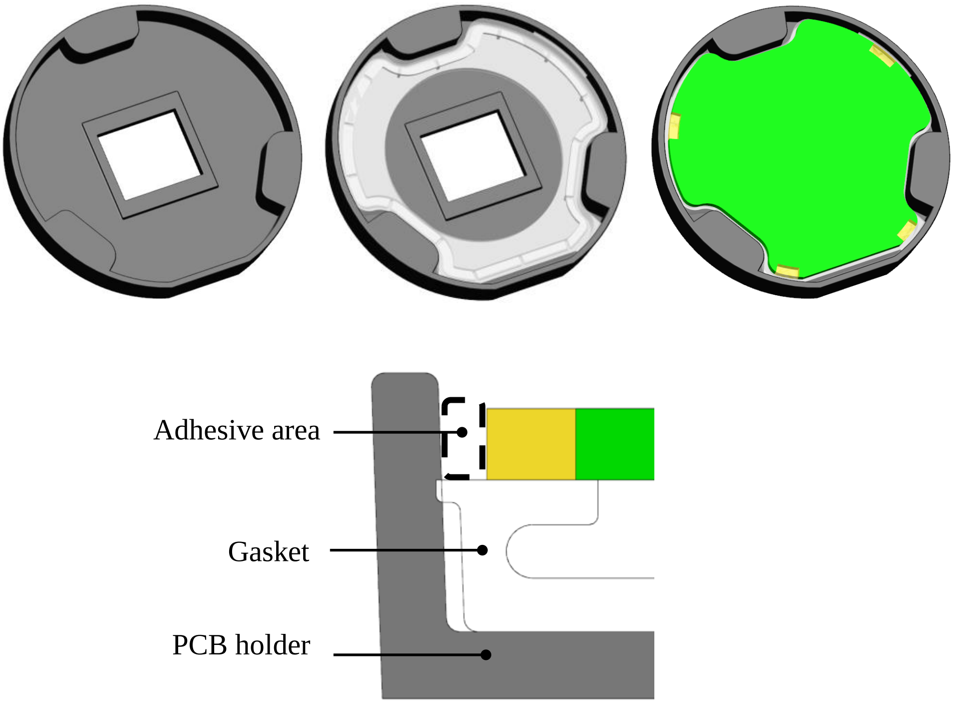


Figure 13.4 Illustration of gasket and PCB card assembly.

When this assembling process is completed, the adhesive is dispensed at the four specific areas between the PCB card and the wall, see Figure 13.5. For this application an adhesive with a medium-high viscosity is recommended. The dispensing is done with a dispensing needle. The needle is centered on the PCB card indicator and then placed in the gap between the wall and the PCB card. With the needle kept in place, adhesive is dispensed and fills the area between wall and the PCB card. The bond is then inspected to ensure that the dispensing operation was satisfactory. Then, the assembly is stored in a black box, on its way to the IBAS system, to prevent the adhesive from prematurely curing before alignment process is finished.

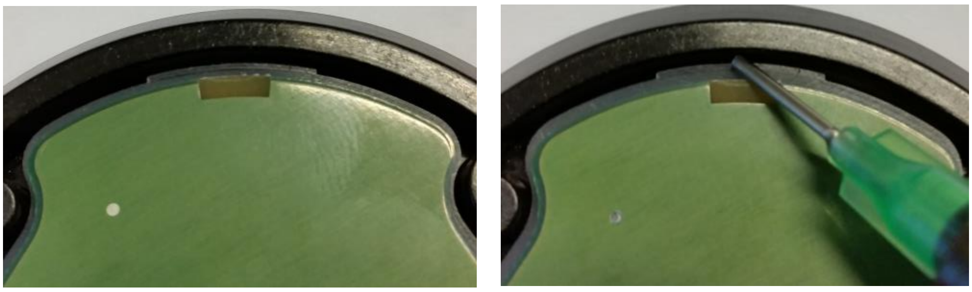


Figure 13.5 Overview of the adhesive dispensing areas.

13.2.2 The Active Alignment Process

The assembled pieces are placed in the IBAS and the final steps of the assembly process can be seen in Figure 13.6. The IBAS needs to connect with the PCB card at the same position every time so that the alignment process is reproducible. For this the current IBAS system could probably be used, with some minor modifications discussed in the forthcoming chapter. Active alignment is then performed. When an optimal position is found the UV lamps are activated and the adhesive is cured.

Figure 13.6 Overview of assembly process in the IBAS.

13.3 Proof of Concept

13.3.1 Silicone Light Dispersion

In earlier tests it was discovered that silicone would not only transmit UV light, but also spread it. With this added benefit, adhesive in an otherwise shadowed area would be reached by some UV light that potentially could cure it. This phenomenon can be seen in Figure 13.7, where the lamp used emits both UV and visible light. A cardboard box with a middle wall was used. The wall was placed on top of the silicone gasket, dividing it in two parts. Additional cardboard was used to cover the gap between gasket and cardboard wall. One gasket side was irradiated by UV light, while the other was observed. UV light spread throughout the gasket, but the rest of the area was left fairly dark, as seen in Figure 13.7.

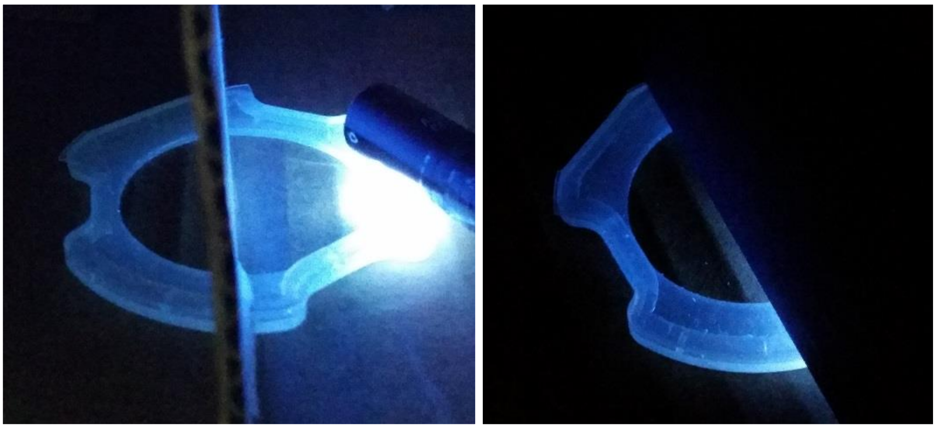


Figure 13.7 Light dispersion of the final design.

Further simple tests were conducted, were adhesive was cured only by using this additional light spreading phenomenon, i.e. no direct irradiation from the UV source. One test was carried out by applying an adhesive film to an area, seen in Figure 13.8, covering it by the silicone gasket and a PCB card. Almost all of the adhesive film was shadowed and could not be cured unless the silicone spread UV light to the adhesive. The small area of the silicone piece which was left uncovered was then irradiated by a UV lamp. The result of the test was that the adhesive film cured, there was however a limited cure length and depth. The adhesive approximately cured 10 mm into the shadowed area. Even though the spread UV light would cure adhesive, its curing depth is limited to a thin adhesive film.

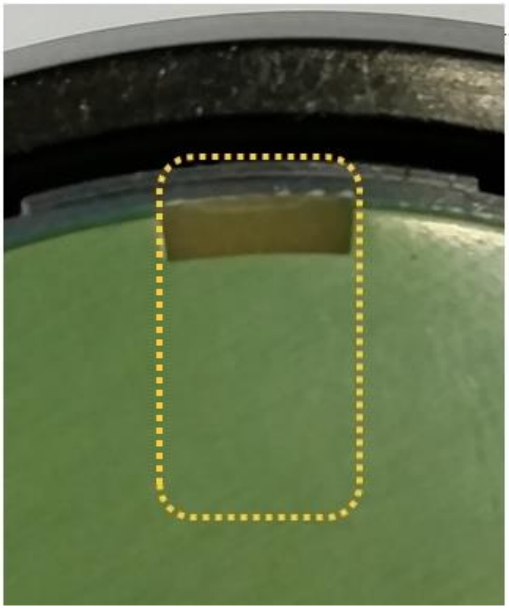


Figure 13.8 An adhesive film was applied over the dashed area. UV illumination was only directed through the narrow gap at the top of the dashed area.

13.3.2 Design Test

In order to validate the new development proposal, tests were performed. The testing methodology was similar to the one used for other Axis products, i.e. similar to the testing methodology used when evaluating the new adhesive, though in smaller scale. For more information about the exact setup of the tests see Appendix E: New , and Appendix J: Proof of Concept .

Due to limited amount of time and number of specimens, priorities regarding the tests had to be made. The bond strength of the design, optimal amount of adhesive and the effects of temperature variances was chosen as the most important aspects. Regarding the effect of temperature, permanent movement was prioritized above temporary movement, in reference to the tests done in Appendix E: New . The greater control and accuracy when specimens could be measured at room temperature was also highly favorable. Hence, the tests of measuring movement at the extreme temperature values were neglected.

The design was tested with currently used fully light curable adhesives *UV 1* and *UV 2*, so that the design and amount of adhesive could be comparable. It was also done to obtain further comparable data between these two adhesives.

13.3.3 Test Setup

The tests performed were the following:

- The force required to deform the gasket in z-direction from 0-0.6 mm was tested with a 0.1 mm interval.
- To evaluate the strength of the adhesive in combination with the design, push-out tests were performed. 10 specimens for both adhesives with 20 mg adhesive.
- To evaluate the movement of the PCB card during changing temperatures, a thermal cycling test was performed with varying temperatures between -40°C and 85°C. The cycle time was 6 hours, including ramp up time. The positions of the PCB card in reference to the PCB holder for all specimens were measured before and after the thermal cycling. 8 specimens for both adhesives.
- To evaluate the optimal amount of adhesive for the design, push-out test of two additional amounts of adhesive were evaluated, 10 and 30 mg. For each of the two variations 5 specimens were prepared, i.e. 10 in total for both adhesives.

13.3.4 Results

13.3.4.1 Gasket Deformation Force

The final design was tested with Shore A hardness of 30 and 40. Additionally a Poron gasket with an outline resembling that of the final design was tested. For this a Shore A hardness around 5 was used. The results of the test can be seen in Figure 13.9, the values for each data point are a mean of two measurements done separately.

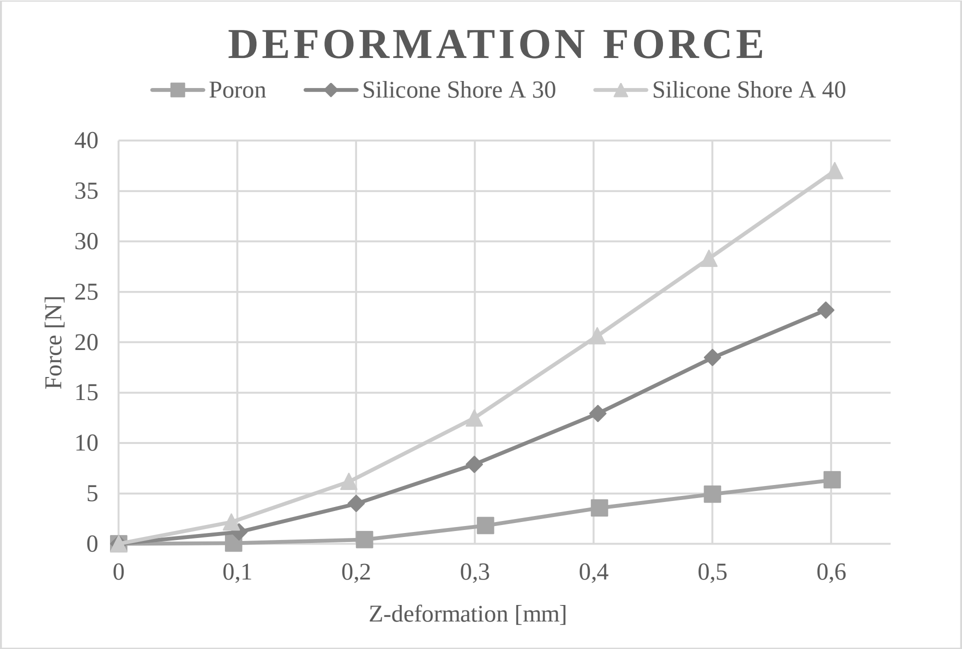


Figure 13.9 Compression force required to deform a gasket in z-direction.

