MICRONIC MYDATA

KTH VETENSKAP OCH KONST

KTH Engineering Sciences

Applied Physics Department, Laser Physics

Establishing Measurement Method of a Large OMEMS and Investigation for Global Planarity Improvements

Howard Andersson

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KTH

Supervisor at Micronic Mydata: Peter Björnängen
Examiner: Lars Gunnar Andersson
Supervisor at KTH: Fredrik Laurell

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Abstract

This thesis investigates if it is possible to further improve the global planarity of the already extremely planar Spatial Light Modulator used in the Laser Direct Imaging machine designed and manufactured by Micronic Mydata. Furthermore it is necessary to establish a method to correctly measure the SLM in-house at the Täby HQ of Micronic Mydata to be able to control whether or not the global planarity has improved during the experiments. The planarity of the SLM is measured by three parameters; P1 which describes the tilt in the short direction, P2 which describes the arch/bow along the short end and finally T that describes the angular change along the long end of the SLM.

The experiments that were executed attempted to force the SLM towards the surface of an aluminum block using a fixed vacuum on the underside of the bock. The equipment used to perform the measurements was a Fisba interferometer with a 50 mm lens. Since the SLM that was to be measured was longer than 5 cm two measurements were taken to cover the whole surface of the SLM. These two datasets were then merged using Matlab to create one cohesive dataset representing the entire SLM. The dataset was then interpolated to a larger dataset to be compatible with a pre-written program to extract the parameters P1, P2 and T.

The experiments showed that the global planarity of the SLM became worse when the surface of which it was glued upon did not have a better global planarity than the SLM itself. To reference whether or not the data merging code could correctly represent the parameters P1, P2 and T an SLM with known parameters was analyzed. The results were that P2 and T could approximately be represented when 10 measurements of the same SLM had been taken and the mean values were used. The mean values for the parameter P1 did not coincide with the values supplied by the manufacturer IPMS of the SLM. Tests were performed to check whether or not the established method could correctly represent P1. The tests showed that P1 could be measured properly although more tests using known twists would be optimal. Since the SLMs used during the experiments and measurements were not bonded to a ceramic as is the norm it is very possible that they did not behave in a usual manner. The measurements performed showed that the shape of the SLM is stable over time when the same results for P1, P2 and T were obtained with two months between measurements.

Acknowledgements

I would like to dedicate this project to my grandfather Reinhold Bengtsson that passed away on the 1st of March 2013. He was an engineer and an extremely honorable man and a true inspiration to me.

I would like to begin with thanking my examiner Lars Gunnar Andersson and my supervisor at KTH Fredrik Laurell for allowing me to do my thesis at their department and being so welcoming. Next I would greatly like to thank my supervisor at Micronic Mydata Peter Björnängen for being so supportive and offering good guidance when it was needed. His insight and experience really helped me during the entire project and for that I am grateful. I am also very grateful that Peter believed in me and chose me for this project. I enjoyed seeing the inner workings of the company life before finally graduating. I would also like to thank Andreas Bergström "the architect" of the pre-existing code my code was supposed to be compatible with. We had many conversations regarding different aspects of the SLM and the code he had written and Andreas helped me several times. I would also like to thank Mikael Blomström for all his assistance in assembling and creating the measurement setup after my design and Drago Babic for his help in measuring the aluminum blocks used in my experiments. Thanks are in order to Fredrik Jonsson, Henrik Karlsson, Charles Björnberg, Mats Rosling and Sten Lindau for helping me in different ways along the course of my project.

I would like to end by thanking my wonderfully supportive wife Hanna because without her I do not know where I would have been!

Contents

Introduction

Background

Micronic Mydata AB

Micronic Mydata is a company that is specialized in developing and manufacturing production/assembly line machines for the electronics industry. The company was founded in 2009 after a merger between MYDATA Automation AB and Micronic Laser Systems. MYDATA Automation AB was founded in 1984 and specialized in Surface Mount Technology (SMT) machines. In 2005 they released the MY500 which was a Jet Printing system for applying solder paste in an extremely flexible manner. Micronic Laser Systems were specialized in designing and producing Pattern Generators (PG). Micronic Mydata AB now offer PG machines to create masks for displays (Prexision series), semiconductors (Sigma and Omega series) and electronic packaging (FPS5500) where the company has a monopoly on the mask display market. The monopoly gained by Micronic Mydata was due to the fact that none of their previous competitors could rival their machines when it came to pattern fidelity and placement accuracy.

The main areas of business for Micronic Mydata are providing the electronics industry with pattern generators, SMT machines (e.g. Pick&Place and Ink Jet printing) and servicing these machines for their customers. Currently Micronic Mydata offers two different types of pattern generators. There two options are mask writers or direct writers such as the LDI (Laser Direct Imaging). The LDI has just entered the market and is considered to be the pattern generator of the future.

Laser Direct Imaging (LDI)

Micronic Mydata have been the market leader when it comes to pattern generators/mask writers and ensures to keep their lead thanks to the LDI. The advantage of the LDI is that it writes the desired pattern directly on the substrate with no need of a mask and without sacrificing any speed or precision. A major advantage with the LDI is that it offers manufacturers the possibility to be extremely flexible when writing patterns which in turn reduces costs. The LDI is dedicated to Chip-Scale Packaging (CSP) also known as Flip Chip and are an evolution of Wafer Level Packaging (WLP) technology. The trend in consumer electronics for smaller, more portable, lighter devices has driven the need for smaller packaging alternatives leading to CSP.

The LDI uses a Spatial Light Modulator (SLM) which is essential when it comes to the pattern generation and will be explained in further detail in the next section. To write a pattern on the desired panel (Figure 1) a table with the substrate is loaded into the LDI via the twin table system and will pass underneath the three wide-field alignment cameras to do the alignment. The alignment is done in real time to compensate for any irregularities or distortions on the panels. At the same time the alignment measurements are being made the focus required to write on the surface is also measured. After the alignment the table is carried using a linear motor (along the Y-direction) towards the LDI's rotor driven writing section. The table is carried continuously in the Y-direction whilst the rotor also moves impulse free in the X-direction during full exposure. The twin table system allows for the LDI system to work on two substrates at the same time. Whilst one of the substrates is being written on the other substrate will be measured for proper alignment and focus. A high powered 355 nm diode-pumped solid state laser is directed towards the SLM via a patented optical path. The SLM generates the desired grey scale pattern which is then projected through a cylindrical lens on to a pyramided prism. This prism is responsible for which rotor arm writes on the substrate.

After an arm has finished writing on the substrate and is no longer above the substrate the prism switches to the next arm. The illuminated pattern on the substrate is parallel with the Y-axis in the figure and about 14 mm long and a few micrometers wide [1].

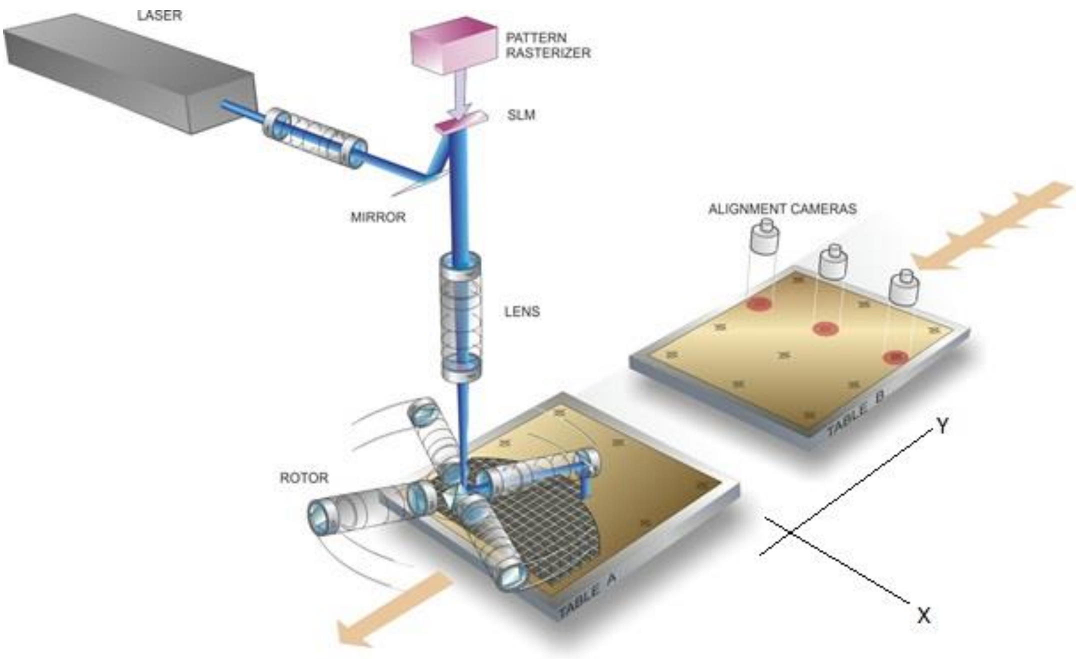

Figure 1 High level schematic for how the LDI pattern generator works. [1]

The technique of direct writing developed at Micronic Mydata with the LDI permits to create copper patterns 15 µm high and ca. 9 µm wide with a spacing of 12 µm to adjacent patterns. The method used for obtaining desired patterns and structures is explained in the following figures. On top of the substrate is a 1 µm thick layer of copper which is addressed as the Copper Seed due to the ability to let copper “grow” on its surface which will be explained further. A 25 µm thick layer of Dry Film Resist is placed on top of the Cu Seed (Figure 2A).

When the LDI writes the desired pattern on the panel the pattern is projected on to the DFR down to the level of the Cu Seed. In the areas where the pattern is projected (light wavelength of 355 nm) the monomers in the DFR form to become polymers. The areas with the polymer filled DFR will then remain after a process is completed that removes the monomer filled DFR. When using 25 µm thick DFR to obtain a certain pattern the “well” that has been written in the DFR can be 12 µm wide and should be placed at least 9 µm away from any other pattern (Figure 2 B).

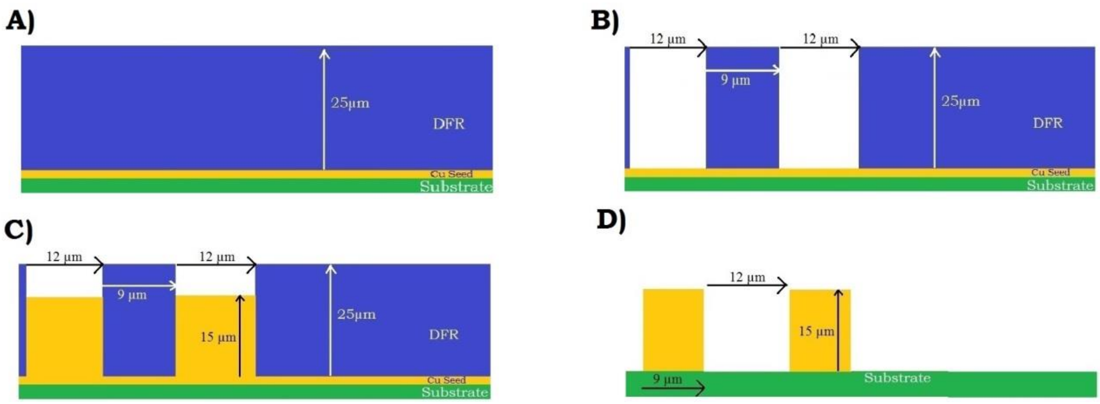

Figure 2 ***The figures above briefly show the process flow for obtaining the desired patterns on a substrate using the LDI.***

After the pattern has been written in the DFR the "wells" are filled with copper via electroplating (Figure 2 C) which is possible due to the Copper Seed. The "wells" are filled with 15 µm of copper at a maximum to avoid any risks of possible spillage of copper outside of the written pattern.

Once the electroplating is complete, the DFR can be removed by being etched away. In a separate process the Copper Seed is etched away to avoid any short circuiting between patterns. Parts of the copper structures are etched away during the etching process along with the Cu Seed. This results in the copper structures to diminish in width from 12 µm to 9 µm and the distance between patterns to increase from 9 µm to 12 µm (Figure 2 D). The height of the copper deposited during electroplating decreases by 1 µm but the 1 µm level of Cu Seed compensates for this and the copper structure remains 15 µm high. When writing in a DFR thinner than 25 µm it is possible to achieve copper structures that are placed more closely together but slightly shorter in height.

Spatial Light Modulator (SLM)

The Spatial Light Modulator is an array of 8193 times hundreds of micro mirrors (Optical MEMS). Each of the 8193 pixels (each containing hundreds mirrors) can be individually controlled and angled into 256 different positions making it possible by the acquired gray scale to optically position the printed line much more accurately than the pixel resolution of the SLM. The projected image of the array of mirrors is reduced resulting in the printed line is much smaller than the actual length of the SLM as is portrayed in Figure 3. The projection optics used as seen in Figure 1 consists of spherical lenses that work as a focus actuators concentrating the projected image on to a smaller surface. This enables the LDI to write a pattern on the substrate in a smaller scale than that of the pixels on the SLM's surface.

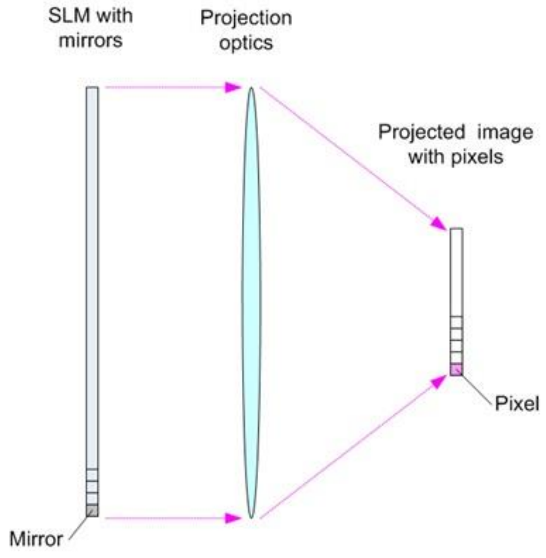

Figure 3 ***The pattern generated by the SLM decreases in size when projected. [1]***

As mentioned previously the mirrors can be angled into several different positions to achieve the right gray scale for the printed line. This is realized using a filter in the form of an aperture as seen in Figure 4.

When a white pixel is desired the mirrors are flat (not angled) so that a peak with the highest light intensity reflected is situated at the aperture. In contrast when a black pixel is desired the mirrors are angled so that the highest reflected light intensities are situated away from the aperture resulting in no light passing through the filter and a black pixel.

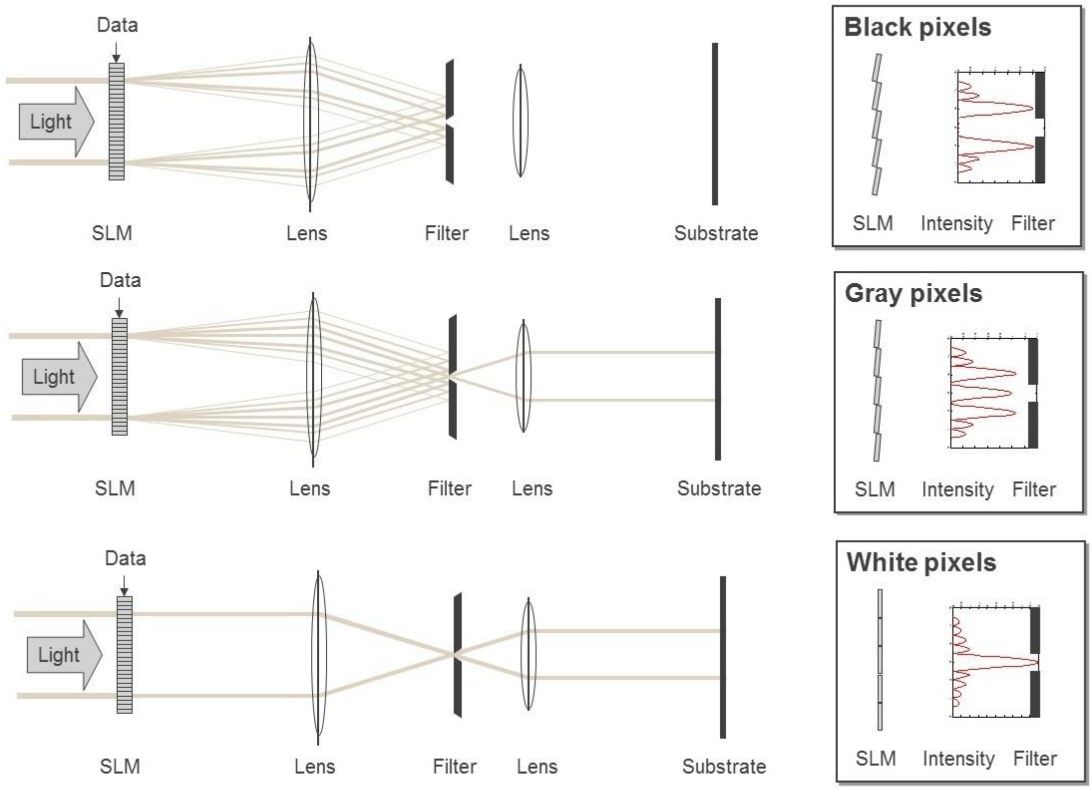

Figure 4 ***The figures above show how the light intensity is seen at the filter resulting in the according color at the substrate. [1]***

To achieve a gray pixel the mirrors are angled so that the peaks of light intensity reflected are dispersed across the filter so the intensity at the aperture is diminished in comparison to that of a white pixel.