13.3.4.2 Push-out Strength

The presented values are the mean values of each adhesive's push-out test, see Figure 13.10. Axis has a guideline of 100 N in the push-out tests. For 10 and 30 mg, five specimens were used while the reference test of 20 mg used 10 specimens. For the cycle tests 8 specimen were used. With *UV 2* all the specimens had separated from the plastic holder after one day of cycling. Therefore no push-out data is presented for this cycle test.

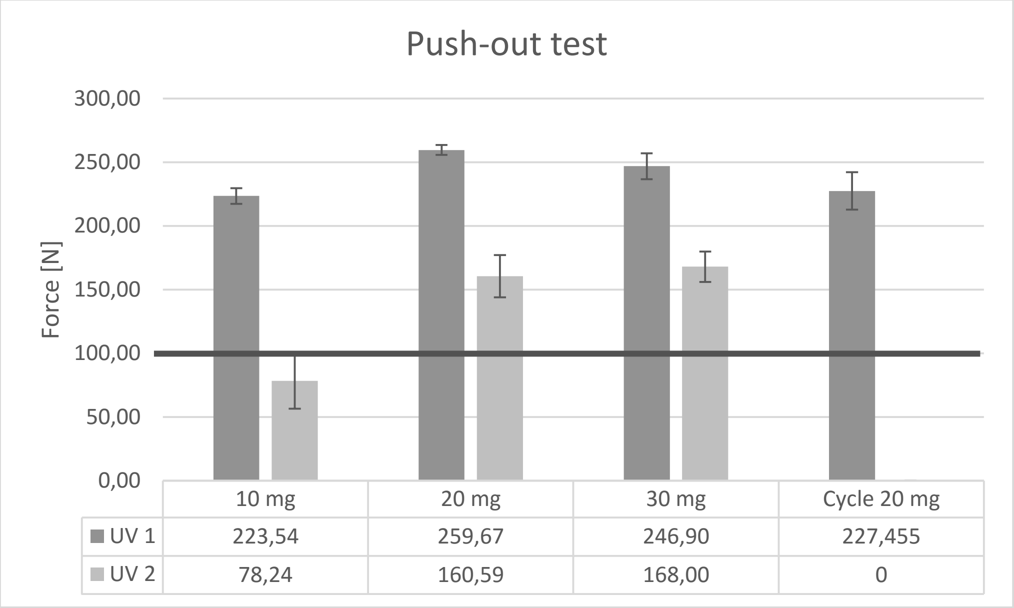


Figure 13.10 Summary of the results from the push-out tests.

13.3.4.3 Resistance to Temperature Cycling

The data represented in Table 13.1 is the positional change for *UV 1* after the temperature cycling test. This was calculated as the difference in position before and after the test. The fail limit, i.e. too much movement, was arbitrarily set to 20 µm for the z-position and 50 µm for the x-/y-position, as it corresponds to earlier tests.

All specimens with *UV 2* had separated from the plastic holder after one day of cycling. Therefore no cycle data is presented for this cycle test.

Table 13.1 Positional change for *UV 1* after the temperature cycling test.

#	X [µm]	Y [µm]	Z [µm]	XY Angle [degrees]	XYZ Angle [degrees]
1	2.00	0.00	-10.75	0.012	-0.019
2	-2.00	-2.00	-8.50	0.018	-0.006
3	-3.00	2.00	-13.00	0.008	-0.012
4	1.00	5.00	-11.50	-0.003	-0.009
5	-3.00	5.00	-13.25	0.026	-0.007
6	5.00	1.00	-10.25	0.001	-0.011
7	12.00	-3.00	-13.50	0.007	0.009
8	9.00	-3.00	-9.00	0.022	-0.001

13.4 Cost Analysis

The final design was compared to the other fully UV light curable solutions within Axis, i.e. *Transparent Cups* and *Plastic Mold*. All three designs were of roughly similar sizes, making the comparisons fairer. The comparisons performed included a Bill of materials, and an Assembling chain. The assembling chain will be evaluated in the forthcoming chapter.

13.4.1 Bill of Materials

When preforming the bill of materials comparison between the different solutions, some assumptions were made:

- The cost of manufacturing tools regarding the developed proposal was neglected.
- The cost of fixtures necessary for the assembling process of the development proposal was neglected.
- Possible necessary adjustments of the alignment equipment, IBAS, regarding the development proposal were neglected. It was concluded that if changes were necessary, there would only be minor adjustments required.

Further assumptions regarding the components of the four different assemblies were:

- The PCB holder for all three solutions was a plastic detail with similar specification for all concepts. The amount of material was more dependent of the size of the particular camera than of the specifications of the solution. Thus, it was assumed that the cost of this plastic part would be similar for all designs and it was omitted in the comparison. A similar assumption was made regarding the PCB card for all three solutions.
- All three solutions needed one gasket closest to the sensor, both to keep the sensor glass in place but also to ensure that only light going through the optics reaches the sensor. Hence, it was omitted in the comparison.

An overview of the bill of materials can be seen in Table 13.2. The data was gathered from internal quotations and mail conversation with project managers. For the transparent cup solution, adhesive was needed when attaching the cup and then filling the cup, thereof the sum of two values.

Table 13.2 Overview of the Bill of Materials.

	Wall & gasket	Transparent cups	Plastic mold
Adhesive	4 x 20 mg	3 x (22.5+10) mg	4 x 20 mg
	Transparent silicone gasket	3 x Transparent cups	Double molded part
	Gasket tape		3 x Screws
Total Cost (USD)	2.01	2.42	2.56

13.5 Fulfillment of the Customer Needs

Finally, the final designs ability to fulfill the customer needs was investigated. The comparison was performed using the same reference concept as earlier in this thesis, during the concept scoring process, i.e. the *Transparent Cups*. The evaluation of the development proposal’s fulfillment of the customer needs was done by the project team, based on the impressions of the final prototypes and the proof of concept tests. A “-“ corresponds to the final concept being “worse than”, “=” corresponds to “equal to” and “+” to “better than” the reference. The result of this evaluation can be seen in Table 13.3.

Table 13.3 Final evaluation of the customer needs.

Customer Needs: Final evaluation	Fulfillment
The fixing process is suitable for mass production	**+**
Components required for the fixing process are easy to manufacture	=
The fixing process is quick in production	+
The fixing process have room for mistakes	=
The fixing process allows for alignment in multiple directions	**=**
The fix is stable during the cameras lifetime	**=**
The fixing process has few uncertainties	**=**
The fixing process has a low risk of damaging components	=
The fixing process is done in simple steps	+
The fixing process ensures quality	=
The fixing process has a low risk of affecting the alignment	=
The new fix method is easy to implement	**+**
The fixing process is affordable	=
A general fixing process would be preferable	+
The fixing solution is space conservative	+
The fixing process for an environmentally sustainable camera	**=**
Ease of recycling	=
Environmental friendly components	=

When comparing the suitability for mass production, the time in production became the main difference. Since the process of assembling the gasket to the PCB holder was concluded faster and simpler than attaching cups with adhesive; the final design received a higher score. This also resulted in a higher score of *The fixing process is done in simple steps*. Both solutions allowed for mistakes in production, an incorrect adhesive amount will for example not critically affect the assembly. The required parts for both designs were also easy to manufacture.

The tests done in proof of concepts indicate that the final design’s adhesive bond will have the same properties as the reference solution. The adhesive bonds should therefore have the same lifetimes.

Both solutions have very few uncertainties. Even though the assembling of the final design included simpler steps, the overall score for *The fixing process has few uncertainties* was seen as equal to the reference solution.

The final design was determined as easier to implement than the reference solution. This was due to the transparent cups being space inefficient and thereby restricting design possibilities, mainly of the PCB card. The final design would also be easier to implement onto smaller PCB cards, than the reference.

Furthermore, since the fixing method was the same for both solutions and the currently used method, the environmental aspects were considered as unchanged.

14 Discussion

In this chapter a discussion concerning several parts of this thesis is raised. The developed proposal is thoroughly evaluated. Its advantages and disadvantages are discussed, along with possible uncertainties of this proposal. Some areas in need of further research is mentioned, but more systematically explored in the next chapter. The complete process of the master thesis is also examined and evaluated.

14.1 Proof of Concept

14.1.1 Silicone Light Dispersion

Curing adhesive with UV light spread by the silicone gasket was indicated to work when curing an adhesive film. This curing mechanism is nonetheless not reliable and the final design does not rely on it to guarantee a fully cured adhesive bond. It is however an added benefit to the design as it functions as an extra curing mechanism. If this mechanism could be utilized more reliably in a new design is left for further studies.

14.1.2 Design Test

14.1.2.1 Adhesive Dispensing and Amount

When discussing with Axis employees the general opinion was that the dispensing areas were intuitive. To further test how intuitive the dispensing is, more tests would have to be conducted.

In production, the instructions would be to dispense adhesive on top of the gasket’s ledges, with the needle resting on top of the center of the PCB indicator. With the right amount of adhesive, only one dispensing is require for each of these areas. If the needle is kept in place, the adhesive will fill the gap between wall and PCB card, minimizing the possibility of the operator dispensing unsatisfactory.

Comparing the three adhesive amounts used in the proof of concept tests, i.e. 10, 20 and 30 mg, 20 mg filled the gap optimally. 10 mg only covered half the designated area while 30 mg would overfill and adhesive would end up on the top side of the PCB card, see Figure 14.1.

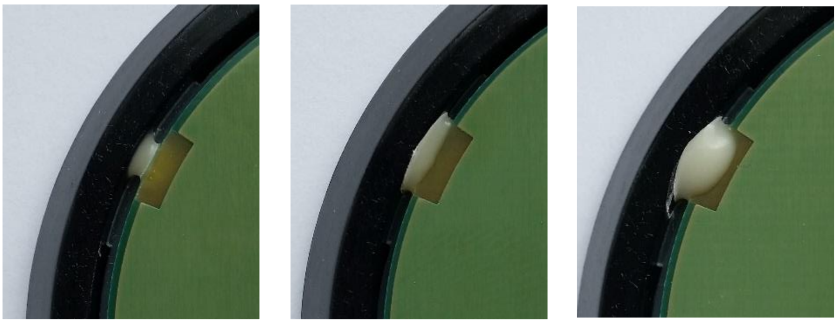


Figure 14.1 Comparison adhesive amount a) 10 mg b) 20 mg c) 30 mg.

When evaluating the strength of the adhesive bond, a guideline within Axis is at least 100 N in the push-out tests. This value was chosen through typical handling forces in production.

With the push-out tests done in section 13.3.4.2 Push-out , additional strength was not gained when the adhesive amount was increased from 20 mg to 30 mg per adhesive joint, 260 N compared to 247 N respectively. The lower strength for the higher amount could be test deviations or an indication of too much adhesive, i.e. the UV lamps cannot cure through the entire adhesive joint. It could also indicate that additional adhesive on top of the PCB card does not provides any extra strength. This is also seen further when investigating the broken joints; the adhesive always break against the wall. In no push-out test was the adhesive separated from the PCB card. Hence, to gain an even higher strength the adhesive, the contact area and or surface structure on the wall could be further optimized.

The 10 mg joints had surprisingly high strength of 224 N. But the joint felt unreliable for production purposes and a higher adhesive amount is recommended. To summarize, all three adhesive amounts had strength higher than the guidelines for Axis’s adhesive joints. An adhesive amount of 20 mg gave sufficient strength and filled the gap appropriately. To further optimize a smaller adhesive amount could be used since it did not lower the strength by too much. 10 mg felt unreliable and therefore an amount between 15-20 mg is recommended.

Generally there was a low spread on the push-out force. This is a huge benefit since, just as in production, the adhesive amount will vary between the specimens but the solution is still stable. Thus, with this solution a wide process window is acquired, guaranteeing a good fix. Even when varying the adhesive amount between 10-30 mg the strength of the bond was stable, referring to the required push-out forces. Current solutions do not possess this property.

14.1.3 Temperature Cycling

A summary of the temperature cycling test for *UV 1* can be seen in . From this a general conclusion can be drawn: the specimens have low movement in x/y-direction and a slightly higher movement in z-direction.

Table 14.1. From this a general conclusion can be drawn: the specimens have low movement in x/y-direction and a slightly higher movement in z-direction.

Table 14.1 Summary of positional change for *UV 1*.