Below each side of the mirrors are address and counter electrodes as seen in Figure 5. By charging these electrodes with a certain voltage an electro static field is created between the electrode and the mirror surface which attracts the mirror's surface with different forces depending on the side of the mirror. This is how the mirrors are controlled to be angled to achieve the desired gray scale image. The voltage used to address the electrode beneath the mirror edge may vary between -25 and +25 V.

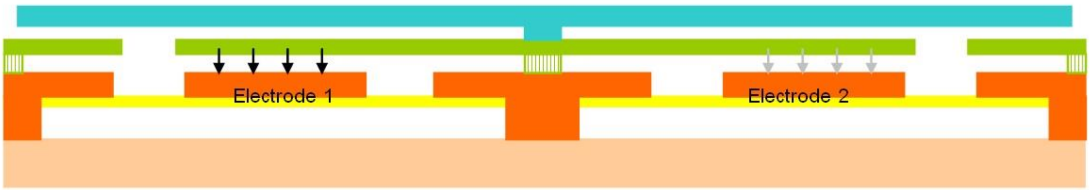

Figure 5 ***Cross section of an SLM mirror. [2]***

Parameters of interest for the LDI's SLM

The parameters which determine the global planarity of the SLM are referred to as P1, P2 and T. The Description of Global Planarity Specification [3] explains these parameters in detail, in this section they are briefly explained to give a general understanding of their value in relation to the planarity of the SLM. These brief explanations can be seen in Figure 6, Figure 7 and Figure 8.

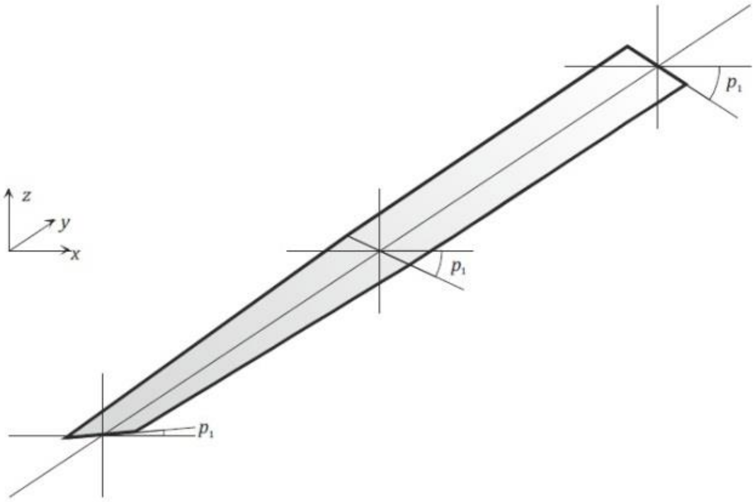

Figure 6

The parameter P1 refers to the angle the short end twists in relation to the X-axis along the length of the mirror array (Y-axis).

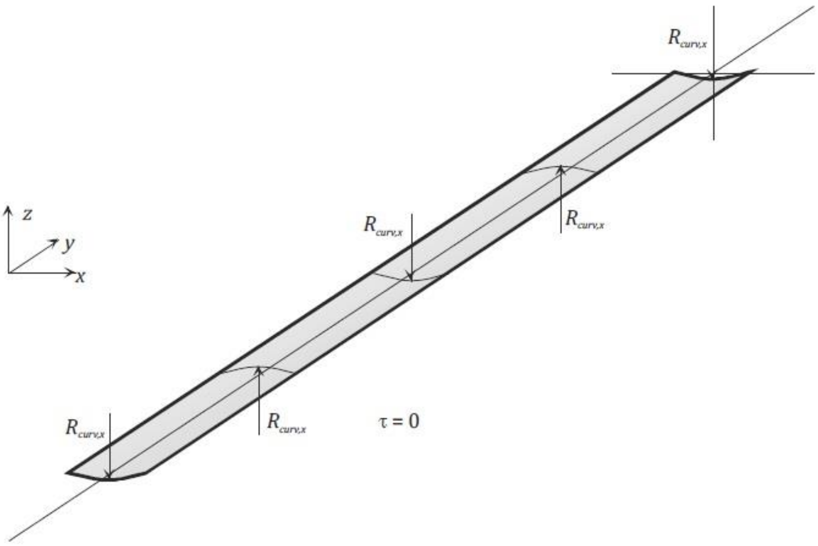

Figure 7

The parameter P2 describes the bow along the short end and is inversely proportional to the radius of the bow.

$$T(y) = \frac{dz_{GF}(y)}{dy}$$

Figure 8 ***Parameter T describes height variation along the length of the SLM. T can also be seen as the angle of change along the Y-axis.***

To be able to achieve the best performance from an SLM it is important that all these are as small as possible. Although when each SLM is installed in an LDI system it is possible to calibrate the optics system that reads the patterns off the SLM to compensate for any spherical shapes that exist along the short or long end of the SLM (P2 and T). Since the spherical shapes can be compensated for it is important that the residual parameters for P2 and T are as low as possible. There is no optical method to compensate for the twist (P1) along the SLM however P1 is compensated for by the writing algorithm [4].

Purpose

Micronic Mydata AB is in the market of producing SMT machines and mask writers and with the LDI (Lased Direct Imaging) they plan to expand their market to Chip Scale Packaging. With the LDI they offer CSP precision writing at sub-10 micron levels. For the LDI, the array of mirrors is built upon a silicon wafer. When the silicon wafer is to be glued, it is difficult to sustain the level of planarity required resulting in slight height variations at a sub micrometer level. When working with such small dimensions all such irregularities are undesired and can result in positioning errors. There has previously been a Master Thesis project [5] to try to improve the global planarity of the semiconductor pattern generator tool Sigma's SLM during the gluing process by vacuum assisted control of the bow during glue curing. The Sigma's SLM consists of 2048*512 mechanical micro mirrors and is used in the Sigma laser pattern generator. This project aims to continue on the work previously completed and see if there is any possibility to improve the current glue curing method used for the LDI's SLM.

A second purpose of the Master thesis project is to establish a method to measure the global planarity of SLM's currently in stock at Micronic Mydata. At the moment there is no way to measure the global planarity of SLM's installed in the LDI at the company's headquarters. When an SLM has been delivered to Micronic Mydata from the manufacturers Fraunhofer-Institut für Photonische Mikrosysteme (IPMS) a datasheet containing the SLM's different characteristics including the planarity is included. When the SLM is to be installed later on it may have been waiting in stock for several months and it would be advantageous to be able to ensure it still has the same properties as when delivered. Hence the need to establish a working measurement method for the SLM used in the LDI. The measurement method will also be used to check whether the planarity of the SLM has improved during the experiments executed to investigate the alternative glue method.

Requirements and Restraints

An employee at Micronic Mydata AB has previously written a program [6] using Matlab that takes the data received from Fraunhofer IMPS and extracts the characteristics of interest. From said data the pre-existing code that was written cropped out the area of interest and extracted the parameters of interest (P1,P2 and T). The resolution used by IMPS to measure the global planarity of an SLM uses a step length of ca. 1µm. The supplied data is averaged over more than ten points. The equipment used at Micronic Mydata AB to measure the SLM has a step length which is larger and will be determined during the project. The program that is to be written must be compatible with the already existing program and the data received from the manufacturer. The data supplied from IMPS contains data regarding the height variation for the whole area of active mirrors on the SLM chip.

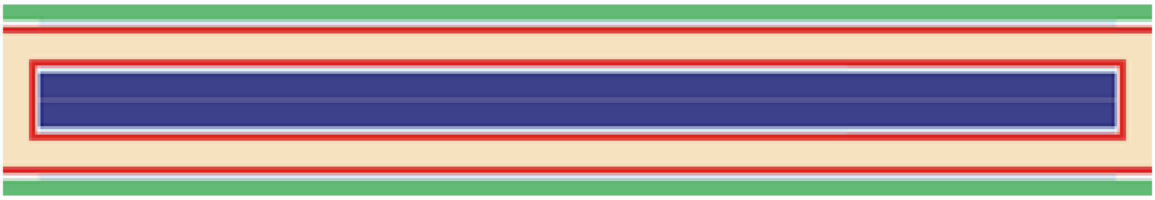

Figure 9 ***The image above represents an SLM seen from a top side view where the blue area represents the area of interest (active mirrors).***

The area of interest that is to be measured and analyzed is that which contains the adjustable micro-mirrors situated along the middle of the SLM (blue area in Figure 9) and is ca. 8 cm long on its long end. The equipment used to measure the planarity of the SLM is a FISBA µPhase interferometer that uses a laser with a wavelength of 628.3 nm and has a 50 mm lens. The FISBA's camera has a resolution of 1024*1020. Since the entire area of an SLM will not fit underneath the lens at least two data sets will have to be stitched together to get a complete data set representing the global planarity of the entire SLM. The difference in step-length between the measurement method used by IPMS and the Fisba interferometer will lead to data sets of different sizes for the same area. This problem will also be addressed so that the final merged data sets will be compatible with the previously existing code.

Previous Work and Reference

A student from Uppsala University named Johan Hansson did his Master Thesis at Micronic Laser Systems (before Micronic Mydata AB was founded by the merger of Micronic Laser Systems and Mydata) named: Improvements of Global Planarity of SLM. The SLM worked on during that project was the one used for the Sigma pattern generator which has different dimensions compared to the one used in the LDI. The area of interest on the SLM used in the Sigma is 32.5*7.2 mm^2 compared to the dimensions of the SLM used on the LDI ca. 8cm long and less than 1 cm wide. For the previously mentioned Master Thesis project the Fisba interferometer was also used for the in-house measurements. When measuring the planarity of the SLM used in the Sigma pattern generator there was no need to merge data sets since the whole surface of the area of interest could fit under the 50 mm lens.

Method

Software

The project had two goals, first to see if it was possible to improve the planarity of the SLM second to create a method to be able to measure the SLM “in house” at the Täby HQ of Micronic Mydata. The first goal would be difficult to realize without accomplishing the second goal since it would be necessary to measure the SLM’s planarity to see if there had been any improvements in regards to planarity.

Deciding the appropriate measuring method

This project consists of intertwining parts of both software and hardware. To be able to write the required program for the merging of the data sets an understanding of the hardware and the physical characteristics of the SLM component are essential. Below in Figure 10 are two data sets from an SLM (all future references to an SLM will be referring to those used in the LDI) as presented by a script written in Matlab. These two data sets overlap at approximately data point 100 on the x-axis for the left data set and approximately data point 700 on the x-axis for the data set to the right.

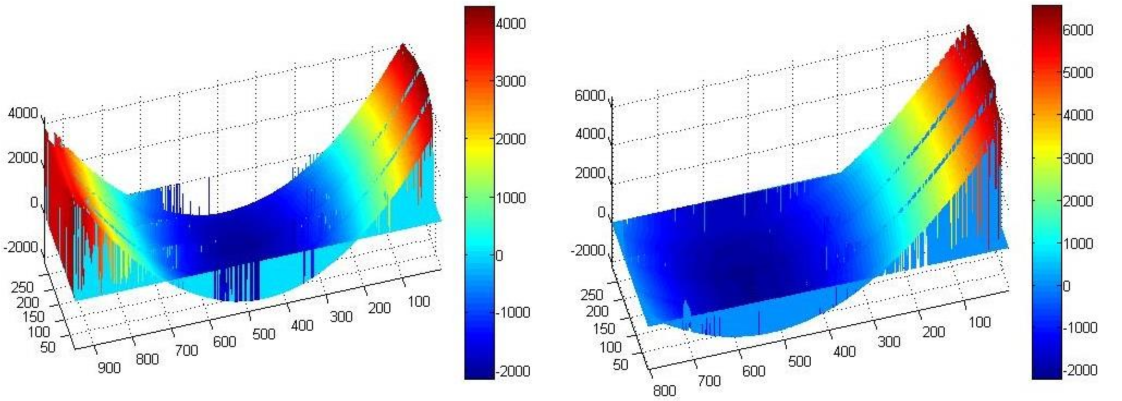

Figure 10 ***Representation of the height variation in two data sets of the same SLM with an overlapping area (X-label and Y-label display measured points and the Z-axis displays the height variation in nanometers).***

Important to note is that the scales of the X and Y axis are not of the same dimension as that of the Z axis. The Z-axis displays height variation in nanometers and the X and Y axis display the displacement along the surface in points measured. The distance between two measurement points is approximately 51.7 micrometers which means that the plot to the left in Figure 10 represents ca. 4.8 cm of the SLM’s surface and the plot to the right represents 4.1 cm of the same SLM. These two plots represent the entire surface of the SLM with an overlapping area in both plots. The spherical characteristic of the SLM is hence exaggerated due to the difference of scales of the X and Y axis in accordance to the Z axis. None the less the spherical shape exists and needs to be taken in to consideration when merging the data sets.

The areas of interest which can be seen in the plots of Figure 10 are situated along the middle of the data sets where the boundaries are visible in certain areas as missing data points with an average width of 81 points between missing data clusters. When using the program µShape Professional to take measurements with the Fisba FST 10 it is

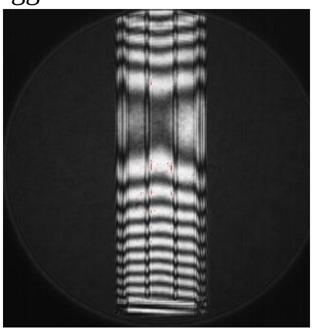

Figure 11 ***An SLM as seen through the Fisba FST 10.***

possible to use what is called a measurement mask to limit the area that is to be measured and analyzed. This feature will be used when the necessary size of the mask has been determined. In Figure 11 one can see how the surface of an SLM is portrayed when using the Fisba. From this view it is difficult to be certain where the boundaries of the active mirrors are. To be able to determine precisely where these boundaries are an SLM was placed underneath a high performance microscope, the Leica INM 100 which is a microscope specifically made for the semiconductor and microelectronics industry. Once underneath the microscope small cut out pieces of a Post-It were placed at the borders on both the long and short end of the active area of the mirrors as seen in Figure 12 and Figure 13. The Post-it appears out of focus since it is at a different height compared to the surface of the SLM. The choice of using a Post-It to mark the edges was made since it does not have a reflective surface, would stay fixed when placed and would be seen clearly when using the Fisba. The pictures were taken using the lowest magnification to see as much as possible of the SLM and Post-It.

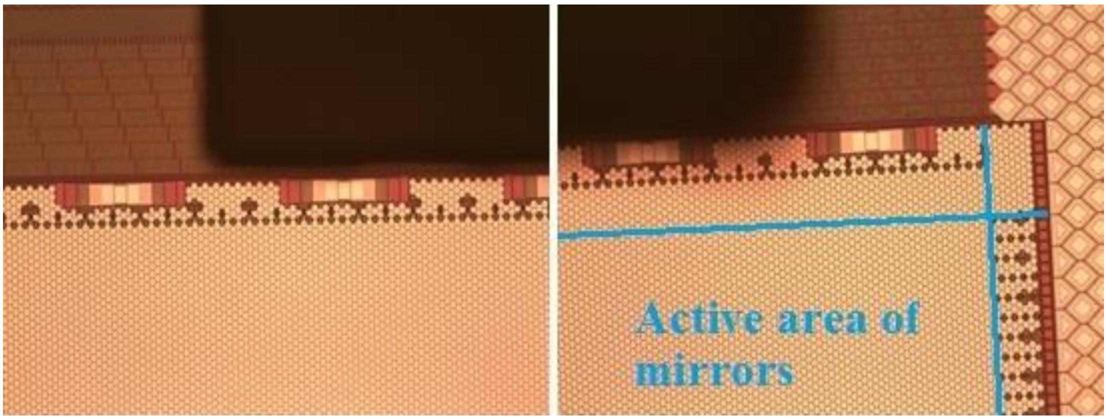

Figure 12 ***Pictures from the Leica INM 100 of the long end of the SLM with the Post-It fixed at the border of the active area of the mirrors.***

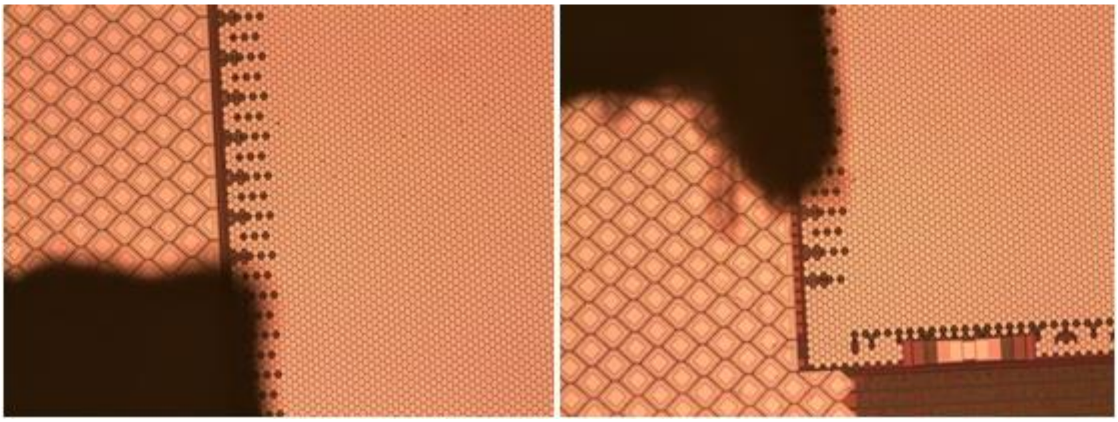

Figure 13 ***Pictures from the Leica INM 100 of the short end of the SLM with the Post-It fixed at the border of the active area of the mirrors.***

The results can be seen in Figure 14 where the Post-Its can be seen as dark areas which resulted in clusters of missing data points in the following measurement. These missing data points confirmed that the boundary of the long end was situated at the same area where the data points were missing in Figure 10. From the cluster of missing data points (generated by the Post-It) to the parallel missing data points at the other boundary area were (on average) 81 points. Thus confirming the area of active mirrors on the SLM to cover 81 data points along the middle of the SLM's length.

The distance covered over the width of the SLM's active mirror area can be calculated by multiplying the number of mirrors with the width of the mirrors [7]. The amount of points required to measure said distance is calculated by dividing the distance by the step length between measurement points. The points required to cover the width of the area of interest will be 75 measurement points.

In addition to the mirrors used covering the width of the SLM there are additional mirrors that are not addressed and add to the distance between the edges. These additional mirrors can be seen in Figure 12 and symmetry with the adjacent side is true. Meaning that on each side there are additional mirrors that are not used and will not be needed for future analysis and data merging. With a known amount of mirrors on each side and the known step length of measurements an additional 3 data points will be rejected from each long end of the SLM to focus on the area of interest. It is stated that slightly more than 3 data points should be removed from each side, this number is rounded down to three since part of the fourth data point is data needed. This means that the 81 measurement points stated earlier to cover the width of the mirror array was a correct amount since 75 points are needed for the mirrors in use and 6 points for the mirrors not in use at the edges (75+6=81).

When analyzing the results from the Post-It attached to the short end of the SLM (Figure 13 and Figure 14) as definitive results were not reached as were possible for the long end. There are no corresponding reference points (as missing data points for the long end) to be able to deduce where the boundary of the area of interest is situated. Instead a new reference point (Point A) was chosen which can be seen in Figure 14. After receiving necessary information from IPMS regarding the distance between the reference point and the edge of the active area of mirrors (Point A and Point B) the number of data points between the two could be calculated [7].

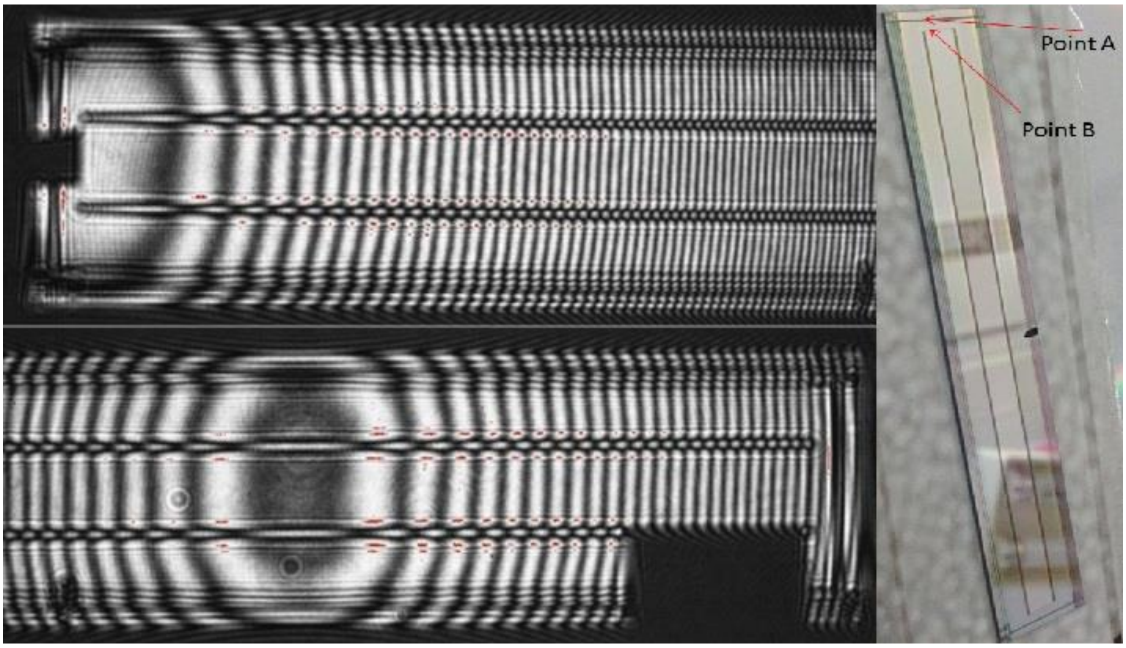

Figure 14 ***The top left picture shows the SLM with the Post-It attached to the short end. The bottom left picture below shows the SLM with the Post-It attached to the long end. Picture to the right displays the newly chosen reference point in relation to the edge on the short end of the zone of active mirrors.***

In regards to the length of the SLM's area of interest the number of data points required to represent the entire length is calculated to 1585 data points [7]. The total amount of measured data points to cover the entire surface of the area of interest will be 75*1586 data points. With the area of interest now clearly defined by number of measured data points a measurement method can be decided.

The program µShape Professional allows the user to perform measurements using what is called a "measurement mask". The measurement mask permits the user to define which area is to be measured allowing to manually crop out an area of interest. Two measurements on the same SLM will be required to be able to gather enough data to merge into one data set. Each measurement will be done using a measurement mask which will be 81 points wide to cover the width of the total mirror area. Furthermore each mask will begin/end (depending on which measurement is being done) at the reference line for the short end which is depicted as Point A in Figure 14. These two masks will be 900 points long to have an overlapping area of 81*172 points. The overlapping area will be necessary to be able to merge the data. The lengths of the masks are restricted by the number of measuring points available (1020x1024). If a surface contains discontinuities or is very uneven it will be difficult to get a proper measurement with the Fisba, thus the need to only measure where it is explicitly necessary. The measurement masks with 900*81 measurement points can be seen in Figure 15. The areas seen in Figure 15 which are lighter represent the measurement masks that were used. The red squares represent where the reference point referred to as Point A previously is situated. The reference line could easily be mistaken for yet another interference line but is straight compared to the arc-shaped interference fringes. In contrast to the fringes that can be seen to move due to vibrations when looking at the SLM using the Fisba the reference line stays fixed at all times.

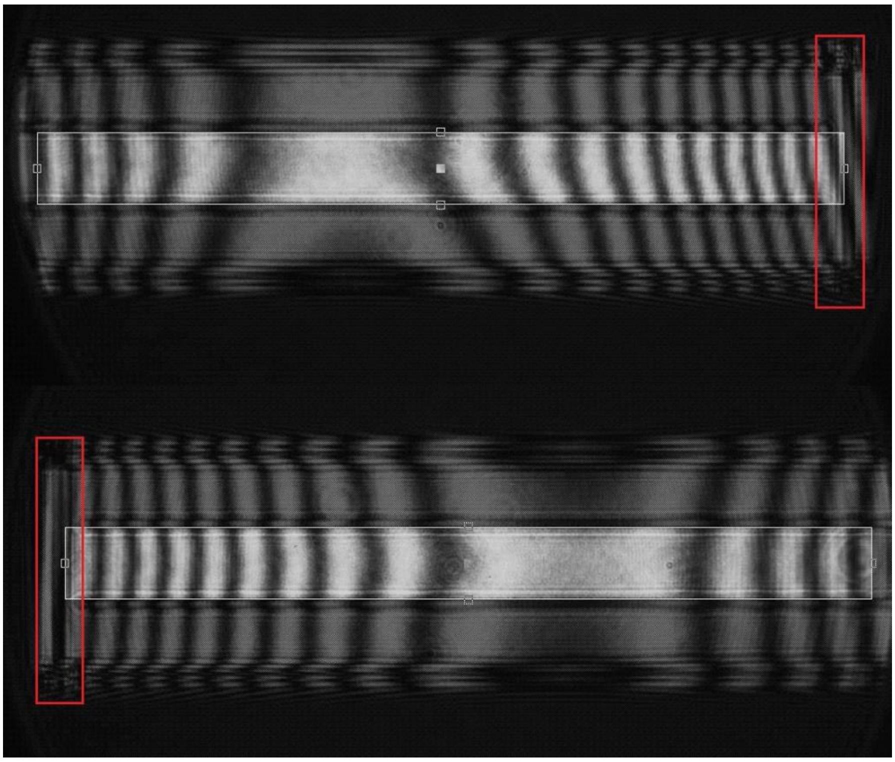

Figure 15 ***Screenshot from µShape Professional showcasing the fit of the measurement masks.***

Adjusting and merging the data

After having chosen the appropriate measurement method as described in the previous section two measurement masks containing 900x81 points are to be manipulated and merged in to a single cohesive data set. From the program µShape Professional it is possible to export data from measurements to text files making it possible to work with the data in Matlab. The text files represent data from the measurements with 1020x1024 measurements where measurement points outside the mentioned masks are equal to zero.
The written program starts by importing the text files and cropping out the measurement masks. These two masks have to be cropped even more, first of all to get rid of the area between the reference point for the short end and the actual short end of the area of interest. The amount of rows to be removed from each mask was calculated to 26 rows [7]. For the first of the two data sets this means that rows 900-875 will be removed. For the second data set the first 26 rows will be removed leaving rows 27-900. Thus leading to two data sets 874 points long. In addition to removing rows from one end of each mask, columns will have to be removed from both ends of each mask as mentioned previously. These steps of cropping data via Matlab are necessary since it is difficult to manually or visually do so when using the Fisba.

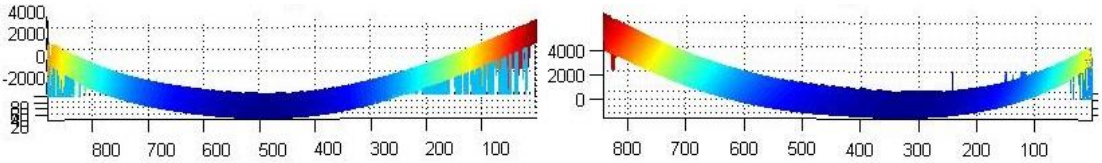

Figure 16 ***Two plots of a single SLM where they overlap at about 790 in the plot to the right and the 100 mark in the plot to the left (Z-label is in nanometers X and Y-labels are in measured points).***

Because of the spherical characteristics of the SLM when looking at the data received as in Figure 16 merging the data will require more than simple stitching of the data. The characteristics at the overlapping points differ from one another (e.g. by amplitude and derivative). The data received from measurements can differ even when examining the same surface. This happens when the alignment has been done differently for the same surface. By adjusting the alignment, the level of the plane on which the object being measured is placed will be tilted. In doing so the surface area that is parallel to the lens of the Fisba will move along the SLM surface depending on how it is being tilted. The position which is parallel will become the local minima of the measurement due to the spherical characteristics of the SLM. This behavior is clearly displayed in Figure 17.

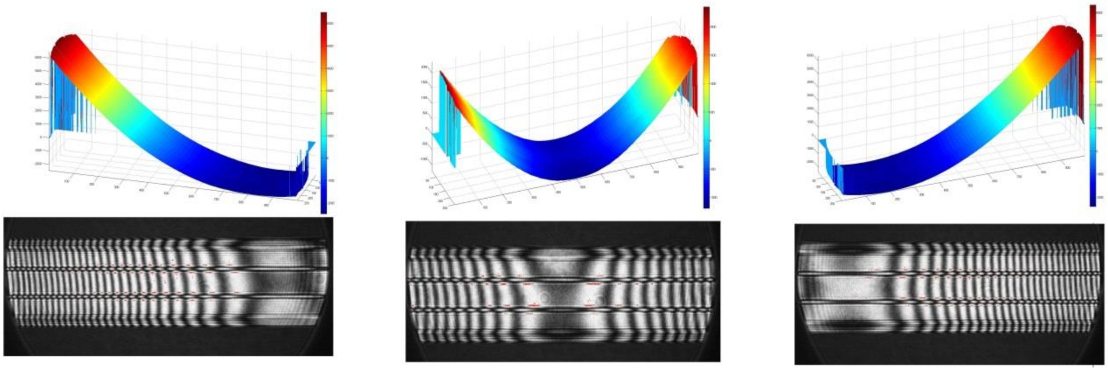

Figure 17 ***Three plots of the same surface of an SLM showing different results depending on which part of the SLM is parallel to the Fisba.***

Since the length of the SLM's area of interest is known along with the step length between measurements the overlapping area can be calculated easily. The total length of the area consists of 1586 points and the middle of the total data set will be at 1586/2= 793. This results in the overlapping rows to be situated at the 793rd row of the first data set and at the 81st row of the second data set with a total overlapping area of 75*162 measurement points. Now that the overlapping areas have been determined the data can be manipulated to successfully merge the data.

When the two data sets are to be merged it is important that when the data is being manipulated that it is altered as little as possible to not affect the actual data. To be able to merge the data sets, the overlapping areas will have to have the same characteristics before any merging can commence. The fact that the SLM is known to have a spherical shape along the long end will be used to adjust the data before merging. An assumption will be made that the middle of the SLM along the long end will be the local minima in height variation along the long end. Using said assumption will lead to that the data sets will have to be rotated so that the overlap at the middle of the entire SLM will be the local minima in both data sets. The middle of the entire SLM is situated at the middle of the overlapping areas confined by the boundaries in Figure 18.

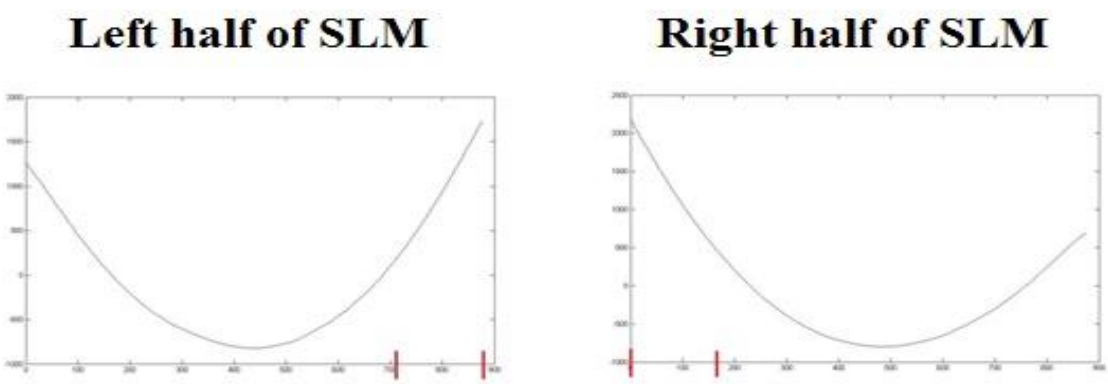

Figure 18 ***Plots displaying the average value along the length of an SLM where the X-axis represents measured points and Y-axis average height variation in nanometers. The red marks on the X-axis represent the boundaries of the overlapping areas.***

To perform the required rotation focus will lay on the boundaries of the total overlapping area. If the data sets are rotated so that the boundaries are at the same level, the middle of the overlapping area will then become the local minima according to said assumption due to the spherical characteristics. In Figure 19 only the overlapping areas are displayed after having performed a rotation of the entire data sets to fix the middle point of the SLM as the local minima.