	Max [µm]	Mean [µm]	Median [µm]	Above limit
X/Y	12.00	3.63	3.00	0
Z	13.50	11.22	11.13	0

The maximum movement is 13.5 µm in z-direction and 12 µm in x/y-direction. No movement was outside the permitted range of 20 µm in z-direction and 50 µm in x/y-direction. When further evaluating the solution in a specific project, the cycle test should be modified to match the cycling of that camera's normal operation.

The observed movement could be a consequence of the gasket being too rigid and therefore applying a too high force on the PCB card. When the adhesive is heated it softens and allows more movement. An indication that the gasket could be the cause of the movement is that all specimens, excluding one, moved upwards in z-direction. This is seen by the negative change in z-direction. With a lower gasket force, the movement with temperature cycling will be minimized. As no movement, in either z- or x/y-direction, was outside of the permitted range with the force from the current gasket design, the movement during temperature cycling was not seen as a problem.

Why the specimens with *UV 2* released from the wall in the cycle tests is unclear. Factors such as UV intensity, irradiation time or structure on the wall need to be taken into consideration. But since it is a rather untested adhesive, no clear conclusion can be drawn. This is especially true since *UV 2* had no problems in the push-out tests.

14.1.4 Required Compression Force of the Gasket

The final gasket design obtained most of the desired features discussed in *Chapter 12 Final Specification*. Though, the required compression force was found to be too high compared to the current design guidelines of Axis cameras. These guidelines could be further evaluated, possibly enabling larger forces to exist. Nevertheless, too large forces could potentially lead to bending forces on the sensor, creeping of the adhesive or difficulties in the alignment equipment. Therefore, this problem should be further investigated and probably easily solved through further design iterations by for example:

- **Using a softer silicone material -** The silicone gaskets received were of hardness shore A 30 and 40. It would be desirable if these shore values could be used, as they are very easy to attain. However, some of Axis distributors have silicone as soft as shore A 10. The difference of required compression force between shore A 30 and 40, seen in Figure 13.9, was substantial. Thus, using shore A 10 would probably result in even larger difference.

- **Optimizing the ridges -** The distribution, amount and design of the ridges used can be optimized. Fewer ridges would result in lower required compression forces.

- **Minimize gasket material -** Minimizing the solid gasket structure between the upper and lower part of the gasket. The final thickness of this structure was set to 1 millimeter, but it could most definitely be thinner while still attaining the desirable properties of the gasket.

- **Optimizing the shape of the gasket -** The design restrictions of the PCB holder chosen resulted in a very complex gasket shape, compared round or square shaped PCB holders. This design resulted in many corners, which are more rigid than the other sections of the gasket. Thus, by removing corners a softer gasket would be acquired.

- **More deformable structure -** By optimizing the deformable shape of the gasket with notches or indications with a bellow structure a more easily deformed gasket would be obtained.

- **Remove gasket material -** By only using the gasket structure at the areas of the adhesive joints. This would dramatically lower the amount of gasket material needed, thus also the required compression force. This feature was not examined during this thesis, as it seemed less elegant and could require further design iterations. Though, with the priority to reduce the required compression force of the gasket, it becomes highly promising.

14.2 Cost Analysis

14.2.1 Bill of Materials

The simple bill of materials comparison made in chapter *13.4.1 Bill of Materials* indicated that the final design would be comparable with *Transparent Cups* and the *Plastic Mold* solution. Though, there might be an additional cost to the adhesive tape if outgassing requirements limits the amount of possible choices of this tape. One important aspect of this cost comparison was that the adhesive amount used in the design, was the main factor governing the price. As discussed in section *14.1.2.1 Adhesive Dispensing and* , the recommended amount of adhesive for the development proposal might be more suitable at 15 mg per joint, making it even more affordable.

14.2.2 Assembling Chain

The assembly chain of the proposed solution was compared to the currently used solutions, i.e. *Transparent cups*, and *Plastic mold*. This comparison can be seen in Table 14.2. Though, no specific data of assembly time was gathered for the different solutions, so the comparison between the solutions was done subjectively.

Table 14.2 Summary of additional assembly steps compared to *pin/hole*.

Wall & gasket	Transparent cups	Plastic mold
Assemble gasket and PCB card	Attach cups	Attach mold

- The final design requires the assembling of an extra gasket. The assembling onto the PCB holder is very quick and sufficiently accurate without fixtures. The assembling of the PCB card requires fixtures to obtain the desired accuracy.
- When attaching the cups to the PCB card, a tweezer is used to pick up the cups and place them in a fixture. Adhesive is added to the cups and the PCB card is then placed in the fixture. The UV lamps are activated and cure the adhesive; attaching the cups to the PCB card.
- The plastic mold is attached to the PCB card by screws.

Attaching the mold with screws was seen as a quick process. Ideally the final design would have the same assembly time. Attaching the transparent cups was seen as a more time consuming task as it required tweezers to handle the small cups and three additional dispensing steps and curing.

14.3 Fulfillment of the Customer Needs

The final designs fulfillment of the customer needs was satisfactory. No large disadvantages could be found, following with mainly similar properties as the *Transparent Cups* of many categories. Some advantages in relation to this solution was also found, which seems reasonable since there were some aspects of this solution that had room for improvements. However, the final proposals fulfillment of these customer needs was done by the development team and should therefore be analyzed with this in mind. It would be preferable to further evaluate this result through the opinions of different development teams within Axis.

14.4 Further Discussion of the Development Proposal

14.4.1 Design Limitations of the PCB Holder

The development proposal offers new possibilities of the fixing process after active alignment. The design of the gasket, which enables these possibilities, was optimized for the design of the PCB holder of the *Transparent Cups*. This was done to save both money and time, especially during the testing phase, as this PCB holder had some of the sought properties. However, by choosing this PCB holder, design limitations were added. Thus, the optimization of the design was performed against the current PCB holder, with unnecessary design restrictions as seen in Figure 14.2. The design of the development proposal, mainly the shape of the gasket and even more where the adhesive joints were placed, would be different without these restrictions.

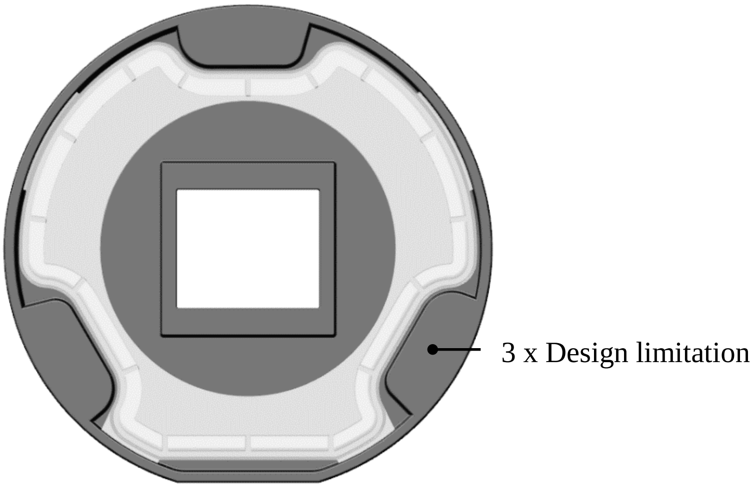


Figure 14.2 Example of design limitation.

For instance, to increase the total strength of the bonds, it would have been preferable to place the adhesive joints as close to the center as possible. This would minimize the bending forces of these joints as pressure is always applied in the center of the PCB card when testing. It would also be logical to assume that in such a load case, the adhesive joints should be symmetrically placed to achieve best results. This was not possible to achieve with the limitations of the PCB holder.

Despite this, the optimization of the whole fixation process is still valid and these results would be fairly similar regardless of the limitations of the PCB holder. These aspects should be considered when evaluating the design of the gasket.

14.4.2 PCB Layout

In comparison to all the current *Pin/hole* designs, the final design does not require any holes to be drilled in the PCB card. These holes pose design restrictions for the layout of electrical components on the PCB card. The closer these holes are to the center, the more valuable is this space on the PCB card [52]. The positions of these holes can also change during the design iterations of the PCB card, which causes further iterative processes regarding the components placements. The development proposal on the other hand, has restricted area around the edges of the PCB card, though this area is seldom used. It should be noted that increasing the area of the PCB card is highly cost inefficient and should be avoided [52]. Yet with more valuable area unrestricted near the sensors position, it is fair to assume that the PCB cards could be kept at the same size.

Although, when placing the electrical components for the PCB card in this proposal, the layout can be very similar in all assemblies, placing components from the center and outwards. This could potentially be of great economic benefit to Axis, regarding the engineering hours needed to create this layout. However, as the economic benefit of this property was difficult to estimate, it was left out of the cost analysis.

14.4.3 Space Conservation

For camera assemblies with a smaller PCB cards, both the *Transparent cups* and the *Plastic Mold* solution becomes very space consuming. Holes for the pins are needed as well as an additional area around to the holes for the attachment of the cups, or additional space for the double molded plastic component.

For the final design proposal, only the gasket is needed which would be easy to handle in production, even for smaller designs. The solution is very space conservative, only using the volume between the PCB card and the PCB holder, which otherwise is unused. The solution does not require space in the center of the PCB card either, but rather at the outline border. Some wall structures will be required, but in some assemblies they are already present. It is believed that this wall can be done using very little space. In an optimal design it might be possible to only use certain wall sections at the adhesive joints. To conclude, the final design was considered more space conservative and especially a better solution for the small camera assemblies.

14.4.4 Attaching the Gasket to PCB Holder

Currently in all of Axis's cameras a gasket is used to protect the sensor from dust and light. This should be placed as close to the sensor as possible to be as efficient as possible [54]. With the final design additional dust sealing is acquired with the proposed gasket. How beneficial the extra dust sealing is have not been evaluated.

If the added gasket is to be used for dust sealing, it will result in further constraints of the placement of components on the PCB card. Cables cannot be connected to the bottom side of the PCB while still maintaining the sealing. Either the cables are restricted to the top side of the PCB or the gasket would have an opening allowing for cables to reach the bottom side. With an open gasket the extra dust sealing is removed.

The final design suggests one double-sided tape on the top side of the gasket to attach it to the PCB card. An additional tape could be used on the bottom side of the gasket to also fix the gasket to the PCB holder. It would provide a better dust sealing and fix between PCB holder, gasket and PCB card. However, it could complicate the assembly of the gasket if it is incorrectly assembled and the tape sticks to the side. In addition to this, most of Axis's cameras do not use this additional tape for dust sealing [52]. Due to this a gasket with only one tape on the top side was chosen. Additionally, the ledges of the final gasket design provide a press fit against the wall. This ensures that the gasket is kept in place, even though the gasket and holder is turned upside down.

14.4.5 Implementation into IBAS

As previously mentioned IBAS needs to connect to the same position at the PCB card every time to ensure a reproducible alignment process. This is currently done by assembling the PCB holder and PCB card separately to IBAS and then bringing the two components together as the first step of active alignment. To ensure that IBAS connects to the right position and that the assembly of the PCB holder and PCB card is done correctly guiding pins are connected to holes on the PCB card. The guiding pins also control the alignment process.

The assembly of the final design into IBAS will differ from the current method as the PCB card and PCB holder already are assembled. Meaning the PCB card and PCB holder does not need to be brought together as the first step of active alignment. This will minimize the risk of dust particles on the sensor, as the dust sealing process can be done at an earlier assembling stage. Furthermore, due to this it might no longer be necessary to keep the IBAS in a clean room environment.

With the final design the challenge of this method is how the IBAS system will connect to the PCB card. The holes could manually be guided to the pins on IBAS. A suggestion brought up by the IBAS team was conical pins. This would allow some variation of the PCB card placement as it would be pushed into correct position by the conical shape of the pins.

Therefore, the current solution with holes on the PCB card and guiding pins on the IBAS system is suggested. The pins would provide the additional strength needed to handle the required forces for active alignment. If the added dust sealing is beneficial, the holes could be placed on the outer limit of the PCB card. In the area around the holes, the gasket would cover up the hole; ensuring the dust-sealing.

Another option would be to grip the outside of the PCB card with claws. With this method additional holes on the PCB card would not be required. Though, the structure of the wall has to be altered at the position of the claws to allow full alignment movement.

14.4.6 Environmental Aspect

The success of this thesis relied on a fixing method that could guarantee fulfilling the requirements of Axis's cameras. Regardless of the sophistication or cost-effectiveness of the design, the examined cameras become useless if sufficient image quality cannot be met. When investigating possible fixing methods the number of methods fulfilling the requirements was few. Hence, the environmental aspect during this thesis was initially secondarily treated. The hope was to involve this aspect further, when the primarily requirements were fulfilled.

Despite this, there was little to no room for involving this aspect during later stages of development. The development proposal suggests using adhesives as fixing method, which poses both advantages and disadvantages when seen in an environmental perspective. As adhesives are currently used, the environmental impact does not become worse with the new proposal. The amount of added components is also minimized, with environmental benefits. Therefore, it might give greater overall environmental results to further emphasize this aspect within other areas of Axis's cameras.

14.4.7 Different Design Proposals

The design team believes there is great potential in the development proposal of this thesis. Despite this, it became evident during this thesis that even the smallest or even unimaginable problems can occur while setting the final specifications. So in the event of a failure for the developed proposal, it could prove useful to revisit some of the concepts examined during this report.

14.4.7.1 Injection Molding Equipment

If there are problems with attaining the required softness of the silicone gasket structure, the possibility to use injection molding to produce the gaskets should be further evaluated. This would produce an even softer silicone material, as soft as Poron [53].

14.4.7.2 Double Molded Part

Another solution related to the softness of the silicone gasket structure, is to use a double molded plastic part as the PCB holder. This part would be similar to the one used in the *Plastic mold* solution, but with transparent walls and a more ridged core (non-transparent). This design would enable the usage of a Poron as the gasket material in the assembly, as the transparent walls allow curing of the adhesive that potentially ends up between the gasket and the wall. It could also result in a design where the Poron gasket would seal the entire sensor area of the PCB card, making it possible to remove the sensor gasket. If not, these two gaskets could perhaps be combined into one gasket, reducing the cost of the assembly.

Comparing to the *Plastic Mold*, the advantages of doing this might be to reduce the cost of the assembly, as one plastic part of the *Plastic Mold* concept becomes unnecessary. Moreover is the possibility to implement this design onto smaller assemblies, where the cups of the *Plastic Mold* solution have to be relatively large in relation to the size of the PCB card.

14.4.7.3 Transparent PC

If there are difficulties attaining the double molded plastic part of the previously discussed design, the PCB holder could possibly be made of the transparent PC. Some effort into making this part rigid and durable is necessary. Furthermore, the transparent PC part enables light to travel through it, which might find its way to the sensor. If the sensor is not sufficiently light sealed, this might become a problem. This could further be solved by labyrinth-like assembling parts, which prevent the light from entering the assembly [54].

14.4.7.4 Ring

The *Ring* proposal together with soldering as a fixing method was discarded in favor for the *Wall and Gasket* proposal and left untested, due to further uncertainties. The advantages of using soldering as a fixing method should be further compared against the cost of evaluating the method.

14.5 The Master Thesis

The workload during this master thesis was evenly divided by the team members. The similarities of expertise between the team members resulted in shared tasks throughout the entire project.

14.5.1 Project Plan

Efforts were made to follow the initial project plan of this thesis, seen in Appendix A: Preliminary Gantt-Scheme. With roughly 20 weeks at disposal, the plan seemed realistic. However, fairly large deviations from this initial plan occurred, mainly due to time consuming design iterations, where new problems constantly arose. An illustration of the final project plan can be seen in Appendix B: Final Gantt-Scheme.

14.5.2 Methodology Analysis

The methodology used during this thesis was solemnly based upon Ulrich and Eppinger’s *The Generic Product Development Process.* This methodology was chosen as the team had been in contact with this method during some smaller academic projects. As the methodology was familiar, the next step of the methodology was always known. Despite this advantage, it would probably have been favorable if another method complemented the steps of this thesis, were Ulrich and Eppinger’s methodology was not suitable.

Furthermore, *The Generic Product Development Process* derived by Ulrich and Eppinger, has its main target group as large corporations with the intentions of developing a new product. Because of this, lots of focus during this methodology is based upon understanding the customers subconscious desires, evaluating products to see it meet these desires and finding out if the developed product is profitable before being mass produced. These properties do not agree very well with the aims of this thesis. Thus, when only considering this aspect, it would most certainly have been more preferable if another methodology was chosen.

14.5.3 Fulfilling the Aims of This Thesis

The aims of this thesis were:

- Examine current fixing solutions
- Investigate alternative fixing processes
- Propose a new design which ensures a high quality fixing as well as an improved production process

A thorough exploration of both Axis fixing solutions, other companies fixing solutions and other possible fixing solutions has been conducted throughout this thesis. The result was two methods of fixing with greater potential than others, where one had to be assigned for further studies due to the limited amount of time of this thesis. The fixing method with greatest potential was adhesives, though the quality and simplicity of this process was further optimized with a new proposed design solution. The new design offers new possibilities and advantages for Axis, which after further evaluation and validation could result in major benefits. Therefore, the aims of this thesis are considered fulfilled with content.

14.5.3.1 Ethical Aspects

There was a possibility to raise an ethical discussion about the purpose of this thesis. However, this discussion seemed less associated with the specific topic of this thesis and more related to the overall aspect of surveillance camera industry. Thus, this topic was not further treated during this project.

14.5.4 Difficulties

14.5.4.1 Uncertainties

The uncertainties discussed throughout this report, regarding the adhesive process within Axis, has been hard to define. Opinions differed between and within development teams and when experts were consulted.

One example of this problem was which of the current solutions that is most preferable. Using fully UV light curable adhesives were overall very appreciated, as many agreed upon the oven problematic. This leaves the two adhesive solutions *Transparent Cups*, which by some was criticized for its assembling process, and the *Plastic Mold*, for not being space conservative and for using difficult manufacturing processes. These discussions were the main reason for doing the adhesive benchmarking in section *6.3 Benchmark of Current Adhesive Solutions*.

Another example is the ever returning subject of fully cured adhesive, which becomes very subjective between the different tests. Some thoroughly examined adhesive bonds made by the development team, which were seen as fully cured, could very likely be determined as uncured by experts. Hence, during this thesis, one central issue was to eliminate all these uncured adhesive uncertainties, by completely eliminating all possibilities of shadowed areas and further only permit designs which can guarantee that the recommendations from the adhesive distributors are met. Only then can these uncertainties be discarded, enabling easier troubleshooting if problems were to arise during the production process.

14.5.4.2 Gaining Knowledge and Discarding the Different Fixing Methods

The process of evaluating all possible fixing methods was a difficult task. Some methods were completely unknown for the team at the beginning of this project. The amount of specific customization within each method was numerous. So even though all decisions made throughout this report is motivated using the information gained, there are most definitely ways to overcome some of the problems with the fixing methods by customizing certain aspects.

14.5.4.3 Gasket Designs

When the decision of using a silicone gasket was made and it was concluded that a deformable structure was needed, an intense process upon deciding this gasket design started. This process was the main result of the deviation from the initial project plan discussed earlier.

When illustrations of this gasket design were made, the magnification used on the drawings resulted in a variety of design proposals, with what was considered as huge differences in their properties. Though, when later transferred into proper scaling, i.e. when the illustrations were made into 3D-CAD models, many designs seemed much less promising. Even more difficult was the difference between the CAD-models and the prototypes. Structures which seemed rigid in CAD models became extremely weak after 3D-printing.

Furthermore, as ordering a tool for creating silicone gaskets was a fairly large operation, the design of the gasket had to be reliable before this was done. This design validation was performed using 3D-printing prototypes, with a material supposed to mimic silicone. Despite this, it had some unfavorable properties which complicated the process.

14.5.5 Assumptions and Constraints

14.5.5.1 Required Movement

In the initial concept generating process of this thesis, different fixing methods with corresponding concepts were generated. A decision was made not going into the details of the required alignment process at the early concept generating stages, corresponding to the definition of concepts made by Ulrich and Eppinger. So the exact possible movement distances required during the active alignment process was not derived until the very last stage of this thesis. Because of this, a solution which enabled larger movements than those of the final specification was found. This makes it possible to further investigate the development proposal if these larger movements are required. This is seen as a huge advantage, as the proposal's sensitivity became far less dependent of these distances. However, as these distances were not initially derived, the concept generation process focused upon solutions that could enable large schematic movement in all the desired degrees of freedom. Thus, concepts that could not provide these large movements were eventually discarded.

The opposite methodology might have been to derive these requirement movements during the *Establishment of Target Specification* process, by setting ideal *Final specifications* for the concepts. This was seen as difficult, time consuming and limiting during this stage of the thesis, but it would probably have resulted in a fairly different concept generation process. As the final requirements of movement were very small, many concepts could possibly have been further examined by "neglecting" the need of tilting for example, relying on the possibility that this problem would disappear in the final concept. However, it should be noted that this methodology was considered far more risky. The final proposal for such a methodology might have failed miserably during the proof of concept phase, due to, for instance, minimal bending forces created by the assumption of "neglecting" tilting, too small to observe without using the active alignment equipment.

14.5.5.2 Focusing Upon One Solution

During the initial stages of this report, the team received lots of feedback stating that focus should be concentrated upon optimizing one of Axis's products that requires active alignment. As many earlier projects had put a lot of effort in optimizing this process, it was considered difficult to find a process which could be applied for every camera. Despite this, the team did not follow this recommendation and thought it would be more challenging and superior to find a general solution for all different products. It would also pose greater benefit for Axis, assuming a successful result.

This choice resulted in a highly satisfactory general solution, probably applicable to all the current products within Axis. It is however interesting to speculate in the possibility of a completely different design, if optimization had been conducted on a particular product. The developed proposal would perhaps include a more perfected design in terms of the details of the solution, but the question remains, would the development proposal had been the same if this limitation was chosen? The team's opinion is that this would not be the case.

15 Conclusions and Recommendations for Further Studies

In this chapter the conclusions regarding the results of this thesis, will be presented. This will be followed by further recommendations of the development proposal, both examinations and validations needed to further ensure its implementation into production and possible optimizing opportunities.

15.1 Conclusions

This thesis has examined and evaluated possible ways to fix a PCB card to lens packages after active alignment. The result is a new general process, which allows the usage of UV light curable adhesives. By only adding a transparent silicone gasket, control over the adhesive is obtained and the requirement of secondary curing mechanisms disappears.

15.2 Recommendations for Further Studies

15.2.1 Further Evaluate the Advantages of the Development Proposal

The advantages and disadvantages of the development proposal need to be further evaluated against the current designs, regarding its implementation during ongoing production. It might not be profitable to revise the current designs, despite the advantages of the development proposal. Instead, further studies might have to determine if focus should be upon implementing the design into new projects. It is also important to include the opinions of other Axis employees and possibly operators on EMS sites, to further evaluate these aspects. After all, even with some evident advantages, the final proposal has mainly been evaluated by the development team.

15.2.2 Optimizing the Design for Smaller Assemblies

The design proposal is based on the largest PCB card of the examined assemblies. Though, this specific product also includes a production process with minimal insecurities regarding the curing of the adhesive, i.e. transparent cups. The largest problem regarding uncertainties, and most cumbersome production processes, is seen in the smallest camera assemblies within Axis, where there up until now have not been possible to use fully UV light curable adhesives. Therefore, further studies should be done to primarily implement this design onto the smaller assemblies, optimizing the gasket design for these purposes. This includes properties of the gasket such as rigidness, assembling properties etc.

15.2.3 The Adhesive Tape

The adhesive tape used on the upper part of the silicone gasket has to be further evaluated. Due to the lack of time, an appropriate choice of this tape has not been included in this thesis. The important aspects of this tape is keeping the cost of the silicone gasket at minimum, provide enough adhesion to seal the outline of the PCB card from the UV light curable adhesive, as well as meeting the low outgassing requirements of Axis’s cameras. Hence, further studies are needed to include an appropriate adhesive tape to the design of the final development proposal.

15.2.4 Outgassing

Outgassing is a slow process and testing it could therefore not be included during this thesis. Thus, further testing that ensures that both the gasket and the adhesive tape fulfill the outgassing requirements of Axis’s cameras, needs to be performed. These tests are very specific and need to be performed not only regarding the materials, but also along with the complete camera assembly.