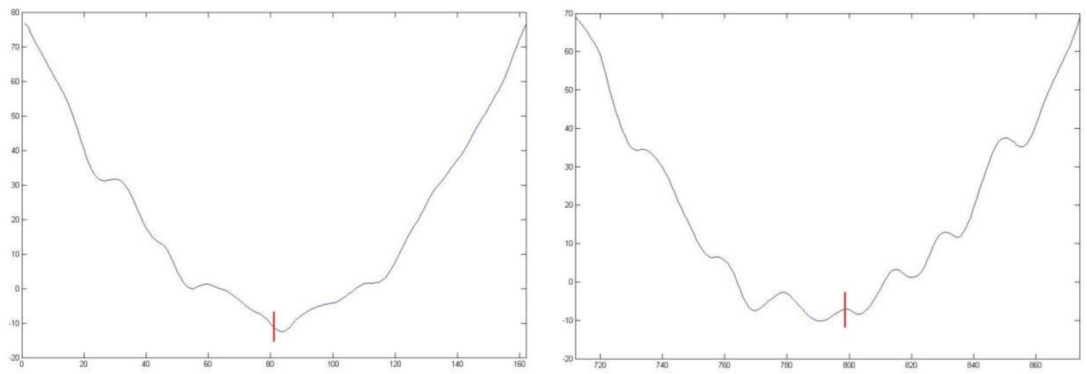

Figure 19 ***Plots displaying the overlapping areas from two data sets for an SLM after having rotated the data sets. The red marks represent the middle of the SLM.***

The rotation was executed by using the derivative between the average values at the boundaries of the overlapping areas. When the lean between the boundaries was obtained a matrix of the same size as the measurement masks was created with the same constant lean as between the boundaries. Said matrix was then subtracted from the original data set which in turn performed the rotation. All these steps can be seen more clearly in the following figures. In Figure 20 the plots can be seen before any manipulations have been done along with the matrixes that were created consisting of the derivative between the overlapping points.

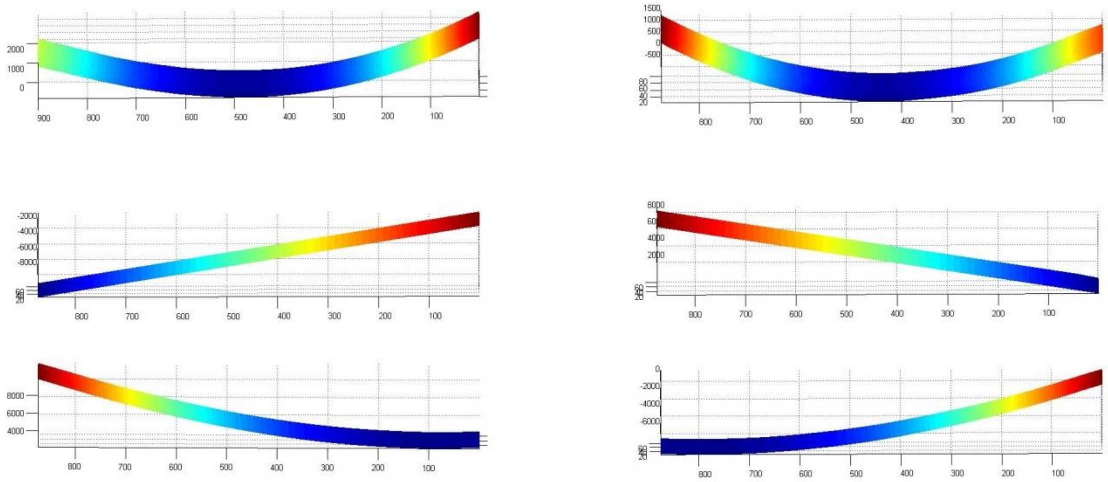

Figure 20 ***On the left are plots representing one half of an SLM and on the right are plots representing the other half of the same SLM. The plots at the top display the data sets before any manipulation has been performed. The plots in the middle display the matrixes representing the lean between the boundaries of the overlapping area. The plots at the bottom display the data sets after the rotation has been performed.***

Before any merging of these data sets can be executed the data sets need to be aligned to be at the same level. At the moment the derivatives are the same at the overlapping points for both plots in Figure 20 but the set to the left has negative values at said points whilst the plot to the right has positive values. The alignment was executed by raising/lowering both matrixes so that the boundaries of the overlapping areas were situated at the same level (i.e. zero level on the Z-axis). After rotating the data sets in order to align the sets in the long direction there may still not be properly aligned in the short direction. No operation was performed upon the measurement data to align any possible tilt there may have been along the short end. Instead the parameter extracted from the pre-existing Matlab code [6] that represented the tilt (P1) was lightly modified to correct a slight offset that occurred when transitioning between overlapping points. Once the plots of the matrixes are correctly aligned after having been rotated the data sets are ready to be merged.

To merge the two data sets a new matrix was created with the dimensions of 1586 * 75 measurement points. The size of said matrix was decided in accordance with the numbers of required data points to correctly depict the area of interest [7]. Said matrix was then filled from its 1st row until its 712th row with the values of the first data set from its 1st row until the overlapping areas were encountered at row 712. From this point on said matrix was then filled with the averaged values between the two data sets for the overlapping area until the 874th row. Once said matrix had been filled with the values for the first data set and the averaged values of the overlapping area the rest of said matrix from its 875th row until its 1586th row was filled with the values of the second data set from its 163rd row until its 874th row.

After having merged the two data sets, the complete data set representing the height variation over the whole of the SLM had to be adjusted to fit with the pre-existing program Globalflatness_calc.m [6] . This was accomplished by interpolating the complete data set from 1586*75 data points to 4384*209 data points using the linear data interpolation method supplied by Matlab. The linear interpolation method was chosen since other methods such as spline interpolation could possibly have a smoothing effect on the data which could possibly corrupt the data and hide certain variations. The end result of all manipulations and merging can be seen in Figure 21 and the code written can be found in stitch_fisba_data_commented.m [8].

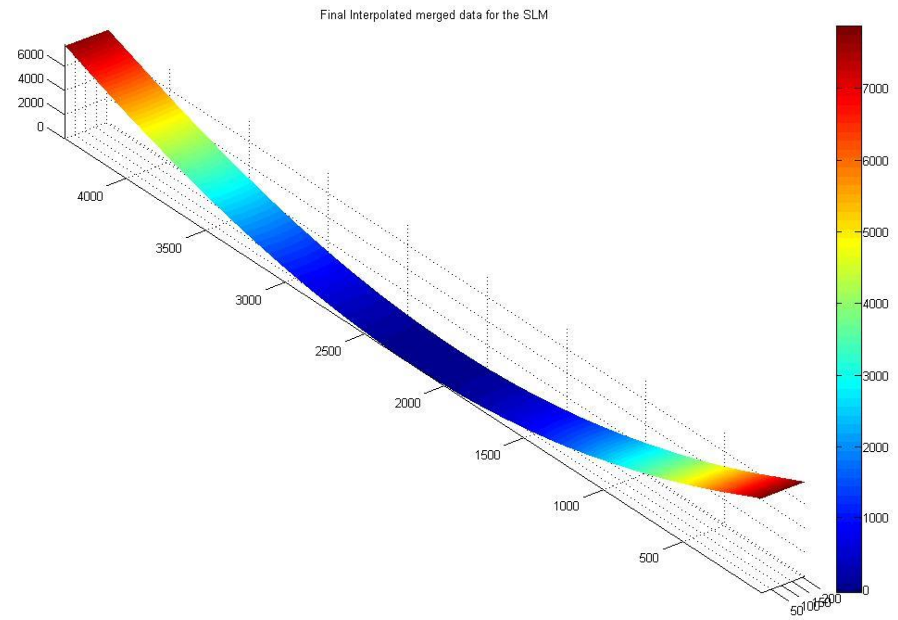

Figure 21 Final merged set of two data sets.

Deciding the Step Length of the Fisba

When working with such small dimensions as is the case when working with the SLM it is important to be as precise as possible. Knowing the distance between measured data points would allow for greater precision when analyzing received data. A pattern with precisely known dimensions and clearly defined contours was analyzed using the Fisba to determine the step length between two measured points. The pattern used was the demo pattern named “Mix n Match” which is used to demonstrate the performance of the Sigma pattern generator and can be seen in Figure 22. The pattern of the Mix n Match is etched into the chrome plating on top of a quartz mask. The chosen pattern fulfilled certain needs to be able to clarify the distance between two measured points. These requirements were that the pattern had to have known dimensions, strong contrast highlighting boundaries and several known points for repeated reference measurements. All these requirements were fulfilled by the Mix n Match with repeatedly recurring squares equally spaced over the whole surface of the mask. Said mask contained patterns of much higher detail and smaller dimensions that were not visible when performing measurements with the Fisba. The patterns used for these experiments were the largest reoccurring patterns on the mask. Each of the squares has an area of 3.00*3.00 mm^2 with a spacing of 2.00 mm between adjacent squares which is displayed in Figure 23 Dimensions of squares on the Mix N Match mask. A measurement of the Mix N Match mask using the Fisba was done to decide the amount of data points needed to represent the known distances. The boxes can be seen quite clearly in the Matlab plot of Figure 24 yet finding the exact boundaries in the measured data proved not as clear since the edges were differently spaced depending on which box was analyzed. This could be due to light being reflected in the edges of the boxes resulting in false data of the edge location. The boxes that were chosen as references are the ones numbered 1-5 and I, IV and V in Figure 24. These boxes were chosen since the measured values representing the boxes were equal to zero and easily located. Since the edges were differently spaced the middle of each box was located and the amount of data points from box to box was calculated.

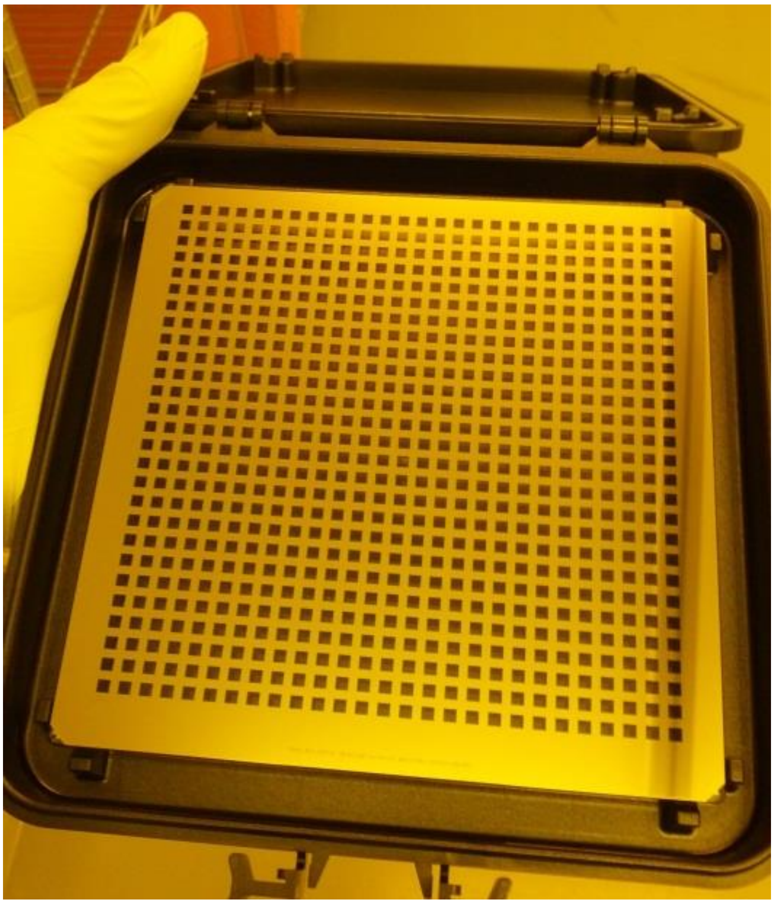

Figure 22 Mix n Match mask

The space between the centers of each box was 5mm as seen in Figure 23 and equal to the width of a single square along with the distance to the next square.

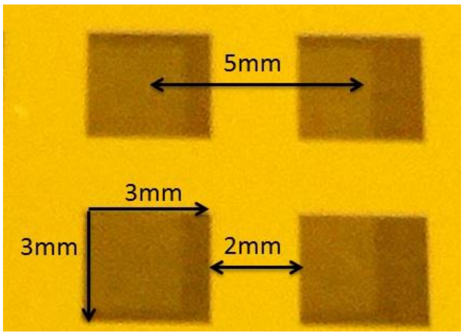

Figure 23 Dimensions of squares on the Mix N Match mask.

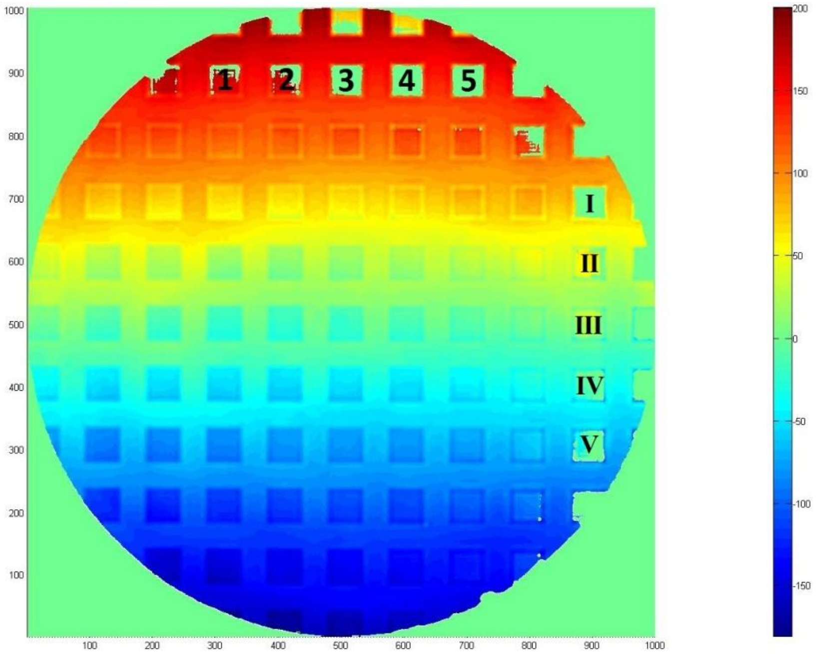

Figure 24 Matlab plot of a segment from the Mix n Match mask

Since there is displacement in both the X and Y coordinates of the centers, the distance between centers has been calculated as the hypotenuse of a triangle with the displacement in X and Y as the sides of the triangle.

After the analyzing the results received the lateral distance between measurement points for the Fisba has been narrowed down to sub-micrometer precision [7].

Hardware

Now that an appropriate measurement method has been put in place the next step is to decide on a method to improve the planarity during glue-curing of the SLM. In an attempt to improve the planarity of the SLM, the component will be glued to an aluminum block whilst being held in place by controlled vacuum as in previous experiments [5]. To conclude whether or not the method proves successful the SLM will be measured before being glued, at the beginning of the glue-curing process, continuously until the glue has completely cured and after the glue has cured to check for long-term stability. The entire process and the different components used are described in the following sections.

The Aluminum blocks

The aluminum blocks used have a surface that is larger than that of the SLM to be able to properly fix the SLM on said blocks. At the center of each block a hole with a diameter of 1 mm has been drilled though to the other side. On the bottom the same whole was made wider by drilling a 4 mm wide hole to the middle of the aluminum block. The larger hole on the bottom will enable to fixate a tube to the block at a later stage to regulate a vacuum between the SLM and the surface of the block. The choice to use a single hole to regulate the vacuum was done after previous experiments concluded [5] the method to be as effective if not more so than using several vacuum points.

Unfortunately the surface of the aluminum blocks could not be measured using the Fisba due to the surface containing too many discontinuities. The planarity of the surface of each block was measured using a Coordinate Measuring Machine (CMM). The CMM measures the coordinates and geometric characteristics of an object in the X, Y and Z axis with µm precision and can be controlled either manually or automatically following a predetermined measurement pattern. The pattern chosen for the blocks (Figure 25) was chosen to display if a blocks surface was generally plane or if it had a certain form. The pattern allows to vaguely describe the characteristics P1, P2 and T of the blocks. The results from the CMM for each block used for the experiments can be found in Appendix A.

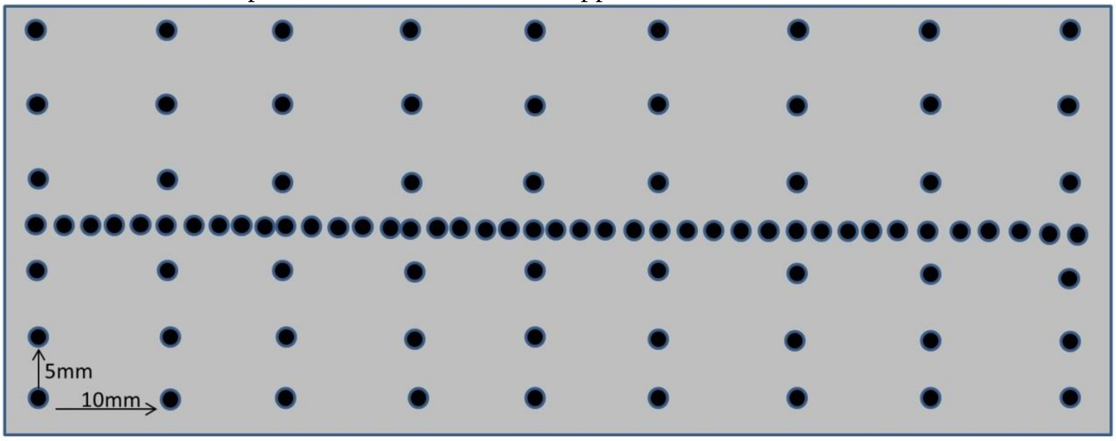

Figure 25 ***The figure above displays the pattern chosen to measure the aluminum blocks used for the experiments. The distance between the horizontally placed measurement points in the middle of the block was 2mm.***

Method for applying the Adhesive

The adhesive used for the experiments was epoxy glue similar to the adhesive the manufacturer uses when bonding the SLM die. A steel mesh was chosen to apply the adhesive in an even manner and would be easily repeated. The sizes of the particles in the adhesive were smaller or equal to 50 microns. For the mesh to work properly, the size of its holes would have to be at least three times larger [5] than the particle size of the adhesive. The steel mesh that was used was a shadow mask that had been produced by one of Micronic Mydata's customers using their own machines. Shadow masks are used in CRT monitors/screens and are steel meshes with rectangular cavities for each pixel of the screen. The size of the rectangular cavities were 450µm*150 µm (Figure 27). The shadow mask which was used had a screen resolution of 720*576 pixels which was much larger than the surface of the aluminum blocks to which the adhesive was to be applied. When applying the adhesive it was important that the mesh would stay flat on the surface of the blocks. For the mesh to rest flat a piece of the mesh ca. 1cm larger from each edge of the block was cut out to not have any significant overhanging weight outside the edges of the block.