15.2.5 Acceptable Gasket Force

To determine the acceptable gasket force was seen as a too comprehensive task for this project. This acceptable force is specific for the different camera assemblies and is thus better investigated by camera projects when implementing the development proposal. Potential room for design improvements relating to this matter is described in section *14.1.4 Required Compression Force of the* .

15.2.6 Implementation into IBAS

To propose a fully IBAS implementable design was regarded as a too wide scope of this thesis. Hence, implementing the final proposal into the IBAS system will require further studies, involving the IBAS designers into the assembling chain of this proposal. Discussions of this matter can be seen in section *14.4.5 Implementation into IBAS*.

15.2.7 Combine With Sensor Gasket

Due to the transparency of the developed gasket, a sensor gasket is still required to stop light reaching the sensor. However, it is possible to double mold silicone, combining black and transparent material at the desired locations. The result would be one less component, along with an even simpler assembling chain. This possibility needs to be further evaluated.

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16.1 Figures

Figure 3.1 Schematic illustration of the arrangement of lens elements in a lens, http://www.kenrockwell.com/zeiss/slr/21mm-f28.htm

Figure 3.9 Image plane measurement, tilt and shift corrections to achieve an aligned lens, [4, p. 3]

Figure 3.10 Example of pattern for Modulation Transfer function, http://harvestimaging.com/blog/?p=1294

Figure 3.11 a) Sensor image of a test chart and search areas for the crosses b) example of output data from a through-focus-scan of non-aligned sample, [4, p. 4].

Figure 3.12 An illustration of different stresses that can appear in an adhesive joint, [10, p. 39]

Figure 3.13 UV curing adhesive before and after irradiation, http://www.globalspec.com/learnmore/materials_chemicals/adhesives/uv_curing_adhesives_radiation_light_curable, 2015-05-07

Figure 3.14 Electromagnetic spectrum with a magnification of the typical UV light curing spectrum, http://www.dymax.com/images/pdf/literature/lit008_comprehensive_guide_to_uv_light_curing_technology.pdf, p. 15, 2015-01-19

Figure 6.2 Example of the pin/hole solution, unpublished internal Axis document

Figure 6.4 Example of the pin/hole & plastic mold solution, unpublished internal Axis document

Figure 6.6 Overview of an alignment process used in the automotive camera, http://www.delo.de/fileadmin/upload/dokumente/en/broschueren/Automotive_Camera_Module_Assembly.pdf 30-5 2015

Figure 7.3 Illustration of two-component adhesive dispenser, http://us.henkel-adhesives-blog.com/post/LED-Assembly-Solutions/Dispensing-2-Component-Adhesives-LED-Assembly/ 2015-06-01

Figure 7.5 Illustration of heat staking, http://www.phasa.co.uk/phasa-process, 2015-05-21

Figure 10.6 Example of Pin/hole soldering with the ring concept, [40, p. 6]

Figure 11.3 Different shore hardness scales and product examples, http://www.techsil.co.uk/material-properties, 2015-05-27

Figure 11.4 Illustration of a Poron material, http://www.stockwell.com/poron-foam-cellular-urethane.php, 2015-05-27

Figure 11.5 Examples of silicone gaskets, http://www.customgasketmfg.com/Products/SiliconeGaskets, 2015-05-27

Figure 11.6 Compression molding, [38, p. 48]

Figure 11.13 Example of a transparent silicone gasket, http://www.coleparmer.com/Product/Sanitary_Gasket_Silicone_1_1_2_10_pk/EW-30548-04, 2015-05-27

Figure 11.14 Transmittance for silicone with or without fillers. The blue lines represent silicone without additives, for coloring etc.,
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Figure 11.18 Illustration of solidification shrinkage, [45]

Figure 11.19 Illustration of thermal contraction, [45]

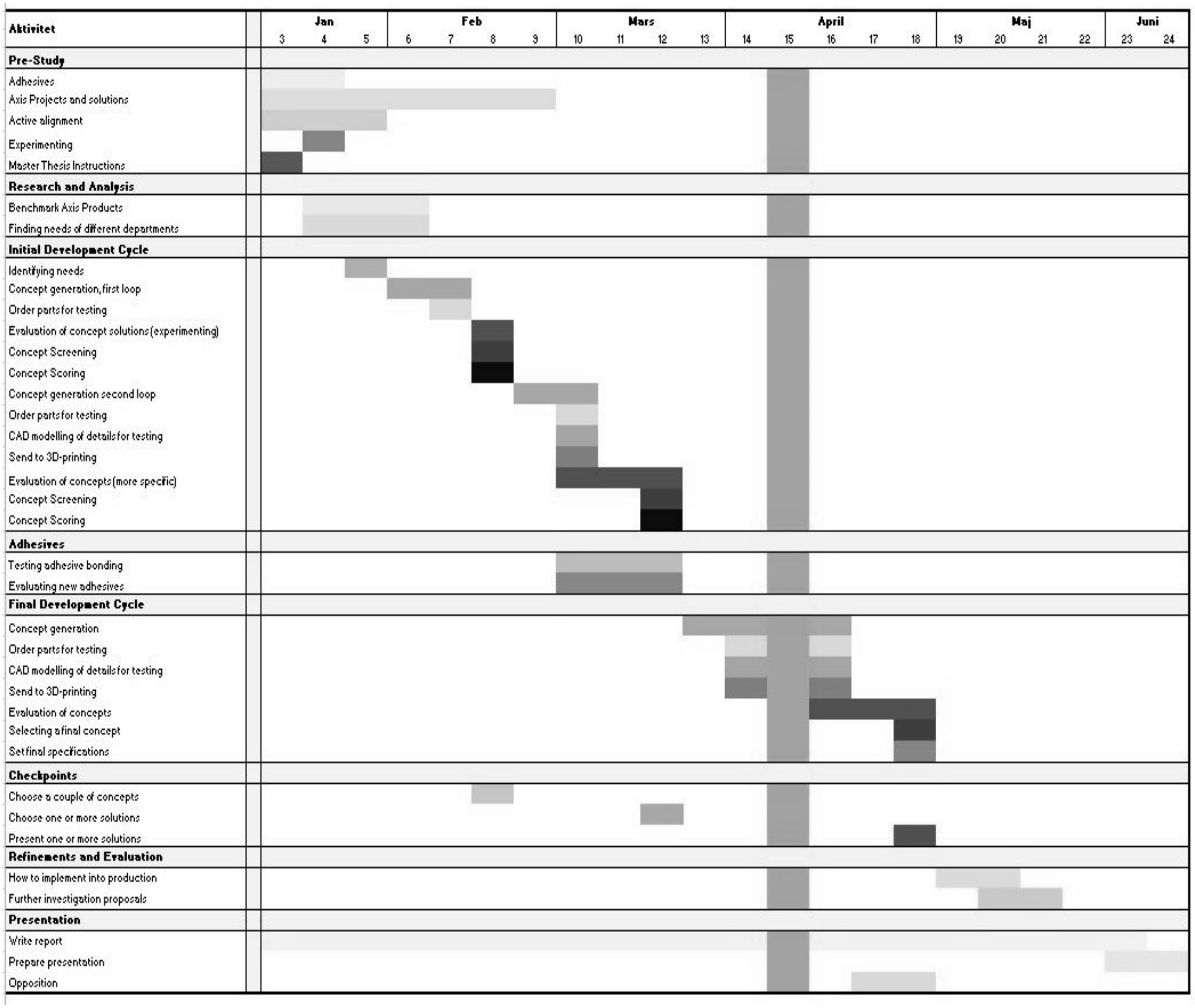
Figure C.1 Laminar flow cabinet classification, http://www.particle.com/technical-library/faqs/laminar-flow-cabinet-classification, 2015-12-06

Figure E.1 Example of push-out test, unpublished internal document, photo by Florian Borza

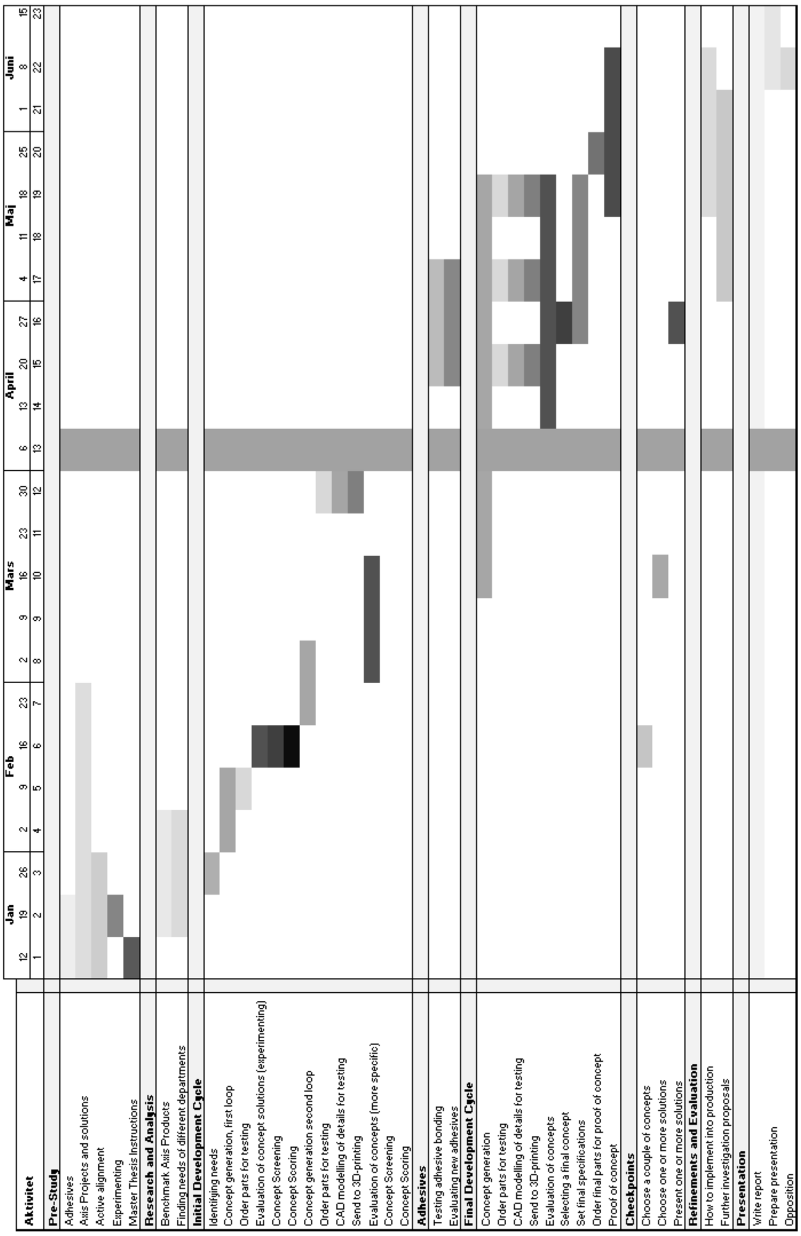
Figure E.2 One cycle in the temperature cycle test, unpublished internal document, photo by Florian Borza

Figure E.4 Angle between PCB card and reference surface**,** unpublished internal document, photo by Florian Borza

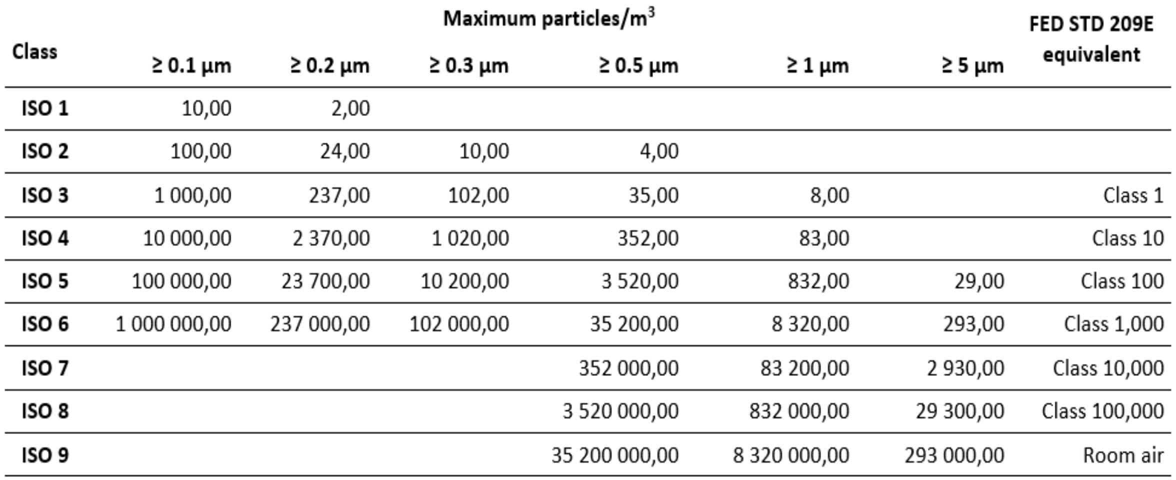
Appendix A: Preliminary Gantt-Scheme



Appendix B: Final Gantt-Scheme



Appendix C: ISO Class



Class	Maximum particles/m^3						FED STD 209E equivalent
	≥ 0.1 µm	≥ 0.2 µm	≥ 0.3 µm	≥ 0.5 µm	≥ 1 µm	≥ 5 µm	
ISO 1	10,00	2,00					
ISO 2	100,00	24,00	10,00	4,00			
ISO 3	1 000,00	237,00	102,00	35,00	8,00		Class 1
ISO 4	10 000,00	2 370,00	1 020,00	352,00	83,00		Class 10
ISO 5	100 000,00	23 700,00	10 200,00	3 520,00	832,00	29,00	Class 100
ISO 6	1 000 000,00	237 000,00	102 000,00	35 200,00	8 320,00	293,00	Class 1,000
ISO 7				352 000,00	83 200,00	2 930,00	Class 10,000
ISO 8				3 520 000,00	832 000,00	29 300,00	Class 100,000
ISO 9				35 200 000,00	8 320 000,00	293 000,00	Room air

Figure C.1 Laminar flow cabinet classification.