Worth noting is that the curing period for the adhesive is 3 days at room temperature. The adhesive used was a two-part adhesive and each time an SLM was to be glued ca. 4 grams of adhesive was mixed. Before applying the adhesive the mesh was placed firmly against the surface of the aluminum block. Once firmly placed the adhesive was poured in a random pattern on the mesh. A squeegee was used to spread the adhesive evenly across the mesh. When sufficient adhesive had been spread across the surface of the mesh it was time to carefully remove the mesh. This had to be done by lifting the mesh from one side slowly at constant speed and force so that the dispersion of adhesive remained constant. After having removed the mesh air bubbles could be seen in the adhesive that had been applied to the surface of the aluminum block, these disappeared after waiting a few minutes.

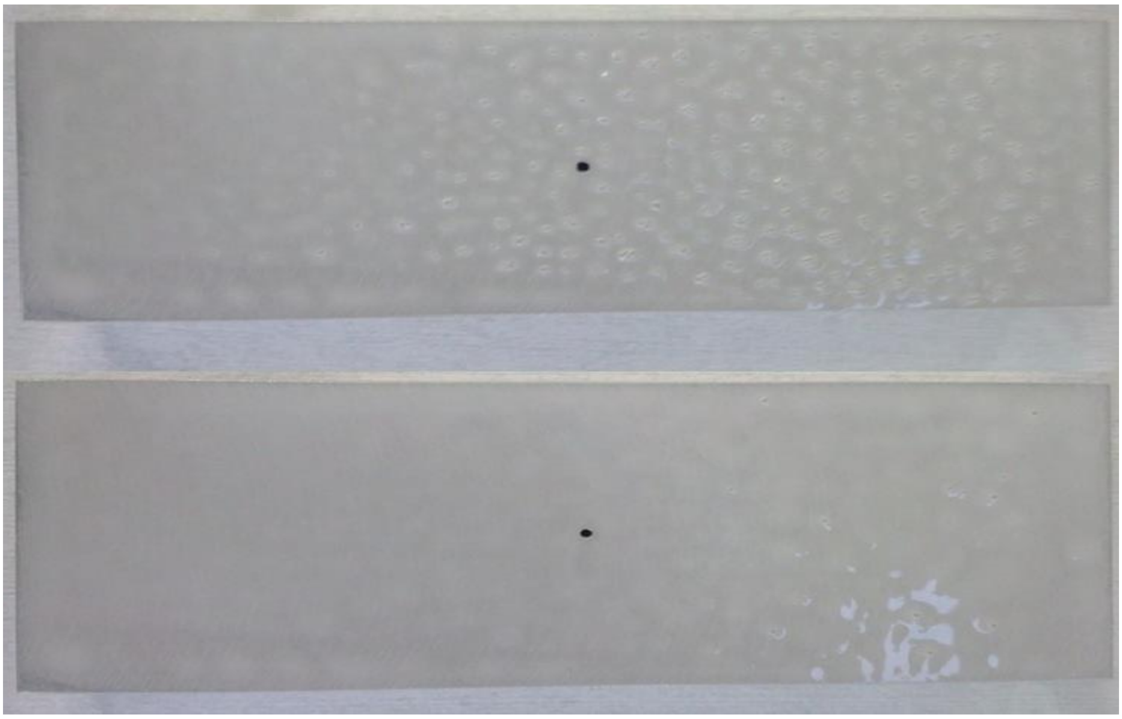

Figure 26 ***Top picture shows the air bubbles in the adhesive just after removing the mesh. The bottom picture shows that after 8 minutes most of the air bubbles had disappeared. The black dot at the center of the block is the vacuum hole.***

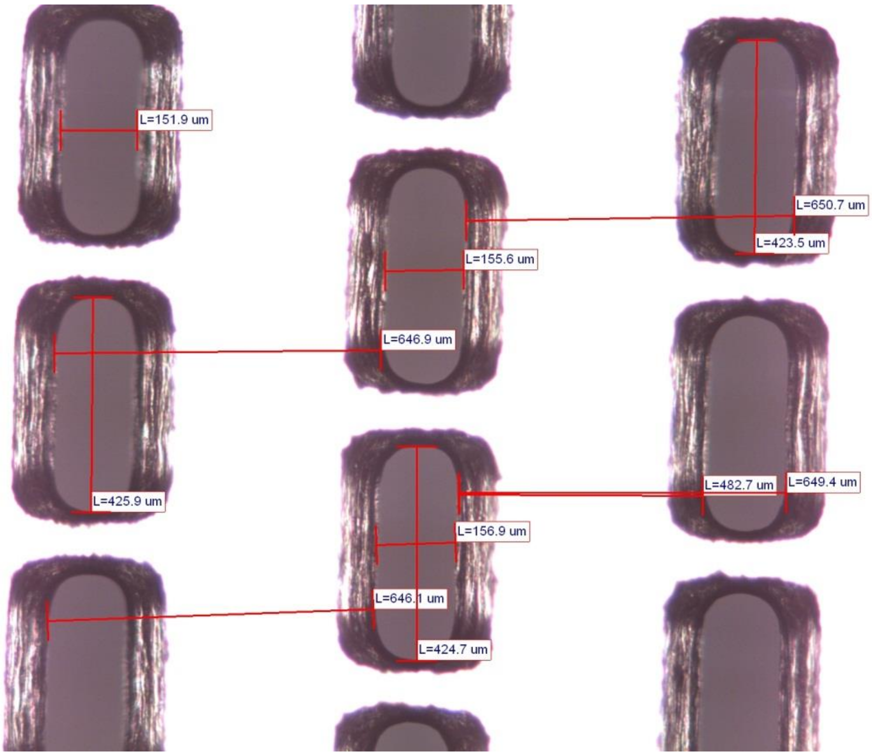

Figure 27 Picture taken using the Leica 100 of the shadow mask used as a mesh for applying the adhesive.

Measuring station

To be able to regulate a vacuum between the surface of an aluminum block and the bottom of an SLM a measurement setup had to be designed and built. Said setup would have to be easily mounted under the lens of the Fisba to take measurements during glue-curing, allow moving/adjusting the aluminum block for measurements and permit a tube to be connected to the bottom of the aluminum block (to regulate vacuum).

The slit in the top of the measurement setup (Top Left in Figure 28) allowed having a tube fixed to the bottom of the block whilst measuring. The size of the slit permitted the setup to be still whilst sliding the aluminum block back and forth under the lens of the interferometer. This was necessary to be able to take the two measurements needed for the data merging. The tube that was used to regulate the vacuum between the SLM and the aluminum block was very rigid; a strap was attached to the measurement setup (as seen in the bottom right of Figure 28) which helped hold the tube perpendicular to the bottom of the aluminum block. The tube was passed underneath the strap, lead up through the slit and attached to the bottom of the aluminum block (right picture in Figure 28). To monitor and regulate the vacuum that was achieved between the SLM and aluminum block a pressure regulator and unit to measure the vacuum were connected in series between the vacuum source and the tube connected to the aluminum block (Figure 29).

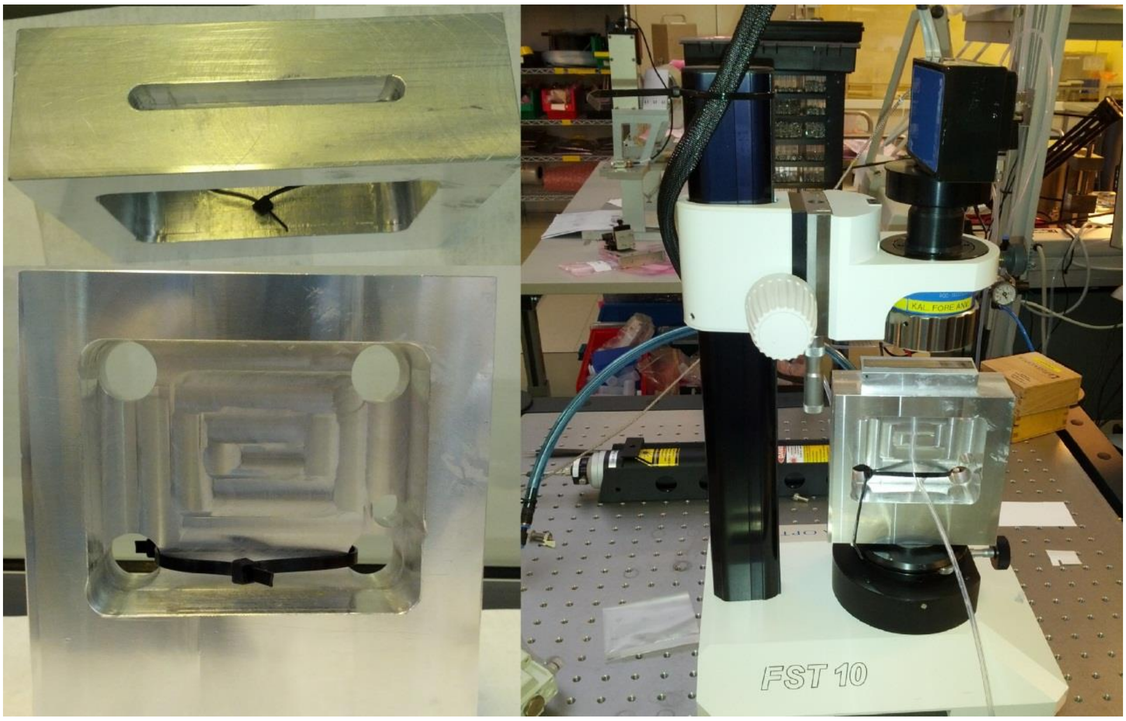

Figure 28 *Top left: Top view of measurement setup. Bottom left: frontal view of measurement setup. Right: The measurement setup mounted under the Fisba whilst performing a measurement.*

Figure 29 Pressure regulator and vacuum gauge.

Results and Discussion

Data merging code

In order to have a proper reference for the results of the data merging an SLM was delivered from the manufacturers Fraunhofer- Institut für Photonische Mikrosysteme (IPMS) with the data describing said chips planarity. The SLM chip was measured using the Fisba interferometer without being glued or exposed to any vacuum effect to be able to determine the quality of the data merging. Measurements were performed directly upon delivery to compare the results from the data merging code to the data delivered from IPMS and after several months to compare the results of any affect over time. When the SLM chip was delivered it was delivered not bonded to a die which is not the norm, usually when SLM chips are delivered from IPMS they are bonded directly onto a ceramic. The SLMs used in the experiments were delivered un-bonded to be able to test the alternative bonding/glue method. It is important to note that since the SLM was not bound to a ceramic it may have behaved in a different manner than it would in bound form. This means that the behavior of the shape of the SLM over time may not correctly represent the actual behavior of SLMs supplied by IPMS.

In order to have a substantial base of reference 10 measurements were performed directly upon delivery of the previously mentioned SLM. The number of measurements chosen was to be able to have a significant amount of measurements to statistically analyze the results. Said measurements were performed in a repeated method where two individual measurements were required to represent one chip. The repeated method referred to which half of the SLM was measured first and second which in turn affects the data stitching. Three months after delivery another 10 measurements were taken to see if there had been any affect over time on the SLM. The code that was written merged the data from two different data sets in to one cohesive data set and interpolated the data set to fit a pre-existing Matlab script [6]. The results are presented in the following sections.

SLM VC_3124_13_01 measured delivered from IPMS

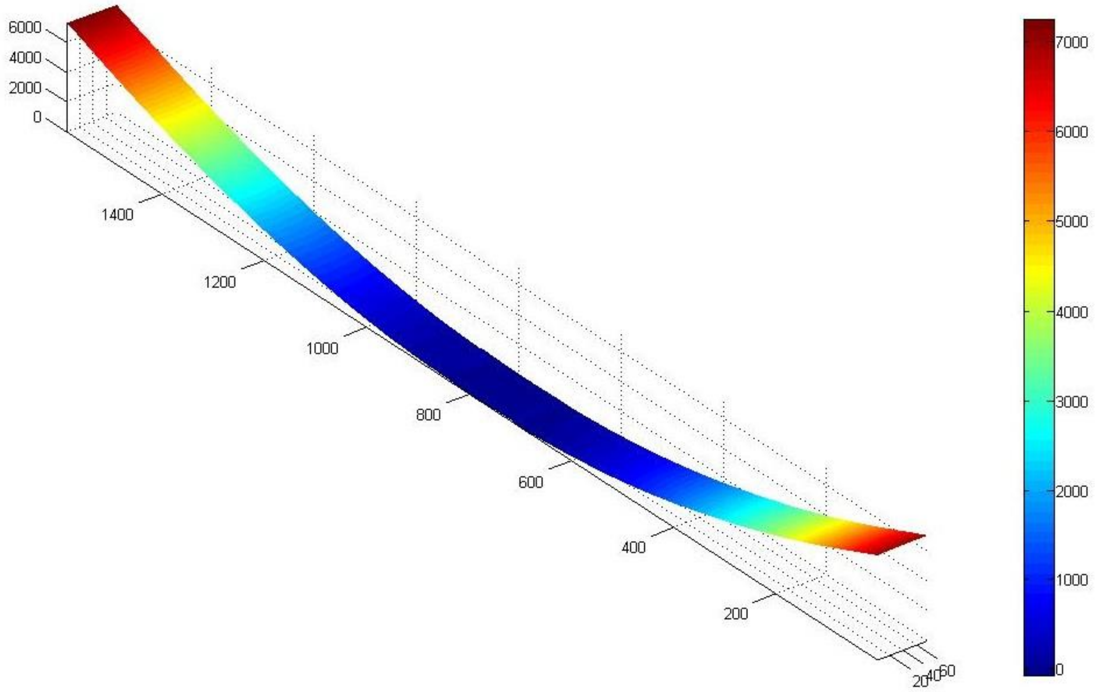

Figure 30 ***The final merged and interpolated data set for VC_3124_13_01. The scales in X and Y represent data points and the Z-axis represents height variation in nanometers.***

The topographic results from the merging of two data sets for the SLM chip VC_3124_13_01 can be seen in Figure 30. At first glance the data merging seems to have been successful the dimension and allure of the SLM form coincide with previous chips with known data. The bow in the long direction has a max to min peak of 6 µm which can be considered a typical value for an SLM. To see how precisely and effectively the data merging has been the parameters P1, P2 and T will be analyzed. These parameters will be more descriptive when it comes to analyzing the data merging. To compare the measurements made by IPMS with the measurements made during this project the mean values and standard deviation of the results will be particularly interesting.

Results and analysis of P2 (arch/bow of the short end)

The plots in Figure 31 portray the mean value of P2 over the length of the SLM along with the standard deviation displayed using error bars. The size of the error bars was chosen to encompass as many measurements as possible. In order to encompass 99.8% of possible outcomes 3.0902 standard deviations are required [9], if the dispersion of the measurement results are distributed according to normal standard distribution. Since there is a relation between the standard deviation of the mean and the number of measurements by [9]:

$$Std_m = \frac{Std}{\sqrt{N}} \qquad \text{Equation 1}$$

and $3.0902 \times Std \div \sqrt{10} < 1 \times Std$ the size of the error bars used were that of one standard deviation from the mean value at each precise position.