Appendix D: Interviewees

Table D.1 Interviewees within Axis

Interviewee	
Elin Carrander	Mechanical project lead, Axis
Fredrik Kullgren	Consultant Fixed dome cameras, Axis
Magnus Klügel	Polymer Specialist, Axis
Fredrik Sterngren	Senior engineer, Axis
Robert Boks	Regional Sales Manager, Delo
Thomas Elfström	Engineer production technology, Axis
Stig Frohlund	Experienced engineer, Axis
Ola Andersson	Mechanical project lead, Axis
Håkan Schultz	Experienced quality engineer, Axis
Glenn Svärd	Senior engineer PCB CAD, Axis
Martin Nyman	Production system manager, Axis
Mikael Persson	Engineer PTZ cameras mechanics, Axis
Carl Oreborg	Mechanical engineer, Axis
Johan Borg	Experienced Engineer, Axis
Jens Abrahamsson	Senior account manager, Boyd
Claes Andrén	Senior account manager, Boyd
Anthony Hornby	Sales Enquiry Contact, JK Lasers
Peter Betmark	Experienced Engineer, Axis

Appendix E: New Adhesive Evaluation

E.1 Purpose

A new adhesive was tested in order to give recommendations of production implementation and due to possible advantages together with the adhesive solution that were under consideration.

The purpose of these tests was to evaluate the new *UV 2*, in comparison to the currently used adhesive *UV 1*. Both adhesives require full UV light curing. They possess similar properties although the major difference being the viscosities. The viscosity of *UV 1* has been causing some troubles at Axis's EMS sites and the viscosity of this new adhesive could easily be changed. Thus, it would be preferable if this new adhesive could be used as a supplement to *UV 1* or even replace it in the future.

The tests were executed as test of comparison, i.e. both adhesives were used under similar circumstances. This was done to minimize the possible parameters of influence that affects could affect the results. Hence, the values of these experiments should be used as values comparable within the experiment, and with caution otherwise. The bond strength of the adhesives both at room temperature and after influence of temperature changes was tested. The position of the assembled components was also measured before and after temperature changes. The tests were done in resemblance to earlier adhesive tests done by Axis.

E.2 Experimental Setup

Testing of different adhesives has been done previously at Axis. Thus, the experiments were carried out in the same methodology as previously.

The curing equipment used had an output intensity of 20 000 mW/cm^2. The exact intensity at the adhesive was not measured. The light guide was approximately 15 mm from the adhesive giving an approximate intensity of 1700 mW/cm^2 at the adhesive.

The pins of the PCB holder were cleaned with isopropanol in order to minimize the risk of contaminations affecting the adhesive bonds.

The position of the PCB-cards was calibrated so that the pins of the PCB holder were centered in the holes of the PCB-cards with 0.1 mm offset. However, variances from the manufacturing of the PCB holders resulted in some pins with off-centered alignment. Therefore, efforts were made to find the optimal position for each PCB holder, i.e. having all pins as centered as possible.

The amount of adhesive used was approximately 6.8 mg/hole for *UV 1* and 7.3 mg/hole for *UV 2*. This was taken as the average value of ten adhesive drops.

In order to minimize the risk of uncured adhesive in the lighted bond area, the curing time was set to 30 seconds for both adhesives. The adhesive joints were also evaluated and no uncured adhesive could be found in the lighted area. However, a small amount of uncured adhesive was located in the shadowed areas of the backside of the PCB-card for many joints.

E.3 Tests

100 PCB-cards were assembled together with a sensor gasket and then glued onto PCB holders, and overview can be seen in Table E.1.

Table E.1 Specimen overview.

UV 1	UV 2
•10 pieces of reference	•10 pieces of reference
•20 pieces in temperature cycling	•20 pieces in temperature cycling
•10 pieces heated	•10 pieces heated
•10 pieces frozen	•10 pieces frozen

E.3.1 Push-out Test

The strength of the adhesive was tested at room temperature for all different specimens. The test was performed in a machine where the PCB card was pushed until failure, i.e. the PCB card is released from the holder. The push-out probe of the machine was centered in the hole of the PCB holder. An example of this can be seen in Figure E.1. For each adhesive, 10 specimens where used as a reference to this test.

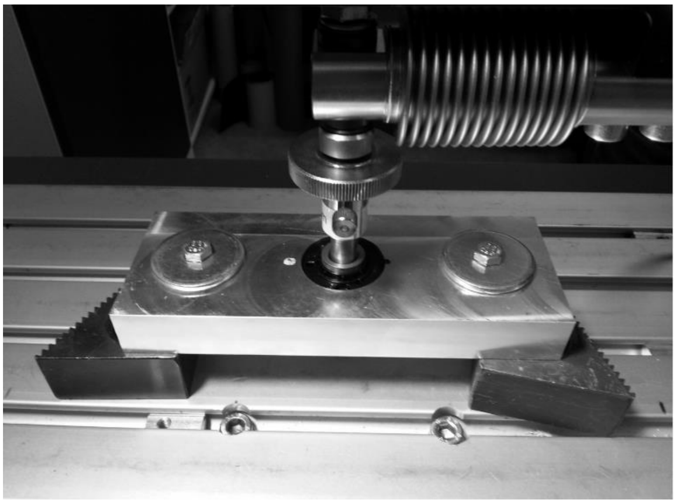


Figure E.1 Example of push-out test.

E.3.2 Temperature Variation

Test were performed to examine if cycling between the boundary temperatures, -40°C and 85°C, had an effect on the bond strength and positioning of the PCB-card, after returning to room temperature. The temperature cycling process was ongoing five days, i.e. 120 hours. The position of the PCB cards were measured prior to the climate chamber, and then later measured at room temperature. An illustration of one temperature cycle can be seen in Figure E.2. For each adhesive, 20 specimens were evaluated, see Figure E.3.

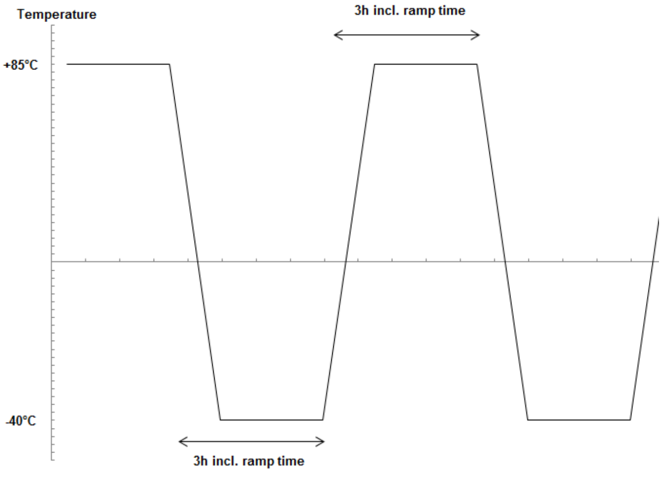
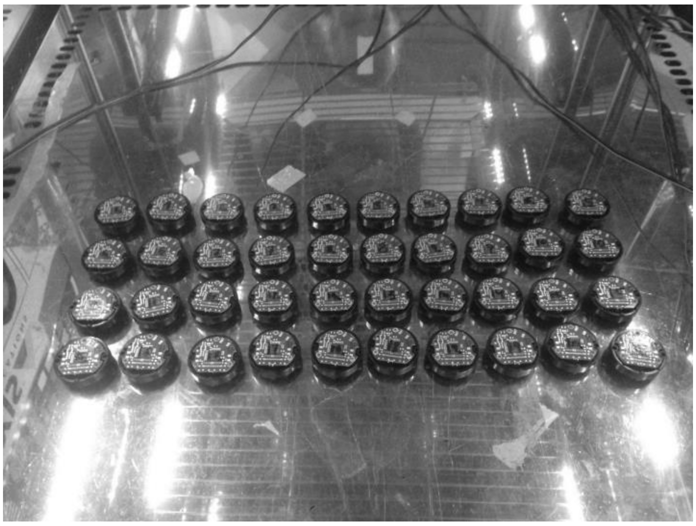


Figure E.2 One cycle in the temperature cycle test.

Further tests were done to investigate the PCB card's positional changes at outer boundary temperatures: -40°C and 85°C. For each adhesive, 10 specimens were put in a climate chamber for 3 hours at -40°C and 10 specimens were put in a climate chamber for 3 hours at 85°C. The position of these PCB cards was measured prior to this, and after three hours, the specimens were taken out of the climate chamber one by one the PCB cards positions were quickly measured. The temperature change during the measurements was also recorded. As temperatures changed during the measurements, both tests should be analyzed with these variations in mind.



E.3 Specimens in a climate chamber.

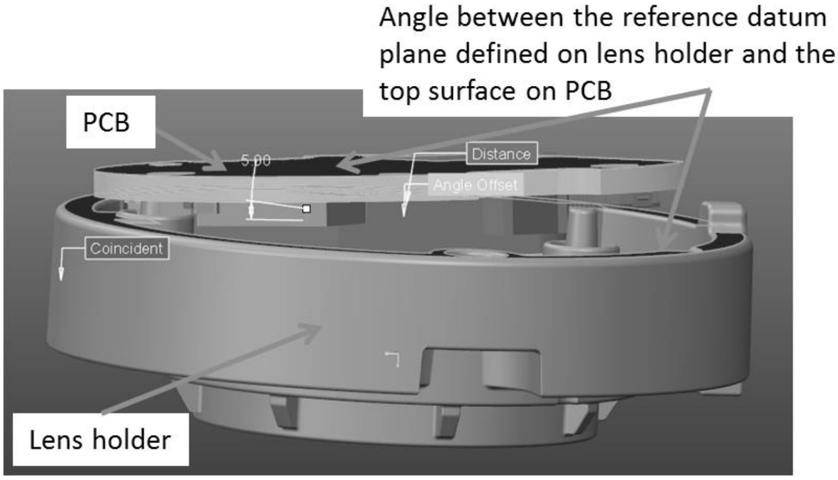
E.3.3 Measuring Displacement

Measurements of the PCB-card's relative position to the PCB holder, see Figure E.4, were performed using optical equipment. The optical instrument was calibrated to recognize small areas of the PCB cards, where certain shaped were present, though in the proximity of the pins. When the z-distance later was measured, much more accurate results was obtained by measuring on these specific areas with gold plating, than measuring on an arbitrary surface of the PCB card. The measurements gave the:

- X-position
- Y-position
- Z-position

at three different positions of the PCB card. Further calculations gave the:

- Planarity of the PCB card
- Maximal angle between the PCB card and the reference surface of the PCB holder, see Figure E.4.



Angle between the reference datum plane defined on lens holder and the top surface on PCB

Figure E.4 Angle between PCB card and reference surface.