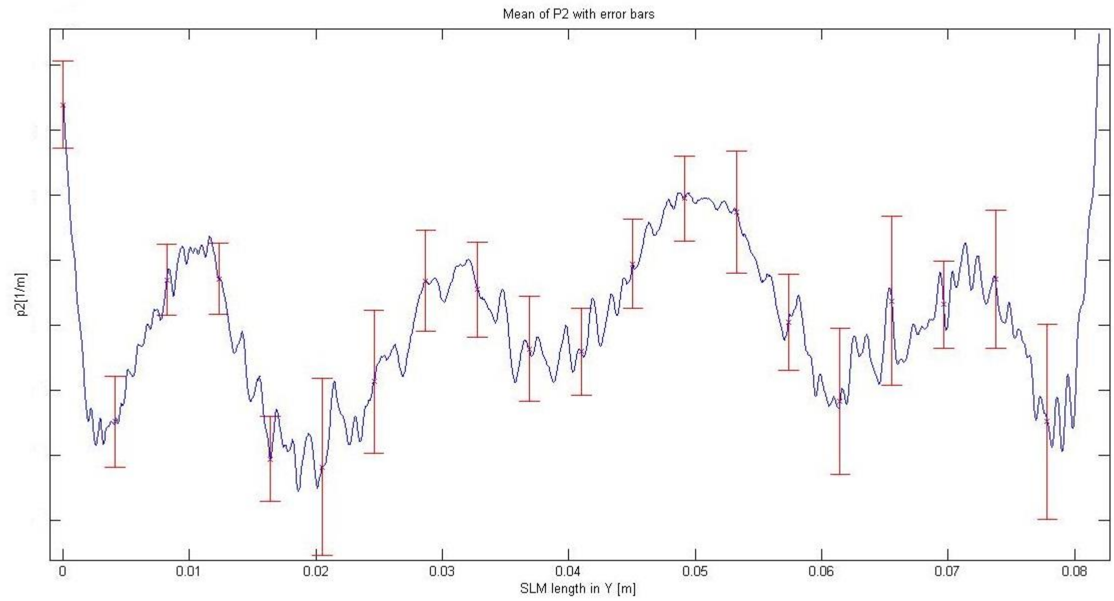

Figure 31 Mean value of P2 with error bars representing the standard deviation.

By analyzing the results of the repeated measurements of P2 in Figure 31 the standard deviation shows that the 10 different measurements are dispersed quite a bit in scale when considering the relation between the size of P2 and deviation. The mean value of the standard deviation for P2 is $8.5*10^{-4}$ and the mean size of P2 varies between ca. $-25*10^{-4}$ and $40*10^{-4}$. With said relationship being quite prominent the relation between the mean of P2 and the P2 extracted from the reference data from IPMS will be particularly interesting. The relation between the mean value of P2 and the data from IPMS can be seen in Figure 32. When comparing the two curves for P2 the curve representing the mean values follows the same shape and has the same magnitude as the P2 from IPMS.

When comparing the results (Figure 33) of P2 from the measurements made upon delivery and after three months it is clear that the SLM retains the same shape and that the measurement reproduced gives the same results. The measurement results also prove that the shape of the SLM is stable over time in regards of the parameter P2. The slight variation between the results in Figure 33 can be contributed to an uncertainty in the measurement method which in turn is due to the large standard deviation of the P2 results. When analyzing the uncertainty and deviation of the measurements the amount of measurement points plays an important role. The parameter P2 representing the bow along the short end of the active mirrors spans a distance of ca. 4mm. This distance is measured using 75 points in comparison to the 209 data points used by IPMS (which are averaged from more than 3000 measurements). The difference in amount of data representing the short end will result in a less precise representation P2 but will give a correct representation of the form and amplitude of P2.

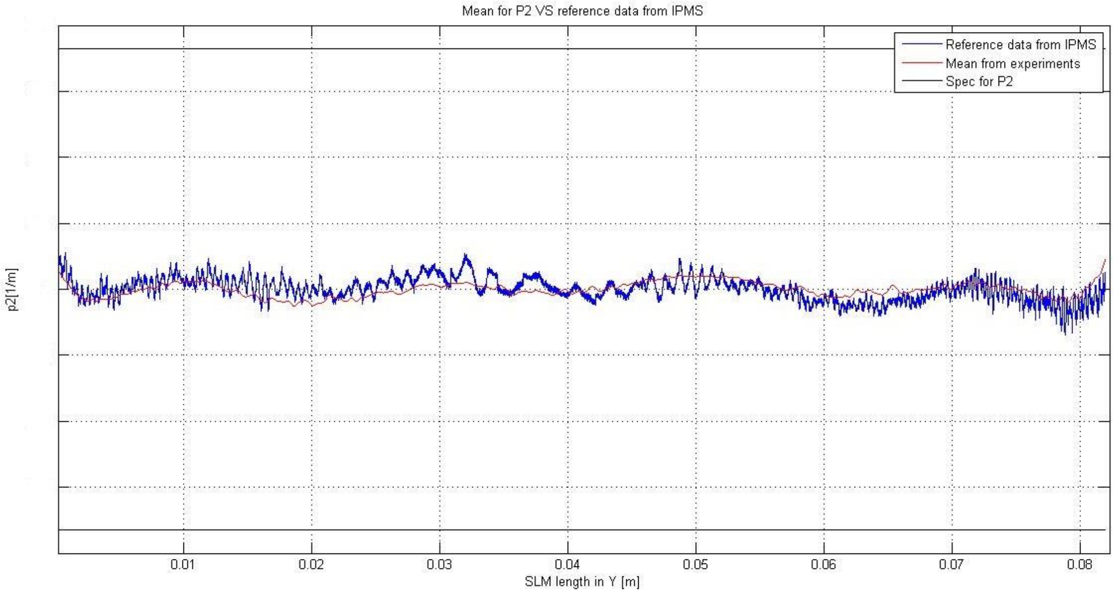

Figure 32 Plots of the mean value of P2 and P2 from the reference data.

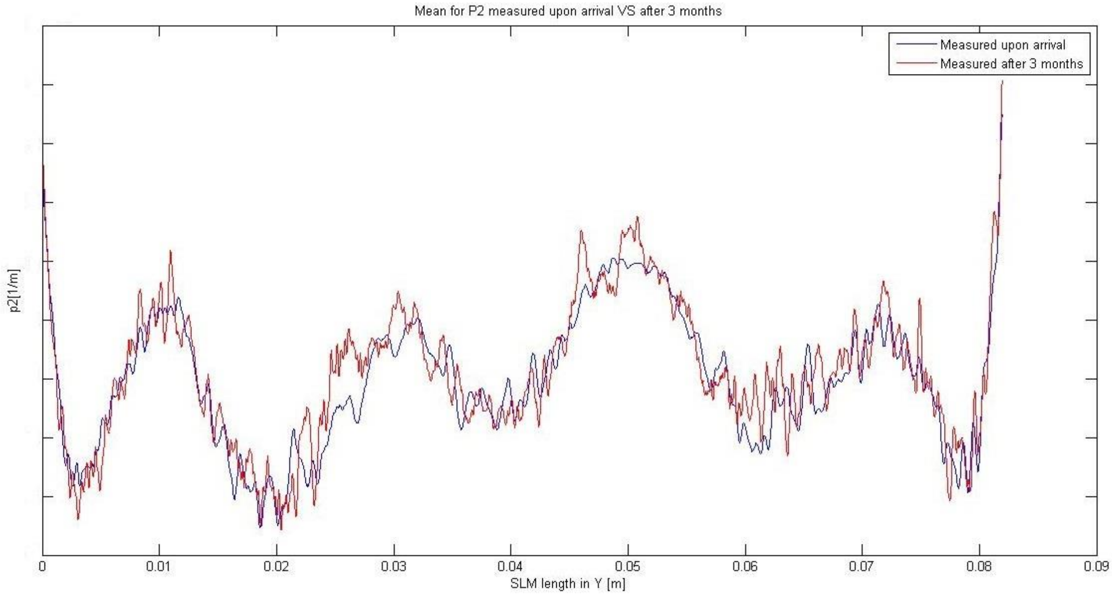

Figure 33 Plots for stability verification displaying the mean values of P2 along the length of the SLM measured upon delivery at Micronic Mydata and after three months.

Results and analysis of T (arch/bow of the long end)

In the same manner as for P2, the mean value of T extracted from the ten measurements will be analyzed along with the standard deviation of those measurements and with the measurements after three months.

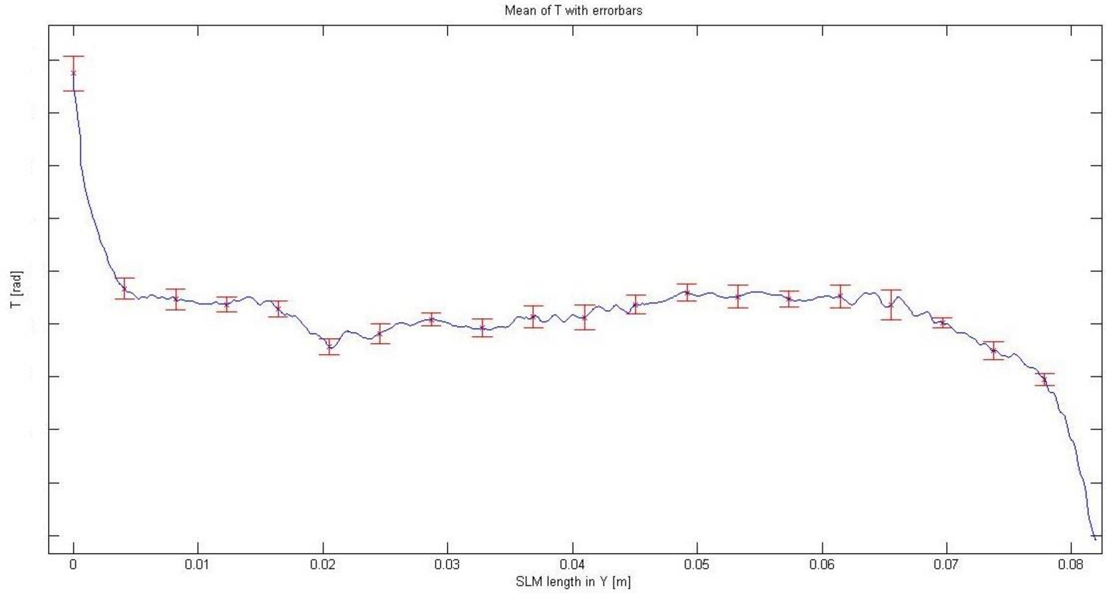

Figure 34 Mean value of T with error bars representing the standard deviation.

The plots in Figure 34 display the variation of the mean value of T extracted from ten measurements and its standard deviation along the length of the SLM. In contrast to the standard deviation of P2 the standard deviation of T is not as large in relation to the mean. For T the standard deviation varies with an average magnitude of 3.48×10^{-6}m whilst the mean varies between -10^{-4}m and +10^{-4}m. The uncertainty between measurements is quite small since the standard deviation is small in relation to the overall variation of T. But there still seems to be a degree of uncertainty in the measurement when comparing the mean value of T to the value received from the data measured by IPMS. The overall form between the plots in Figure 35 shows that the mean value of T follows the form in large but that the smaller variations of T in the IPMS data (not considering the large peaks) are not registered in the mean value of T.

When comparing the mean values of T from the measurements performed upon arrival of the SLM and after three months in Figure 36 the values are very similar. They have the same variations, magnitude and form. From said plots it seems as if repeated measurements reproduce the same results and that the mean value of T can in an approximate manner correctly represent the parameter T of an SLM. The uncertainty between the data from IPMS and the measured mean value of T could also be due to the difference in measured data points. Another reason that may affect the certainty and reliability of the measurements is the performance of the measurement instrument. This will be analyzed in further detail after the results of P1.

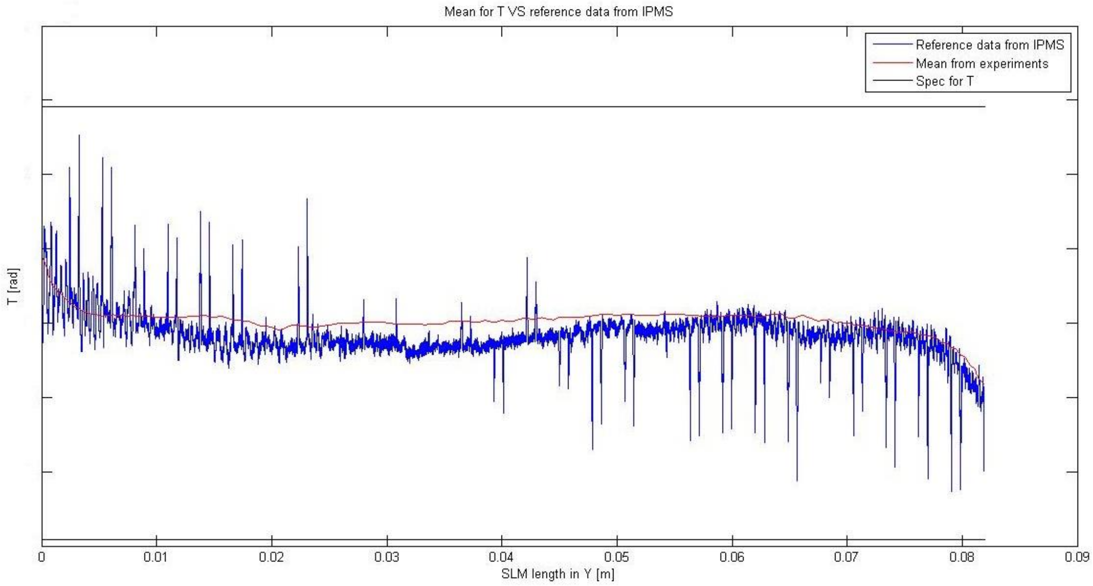

Figure 35 ***Plots of the mean value of T and T from the reference data.***

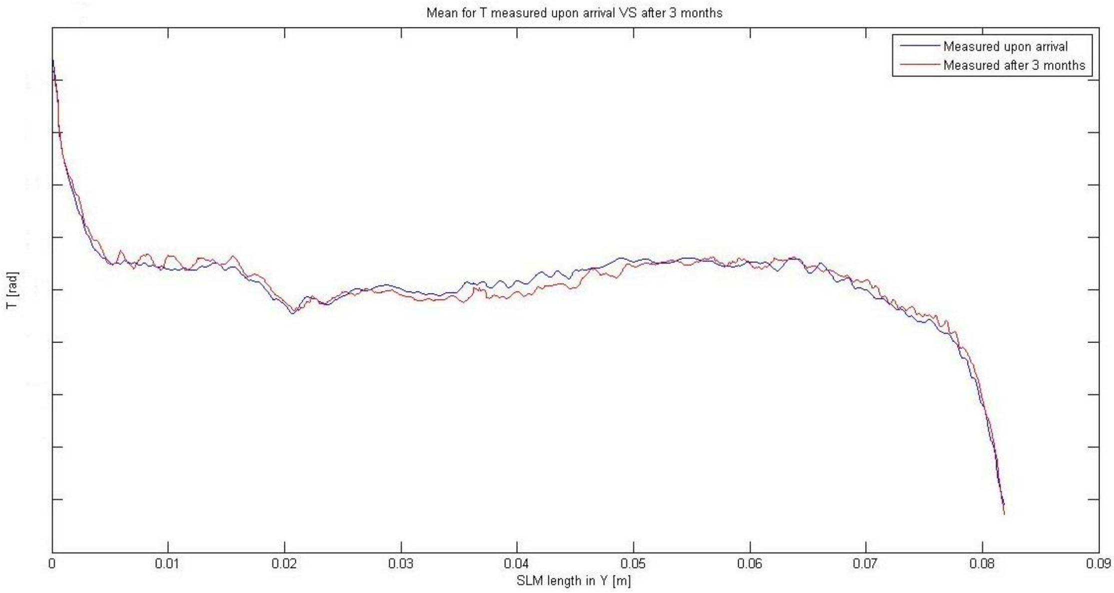

Figure 36 ***Plots displaying the mean values for T along the length of the SLM measured upon delivery at Micronic Mydata and after three months.***

Results and analysis of P1 (tilt across the short end)

The mean value and standard deviation for P1 are displayed in Figure 37. The average standard deviation of the ten measurements is 3.48×10^{-6}m, similar to the standard deviation of T. But since the magnitude in which P1 varies is much smaller than that of T it plays a more prominent role as can be seen in Figure 37.

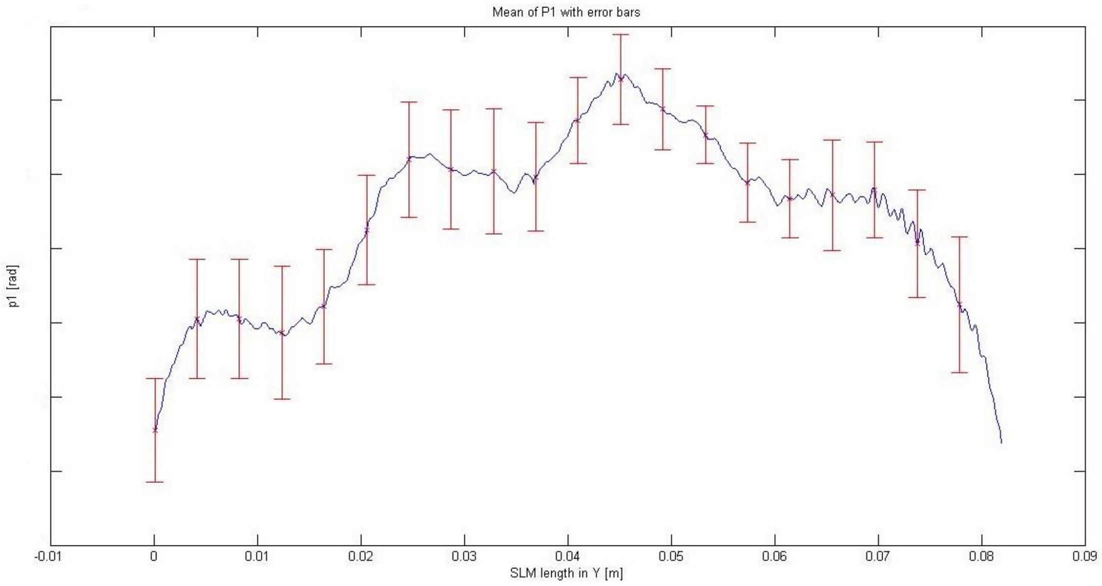

Figure 37 Mean value of T with error bars representing the standard deviation.