E.4 Results

Regarding the measurements of the PCB-card's relative position to the PCB holder, failure aspects of the specimens were set at level where the movement would cause a deteriorated image quality. This level is project specific and the chosen corresponds to the limit of the chosen test camera. Maximum allowed movement for the PCB cards during this test were chosen similarly to earlier tests. Thus, z-movement above 20 µm, and x-/y-movement above 50 µm resulted in failed samples. The final results of the measurements can be seen in Figure E.5, E.6 and E.7.

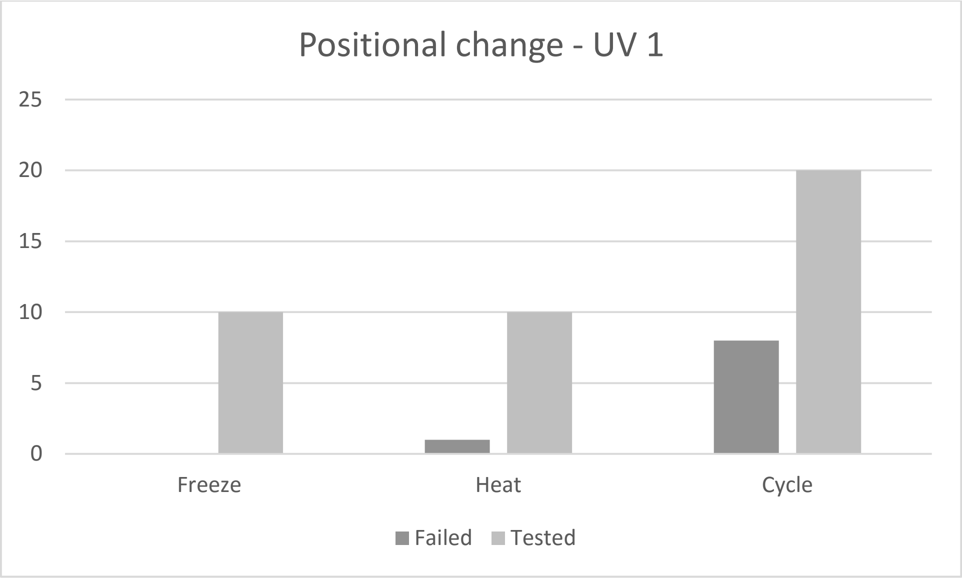


Figure E.5 Evaluation of the positional changes during temperature cycling for *UV 1*.

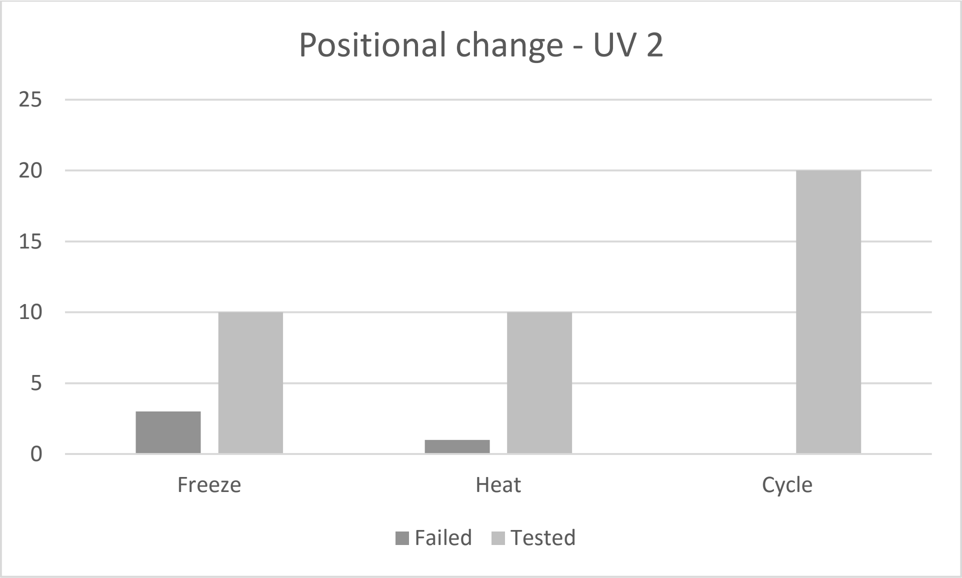


Figure E.6 Evaluation of the positional changes during temperature cycling for *UV 2*.

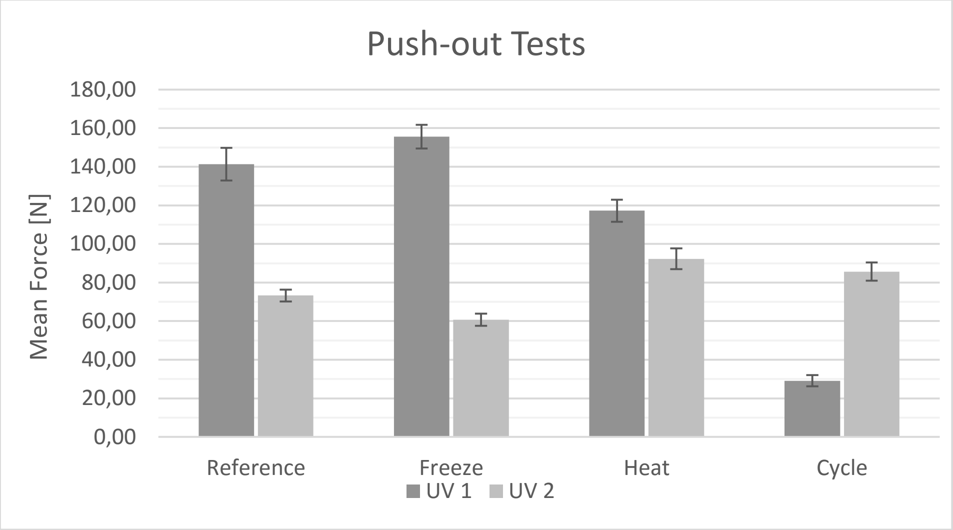


Figure E.7 Results of the push-out test for both *UV 1* and *UV 2*.

E.5 Discussion and Conclusions

E.5.1 UV 1

The adhesive joints of *UV 1* were strong at room temperature and after the freezing test. After the heating test as well as the temperature cycling, the adhesive became soft. This is also confirmed in both the push-out test and the positional change of the PCB-card. Other tests have shown that additional curing in an UV oven prevents *UV 1* from softening at high temperatures. See "Test report M30-rework units".

E.5.2 UV 2

The adhesive had lower bond strength at room temperature than *UV 1*, and seemed fairly unaffected by the lower temperature test in regards to bond strength. However, movement outside of the permitted range was detected. In comparison with *UV 1* there was more movement for *UV 2* in the freeze test.

A further interesting analysis is that the adhesive seems to have heat curing effects, seen at the push-out results. It becomes evident that something has occurred during the heating of the adhesive, which is permanent even during the temperature cycling. Why this occurred is not clear, but similar unexplainable behavior had been observed before with purely UV curing adhesive.

The lower bond strength of *UV 2* at room temperature could possibly relate to the small amount of adhesive used in the joints. In resemblance to the earlier tests the difference between using 10 milligrams and 15 milligrams per adhesive joint resulted in push-out tests corresponding to approximately 75 N to 175 N.

After the tests were completed it was suggested that a wavelength of 400 nm instead of 365 nm might improve the bond properties. Measuring the intensity at the adhesive joint and then calibrate it to 200 mW/cm^2 might also improve the properties.

E.5.3 Conclusion

This was the firsts tests carried out on the new adhesive *UV 2*. These indicate that it can be used as an alternative to *UV 1*, but it requires a more thorough evaluation. The adhesive also needs to be tested for the specific project wanting to implement it.

Appendix F: Concept Scoring – Adhesive

Table F.1 Concept Scoring - Adhesive

Selection Criteria	Weight	A1 - WALL		A2 - PCB-CONNECTOR		A3 - CONTROL ADHESIVE		A4 - MIRRORS		A5 - REDIRECT LIGHT	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Suitable for mass production	**20%**	-	**0,6**	-	**0,775**	-	**0,8**	-	**0,7**	-	**0,7**
Ease of manufacture	2,5%	4	0,1	3	0,075	4	0,1	3	0,075	3	0,075
Time in production	7,5%	4	0,3	4	0,3	4	0,3	3	0,225	3	0,225
Room for mistakes	10%	2	0,2	4	0,4	4	0,4	4	0,4	4	0,4
Degrees of alignment	**15%**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**
Good fix	**15%**	**4**	**0,6**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**
Risk	**30%**	-	**0,65**	-	**1**	-	**1,05**	-	**1**	-	**1**
Undamaged components	5%	2	0,1	3	0,15	4	0,2	3	0,15	3	0,15
Stable fixing process	10%	1	0,1	4	0,4	4	0,4	4	0,4	4	0,4
Method not affecting alignment	15%	3	0,45	3	0,45	3	0,45	3	0,45	3	0,45
Implementation	**15%**		**0,55**		**0,45**		**0,55**		**0,3**		**0,3**
Investment cost	5%	3	0,15	3	0,15	3	0,15	3	0,15	2	0,1
Generality of method	5%	4	0,2	3	0,15	4	0,2	1	0,05	1	0,05
Space conservative	5%	4	0,2	3	0,15	4	0,2	2	0,1	3	0,15
Environment	**5%**		**0,15**		**0,15**		**0,15**		**0,15**		**0,15**
Ease of recycling	2,5%	3	0,075	3	0,075	3	0,075	3	0,075	3	0,075
Environmental friendly	2,5%	3	0,075	3	0,075	3	0,075	3	0,075	3	0,075
Total	**100%**	-	**3**	-	**3,275**	-	**3,45**	-	**3,05**	-	**3,05**

1 Much worse than reference, 2 Worse than reference, 3 Same as reference, 4 Better than reference, 5 Much better than reference

Table F.2 Concept Scoring - Adhesive

Selection Criteria	Weight	A6 - GLUE MODULE Rating	A6 - GLUE MODULE Weighted Score	A7 - SPIDER Rating	A7 - SPIDER Weighted Score	A8 - REMOVABLE WALL Rating	A8 - REMOVABLE WALL Weighted Score	A1 + A3 - WALL + Control Adhesive Rating	A1 + A3 - WALL + Control Adhesive Weighted Score
Suitable for mass production	**20%**	-	**0,725**	-	**0,625**	-	**0,7**	-	**0,875**
Ease of manufacture	2,5%	3	0,075	3	0,075	3	0,075	3	0,075
Time in production	7,5%	2	0,15	2	0,15	3	0,225	4	0,3
Room for mistakes	10%	5	0,5	4	0,4	4	0,4	5	0,5
Degrees of alignment	**15%**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**
Good fix	**15%**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**	**4**	**0,6**
Risk	**30%**	-	**1,05**	-	**0,95**	-	**0,8**	-	**0,9**
Undamaged components	5%	4	0,2	5	0,25	4	0,2	4	0,2
Stable fixing process	10%	4	0,4	4	0,4	3	0,3	4	0,4
Method not affecting alignment	15%	3	0,45	2	0,3	2	0,3	2	0,3
Implemtation	**15%**		**0,4**		**0,4**		**0,4**		**0,5**
Investment cost	5%	3	0,15	3	0,15	3	0,15	3	0,15
Generality of method	5%	3	0,15	2	0,1	2	0,1	4	0,2
Space conservative	5%	2	0,1	3	0,15	3	0,15	3	0,15
Environment	**5%**		**0,15**		**0,15**		**0,15**		**0,15**
Ease of recycling	2,5%	3	0,075	3	0,075	3	0,075	3	0,075
Environmental friendly	2,5%	3	0,075	3	0,075	3	0,075	3	0,075
Total	**100%**	-	**3,225**	-	**3,025**	-	**2,95**	-	**3,475**

1 Much worse than reference, 2 Worse than reference, 3 Same as reference, 4 Better than reference, 5 Much better than reference

Appendix G: Concept Scoring - Melting

Table G.1 Concept Scoring - Melting

Selection Criteria	Weight	M1 - BALL		M2 - RING		M3 - MELTING WALLS	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Suitable for mass production	**20%**	-	**0,875**	-	**0,875**	-	**0,425**
Ease of manufacture	2,5%	3	0,075	3	0,075	3	0,075
Time in production	7,5%	4	0,3	4	0,3	2	0,15
Room for mistakes	10%	5	0,5	5	0,5	2	0,2
Degrees of alignment	**15%**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**
Good fix	**15%**	**4**	**0,6**	**4**	**0,6**	**5**	**0,75**
Risk	**30%**	-	**0,7**	-	**1**	-	**0,45**
Undamaged components	5%	4	0,2	3	0,15	4	0,2
Stable fixing process	10%	2	0,2	4	0,4	1	0,1
Method not affecting alignment	15%	2	0,3	3	0,45	1	0,15
Implemtation	**15%**	-	**0,25**	-	**0,35**	-	**0,2**
Investment cost	5%	1	0,05	1	0,05	1	0,05
A general method would be preferable	5%	2	0,1	3	0,15	1	0,05
The solution is space conservative	5%	2	0,1	3	0,15	2	0,1
Environment	**5%**	-	**0,175**	-	**0,175**	-	**0,175**
Ease of recycling	2,5%	3	0,075	3	0,075	3	0,075
Environmental friendly	2,5%	4	0,1	4	0,1	4	0,1
Total	**100%**	-	**3,05**	-	**3,45**	-	**2,45**

1 Much worse than reference, 2 Worse than reference, 3 Same as reference, 4 Better than reference, 5 Much better than reference

Appendix H: Concept Scoring - Screwing

Table H.1 Concept Scoring - Screwing

Selection Criteria	Weight	S1 - JOINTED SCREW		S2 - SET SCREW		S3 - FIX SCREW		S4 - ROCKET SCREW		S5 - ADHESIVE SET PLATE	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Suitable for mass production	**20%**	-	**0,55**	-	**0,5**	-	**0,75**	-	**0,75**	-	**0,6**
Ease of manufacture	2,5%	1	0,025	2	0,05	2	0,05	1	0,025	2	0,05
Time in production	7,5%	3	0,225	2	0,15	4	0,3	3	0,225	2	0,15
Room for mistakes	10%	3	0,3	3	0,3	4	0,4	5	0,5	4	0,4
Degrees of alignment	**15%**	**3**	**0,45**	**2**	**0,3**	**1**	**0,15**	**3**	**0,45**	**3**	**0,45**
Good fix	**15%**	**3**	**0,45**	**2**	**0,3**	**3**	**0,45**	**2**	**0,3**	**3**	**0,45**
Risk	**30%**	-	**0,65**	-	**0,7**	-	**0,65**	-	**0,8**	-	**0,8**
Undamaged components	5%	3	0,15	3	0,15	3	0,15	3	0,15	3	0,15
Stable fixing process	10%	2	0,2	1	0,1	2	0,2	2	0,2	2	0,2
Method not affecting alignment	15%	2	0,3	3	0,45	2	0,3	3	0,45	3	0,45
Implemtation	**15%**		**0,4**		**0,35**		**0,35**		**0,35**		**0,4**
Investment cost	5%	3	0,15	3	0,15	3	0,15	3	0,15	3	0,15
A general method would be preferable	5%	2	0,1	2	0,1	1	0,05	2	0,1	2	0,1
The solution is space conservative	5%	3	0,15	2	0,1	3	0,15	2	0,1	3	0,15
Environment	**5%**		**0,2**		**0,2**		**0,2**		**0,15**		**0,15**
Ease of recycling	2,5%	4	0,1	4	0,1	4	0,1	3	0,075	3	0,075
Environmental friendly	2,5%	4	0,1	4	0,1	4	0,1	3	0,075	3	0,075
Total	**100%**	-	**2,7**	-	**2,35**	-	**2,55**	-	**2,8**	-	**2,85**

1 Much worse than reference, 2 Worse than reference, 3 Same as reference, 4 Better than reference, 5 Much better than reference

Appendix I: Concept Scoring - Clamping

Table I.1 Concept Scoring - Clamping

Selection Criteria	Weight	C1 - SPHERICAL CLAMP		C2 - WALL CLAMP		C3 - JOINTED PIN	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Suitable for mass production	**20%**	-	**0,675**	-	**0,7**	-	**0,675**
Ease of manufacture	2,5%	2	0,05	3	0,075	2	0,05
Time in production	7,5%	3	0,225	3	0,225	3	0,225
Room for mistakes	10%	4	0,4	4	0,4	4	0,4
Degrees of alignment	**15%**	**3**	**0,45**	**3**	**0,45**	**3**	**0,45**
Good fix	**15%**	**3**	**0,45**	**2**	**0,3**	**3**	**0,45**
Risk	**30%**	-	**0,55**	-	**0,5**	-	**0,65**
Undamaged components	5%	4	0,2	3	0,15	4	0,2
Stable fixing process	10%	2	0,2	2	0,2	3	0,3
Method not affecting alignment	15%	1	0,15	1	0,15	1	0,15
Implemtation	**15%**		**0,35**		**0,4**		**0,35**
Investment cost	5%	3	0,15	3	0,15	3	0,15
A general method would be preferable	5%	2	0,1	2	0,1	2	0,1
The solution is space conservative	5%	2	0,1	3	0,15	2	0,1
Environment	**5%**		**0,25**		**0,25**		**0,25**
Ease of recycling	2,5%	5	0,125	5	0,125	5	0,125
Environmental friendly	2,5%	5	0,125	5	0,125	5	0,125
Total	**100%**	-	**2,725**	-	**2,6**	-	**2,825**

1 Much worse than reference, 2 Worse than reference, 3 Same as reference, 4 Better than reference, 5 Much better than reference

Appendix J: Proof of Concept Testing

J.1 Test Set-up

The tests were performed similarly to the tests in Appendix E: New .

In order to control the adhesive curing process, a fixture for the UV light guides were constructed. Two of the fixture surfaces were used as reference surfaces, by which the specimens were aligned against. Thus, the position of each specimen was sufficiently accurate to allow fixing the UV light guides onto the fixture. The fixing of the light guides was done with blu-tack. The light guides were centered 10 millimeters above position of the adhesive joints. The fixture can be seen in Figure J.1.

Figure J.1 The UV light fixture.

The wall of the PCB holders and the outer surface of the PCB cards were treated with isopropyl, to remove possible contamination that might have disturbed the adhesive joints. This pre-treatment were done three hours before the adhesive process. The PCB cards were left untreated as they were unpackaged for the tests. Additionally, problems have occurred when cleaning the PCB cards as it easily absorbs the isopropyl, this will lead to a bad adhesion to the PCB card. Due to this risk the PCB cards were not cleaned with isopropyl. The gaskets were not cleaned as the gasket surface should not contribute to the adhesive bonds.

The two gaskets, of two different shore hardness's, were evaluated in the push-out machine to obtain the required force when compressing the gasket 0.3 mm. This was the assumed nominal position of the gasket as alignment begins in production. The two forces was recorded and the softest gasket was selected to the tests were compression of the gasket seemed necessary. The harder gasket was used in the remaining test due to a limited amount of soft gaskets. Then followed a repeatable process for all specimens:

- A gasket was assembled into the PCB holder. The design of the gasket made the positioning of this assembling operation easy, as it became sufficiently centered with manual assembling.
- The PCB card was assembled onto the gasket, with effort on placing it in the center of the gasket. No adhesive tape was used in the tests but should be used in combination in a fixture in production.
- A weight corresponding to the compression displacement of 0.3 mm was used, to evaluate the specimens under static loads, especially during temperature variances.
- Adhesive was dispensed between the wall and the PCB card, at the four adhesive dispensing areas.
- A quick active alignment process was simulated, to mimic the production method and to improve the wetting of the bonds.
- The assembly was placed against the reference surfaces of the fixture.
- The UV light guides were activated for 30 seconds. See Figure J.2.
- Following, the assembly was put in an UV oven for an additionally 60 seconds.

Figure J.2 Fixture with PCB card and UV lamps activated.

The push-out tests were carried out in the same manner as the push-out tests in Appendix E: New . However, a customized fixture was used, which can be seen in Figure J.3.

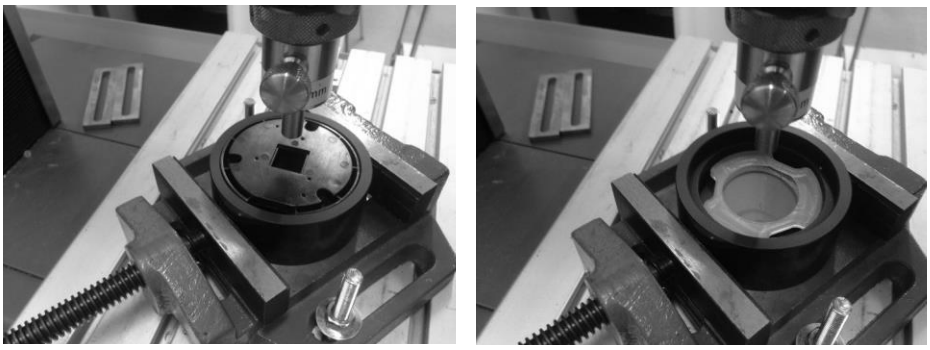


Figure J.3 a) Push-out fixture b) a pushed sample with PCB holder removed.

J.2 Measuring

One measurement was made after the adhesive fixing and another after the temperature cycling. The comparison of these two measurements for each individual assembly, gave the movements of the PCB card corresponding to its PCB holder.

The specimens were measured similarly to the specimens of the Appendix E: New . However, this time a fixture was not used. Similarly to the adhesive curing fixture, two reference surfaces of the PCB holder were used to position the specimens. As in Appendix E: New an optical instrument was used for the measuring. This time, the instrument was set to one additional decimals accuracy.

Initially, the optical instrument measured the absolute position of the PCB holder, as every piece differs due to manufacturing tolerances. Then, a reference plane was created for each PCB holder, i.e. a reference surface for the other measurements determining the position of the PCB card.

Four circles of tin, 1 millimeter diameter, was included in the design of the PCB card, see Figure J.4. These circles were targeted by the optical instrument by shape recognition, and when targeted more accurate z-distances could be measured, as tin has a structure suitable for optical measurements.

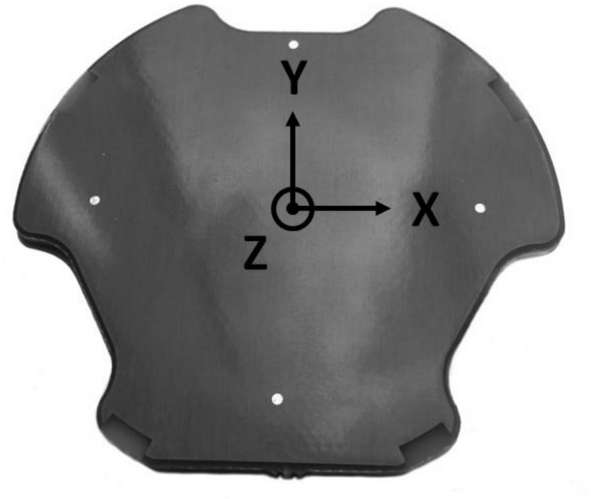


Figure J.4 PCB card with four measurement points.

However, in the manufacturing of these PCB cards, the shape of these circles was not sufficiently accurate to allow automatic measuring. Thus, these circles had to be located and targeted manually. The x- and y-position of each circle was recorded and gave an average position of the center of the PCB card. The z-distance was also measured within these circles. With these positions, a plane of the PCB card could be determined and further give the maximal angle to the reference surface.

J.3 Temperature Cycling

The temperature cycling test was performed as the tests in Appendix E: New . Some reference pieces were put in the oven, where the gaskets had not been compressed at all. In this way, some specimens were unaffected by compression forces, which otherwise could result in creeping during the temperature cycling.

J.4 Discussion

The optical instrument was set to one additional decimals accuracy. This was done to see even smaller movements, but it should be noted that these numbers gives lower accuracy representation than the numbers used in the earlier experiment.

As time was of the essence, preparations for this test were done very quickly. This resulted in fast solutions to the experimental issues, such as the fixture for the adhesive curing. It was unfortunate that the UV light guides were fixed by using duct tape, as this could allow movement during the test. However, the fixture served its purpose extraordinary, and the light guides where kept sufficiently fixed during the entire experiment.

The manual targeting of the tin circles introduces small errors to the measurements, even though it was executed with effort of high accuracy. Yet, this only affected the x- and y-position. Further as these positions where taken at four different places and then averaged to one central position, this error was minimized.