Despite having a large standard variation between results the mean values of P1 upon delivery and after three months represent the same characteristic performance of the SLM (Figure 39). This leads to believe that the shape of the SLM can be considered stable over time in regards of the parameter P1. Now whether or not this is a correct representation of the true characteristic is represented in Figure 39.

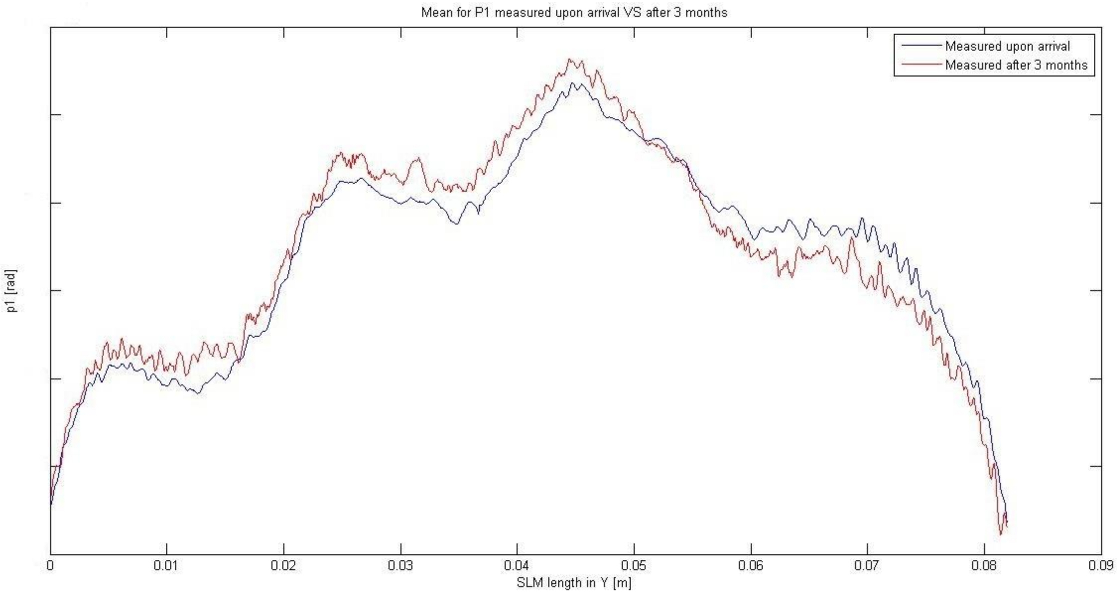

Figure 38 Plots displaying the mean values for P1 along the length of the SLM measured upon delivery at Micronic Mydata and after three months.

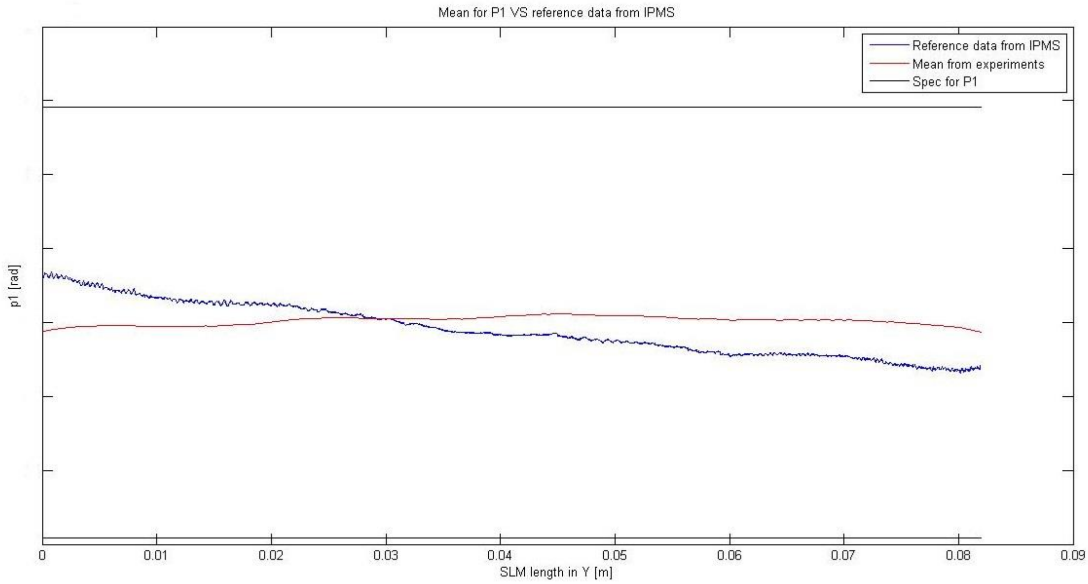

Figure 39 Plots of the mean value of P1 and P1 from the reference data.

Contrary from P2 and T the parameter P1 represented by the mean value of the measurements does not in a correct manner represent the shape or form of the SLM. It would appear as if the short end has barely any tilt when interpreting the mean value of P1. The data supplied by IPMS implies that the SLM has a “propeller” form. Said form is when it is tilted in a positive manner on one end and becomes less tilted approaching the middle of the chip and tilts in the other direction resulting in a negative tilt on the other end. The described “propeller” form cannot be deduced from the data received from the measurements performed.

After several measurements on different SLMs (without reference data) the parameter P1 behaved in approximately the same manner in all cases. It did not vary that much and described the SLMs as extremely flat. Even though the SLMs are extremely flat they usually have a certain tilt where the ends of the SLM are tilted in opposite directions (“propeller”) or in the same direction in relation to the middle. Since the parameters P2 and T could approximately be correctly represented the difficulty in representing P1 led to the reasoning that maybe the interferometer used may not correctly represent smaller angular variations.

Propeller Testing

To investigate whether or not the interferometer could correctly represent small angular variations it would have been optimal to have had an object with a twist of known size and variation other than the supplied SLM. Since no such object was available the following experiment was performed.

The propeller form was explicitly provoked upon the SLM by inserting two metal sheets of a known thickness underneath the SLM 3.5 mm from the edges of the SLM on opposite sides. Counterweights were placed opposite the sheets on top of the SLM to weigh those sides down. The choice of inserting the metal sheets said distance was chosen to try to ensure that the edge of the area of interest would be raised to a known height. Three experiments were executed with sheets of three different thicknesses 10µm, 20µm and 30µm.

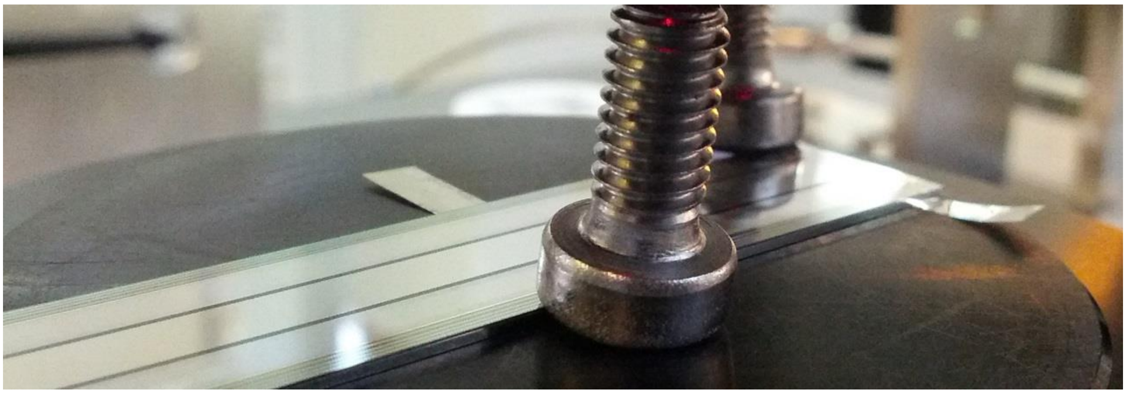

Figure 40 The setup used to provoke the propeller form upon an SLM.

Thanks to Fredrik Johnson at Micronic Mydata the angle at which each respective side of the propeller should be tilted was simulated using the program Comsol Multiphysics [10] [11]. The simulations showed that regardless of the height of the sheet tucked underneath the SLM the total provoked twist between the edges of the active area of the mirrors would vary in an equal manner. The height difference between the edges was -0.21µm at the middle and 0.41µm at the outer edge (Figure 41).

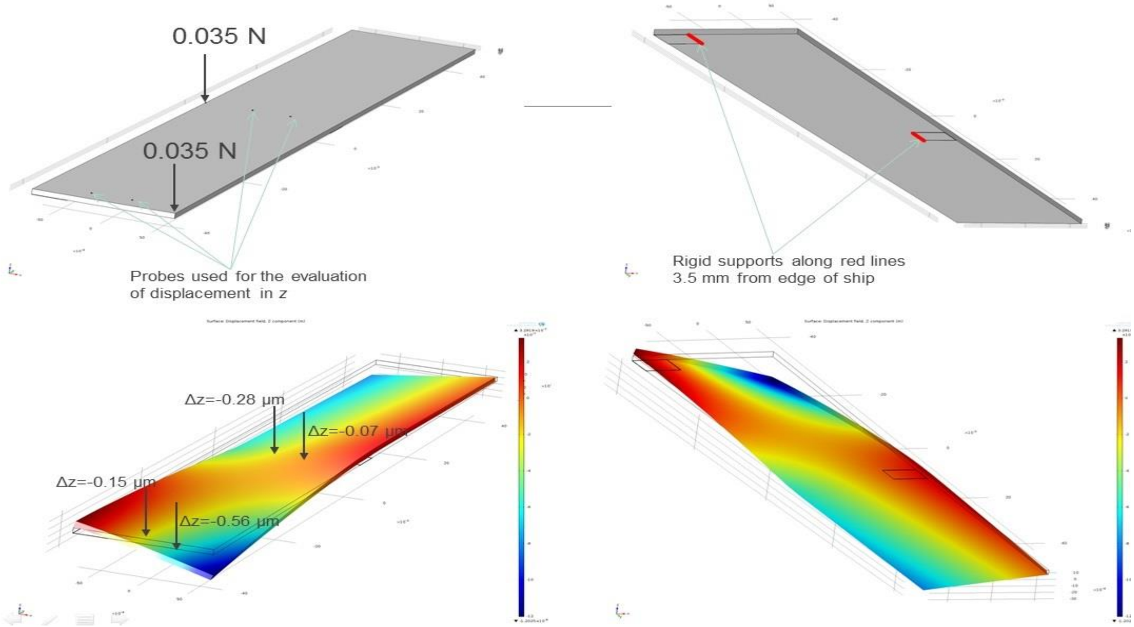

Figure 41 Simulation plots from Comsol Multiphysics.

$$\text{provoked angle} = \tan^{-1}\left(\frac{\textit{Height difference betweens edges of active area}}{\textit{distance between edges of active area}}\right) \qquad \text{Equation 2}$$

Using said equation the provoked tilt upon the SLM should vary from 0.525×10^{-4} rad at the center to -1.025×10^{-4} rad at the outer edge of the SLM for the 10µm, 20µm and 30µm thick sheets.

In order to have as controlled measurements as possible half of an SLM was measured where the propeller effect was provoked upon the edges of that half as seen in Figure 40. The results from that measurement were then mirrored to represent the rest of the SLM. The expected result would be to see the parameter P1 vary in the order of 1.55×10^{-4}rad between the edge of the SLM and the middle of the length of the SLM. The results from the propeller test can be seen in Figure 42. The same code that was used to stitch together two measurements was used for the “propeller tests”. For these experiments only the first half of the data represented in Figure 42 is of interest.

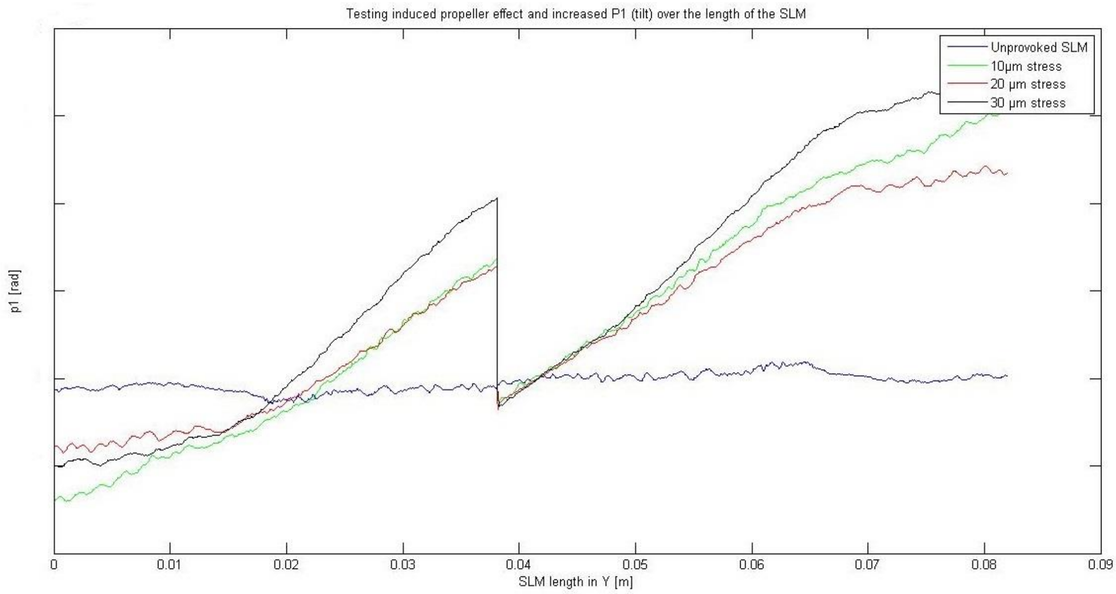

Figure 42 ***Plots displaying the results from the propeller tests.***

Table 1

Applied stress	Expected tilt	Achieved Tilt
10µm	1.55×10^{-4} rad	1.34×10^{-4}rad
20µm	1.55×10^{-4} rad	1.11×10^{-4}rad
30µm	1.55×10^{-4} rad	1.49×10^{-4}rad

Table 1. ***After inducing a severely accentuated propeller twist to the SLM the form could finally be read by the Fisba interferometer.***

The expected and achieved results can be seen in Table 1, the provoked effect seems to be correctly represented by the measurements performed. The variation between the achieved results in Table 1 can be seen as the standard deviation between measurements as mentioned in previous sections when looking at the mean values. What can be concluded is that when a twist is present it is possible to be read by the Fisba interferometer. Furthermore it can be concluded from the results obtained previously that when several measurements have been repeated on the same SLM the mean values can be used to approximately obtain the parameters P1, P2 and T in a correct manner. The shape of the SLM can also be seen to be stable over time considering that the same results were obtained for P1, P2 and T when measuring the same SLM with two months between measurements. The measurements performed differ from those performed by IPMS though and this may be due to a change in shape of the SLM during transportation or other moments when handled under uncontrolled circumstances. It is important to remember that the supplied SLM for the experiments was not bonded upon a ceramic which is usually the norm; this may lead the SLM to behave in an unordinary manner.

Experiments

The initial aim of the hardware experiments was to under regulated vacuum pressure attempt to improve the planarity of the SLM. Before the experiments began the ability to regulate the vacuum was tested. To test the regulatory ability of the vacuum the tube that was to be connected to the aluminum block was sealed. Once sealed the valve to regulate the vacuum (Figure 29) was turned slowly until the vacuum effect was made apparent via the vacuum gauge. During the tests the vacuum could be regulated quite efficiently between -5kPa and -45kPa at increments of -5kPa. When the tests were run with the aluminum block and an SLM mounted on top it was not possible to regulate the pressure in the same manner. The vacuum gauge would switch directly from displaying no vacuum to -45kPa. In the ambition to execute experiments under regulated vacuum settings an attempt was made to start off with the strongest vacuum setting (-45Kpa) and slightly lower the vacuum pressure as much as possible without the vacuum effect disappearing. It was possible to lower the vacuum to -37.5kPa but after three hours the vacuum effect had subsided and there was no longer any vacuum between the SLM and aluminum block. This method was then abandoned to solely concentrate the experiments to test how the planarity of the SLM was effected when glued to a surface under a fixed vacuum (-45kPa).

When the experiments began the method that was eventually reached to measure an entire SLM in the most correct manner had not yet been established. The temporary method used to measure the SLM’s in the beginning of the project made use of a mark from a pen on the actual SLM as a reference. When using the temporary method the area of interest could not be determined as precisely as with the finally established method. Hence the results from the early experiments are not as precise. But since the change in character of the SLM’s parameter was quite considerable they can be considered reliable enough to give an idea of the change of character of the SLM’s parameters. The results of the first two SLMs presented were measured using the temporary and less reliable method.

SLM chip VC_2962_04_06

The tilt P1 increased dramatically after having been glued and exposed to vacuum (Figure 43 The plot above shows the parameter P1 before and after the SLM had been glued.). The drastic jump of P1 at the overlapping points between the data sets is due to that the code written was written to compensate for slight offsets when transitioning between data sets. Since the shape of the SLM changed quite drastically after having been glued and exposed to the fixed vacuum the difference between the two data sets is much more apparent than between two unaffected datasets.

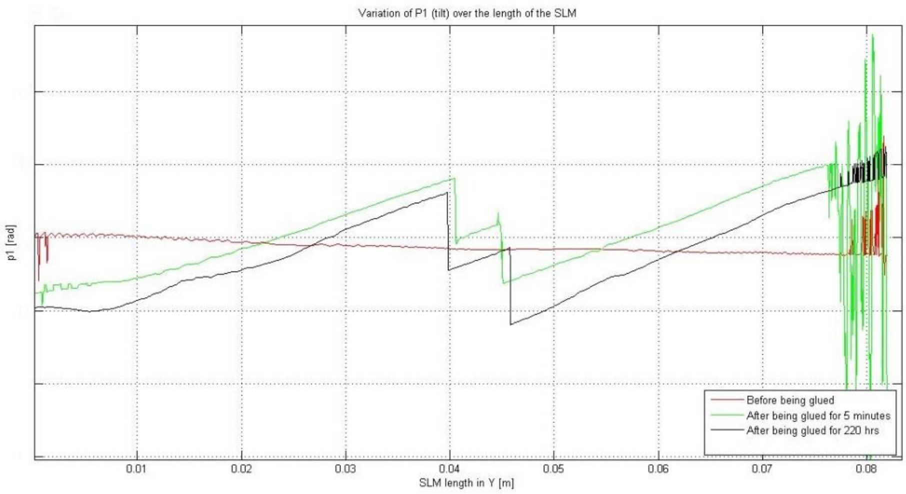

Figure 43 The plot above shows the parameter P1 before and after the SLM had been glued.

The results of P2 from the measurements are difficult to interpret with what seems to be large discontinuities at the outer edges (Figure 44) that affect the calculation of P2. When the calculations are done to extract P2 [6] a cylinder is removed from the surface data leaving the residual bow in the short direction. With poor measurements the cylinder form removed may have been false resulting in very large absolute values.

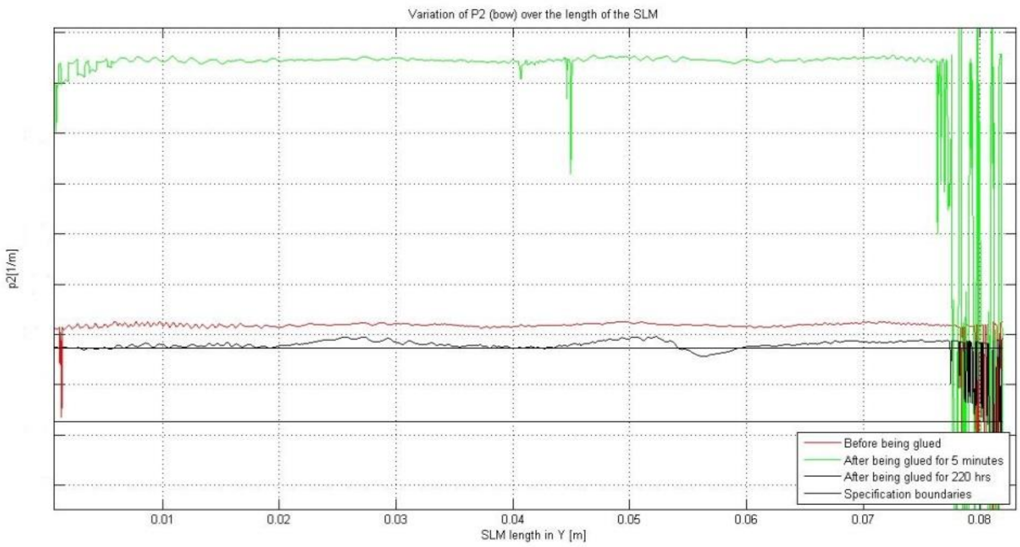

Figure 44 The plot above shows the parameter P2 before and after the SLM had been glued.

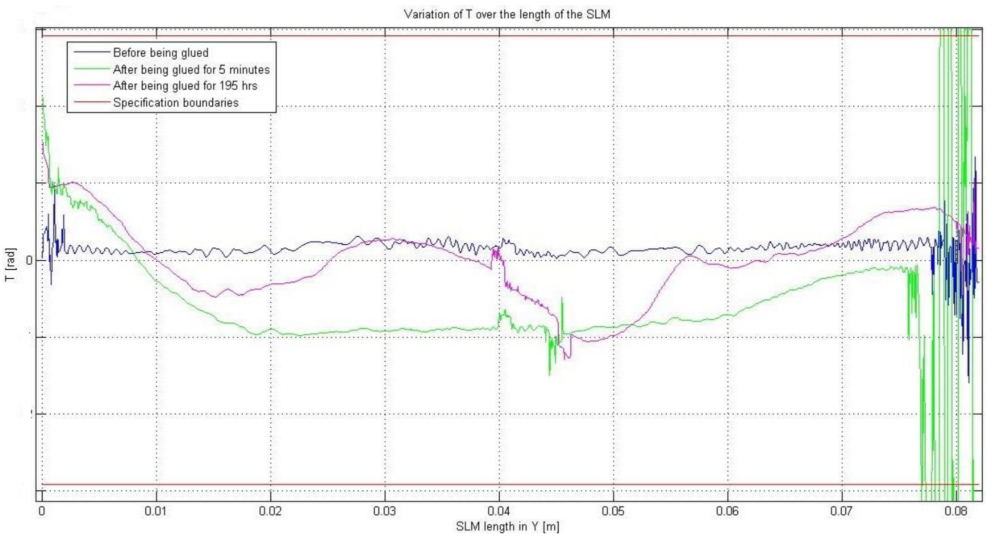

Figure 45 The plot above shows the parameter T before and after the SLM had been glued.

The parameter T increased and became worse as was the case for P1 and P2 after having been glued.

SLM chip VC_2962_04_04

For the chip VC_2962_04_04 several measurements were preformed that did not result in correct readings. As mentioned earlier in the report when taking measurements with the Fisba interferometer if there were large discontinuities it was difficult to get a reading of the topography of the measured object. This lead to only three readings for said chip.

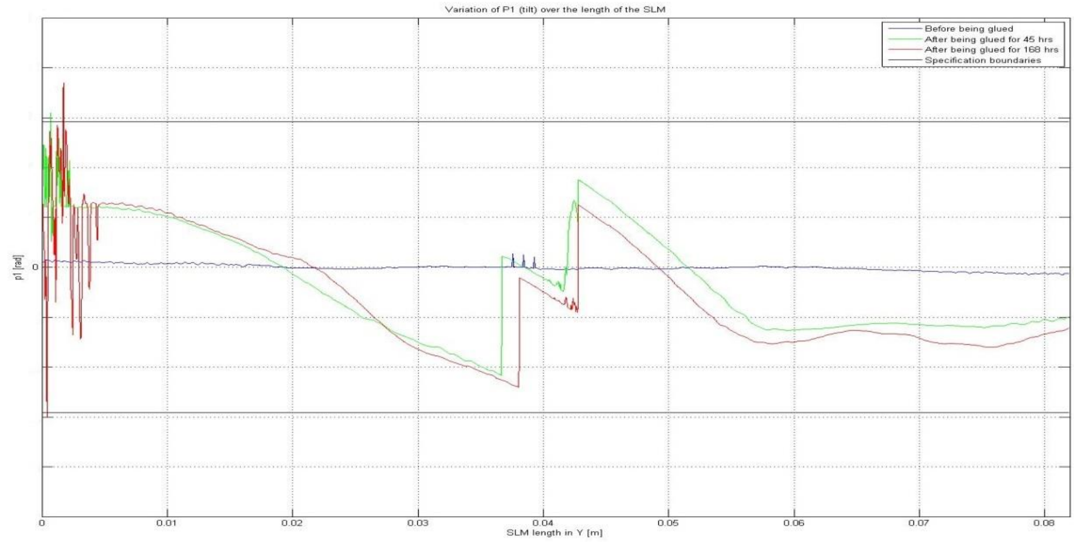

Figure 46 The plot above shows the parameter P1 before and after the SLM had been glued.

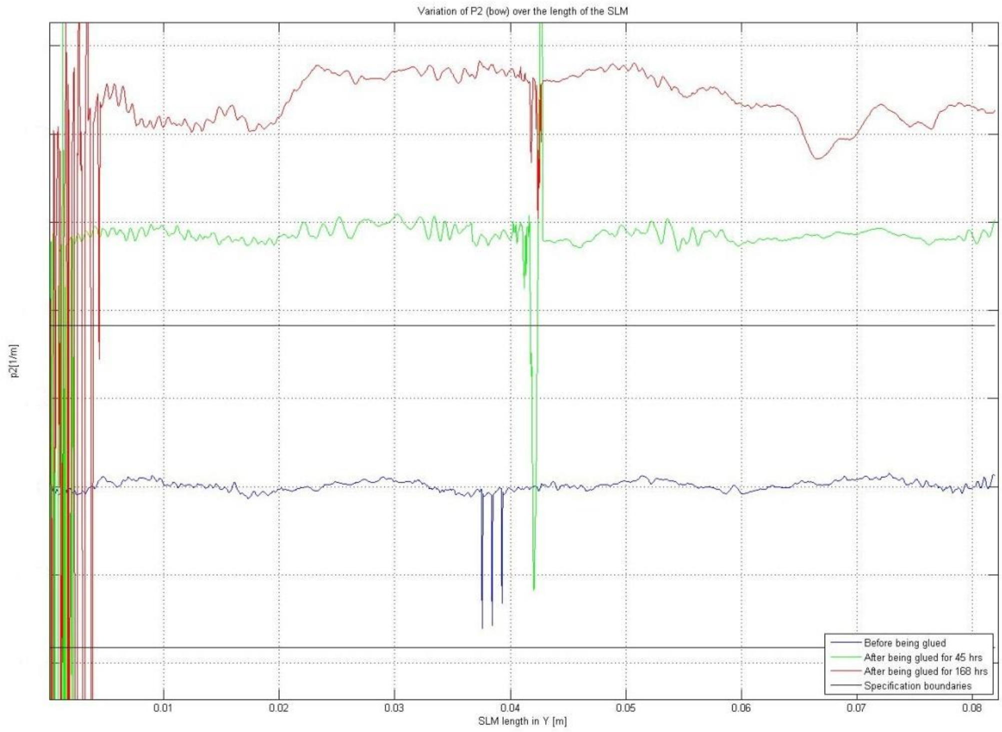

Figure 47 The plot above shows the parameter P2 before and after the SLM had been glued.

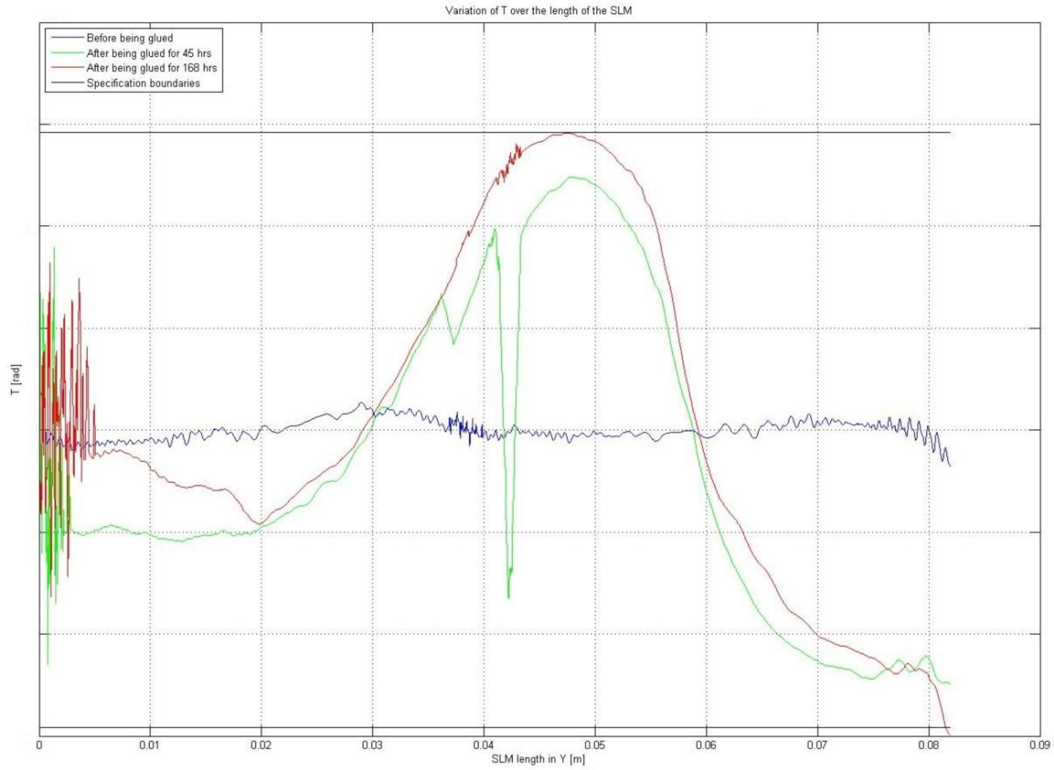

Figure 48 The plot above shows the parameter T before the SLM was to be glued.

SLM chip VC_2962_10_01

For the chip VC_2962_10_10 several measurements were preformed that did not result in correct readings. This lead to four readings for said chip after it had been glued [12]. For reasons visibility the plots below show the parameters before being glued, after five minutes and after 170 hours.

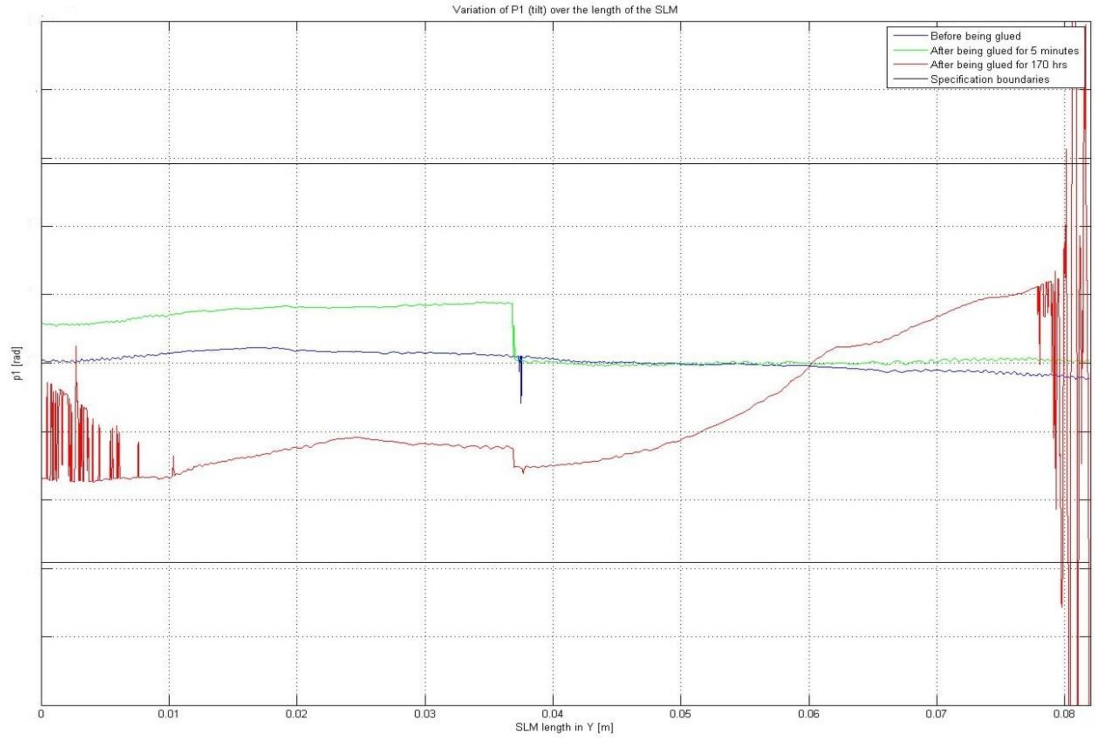

Figure 49   The plot above shows the parameter P1 before and after the SLM had been glued.

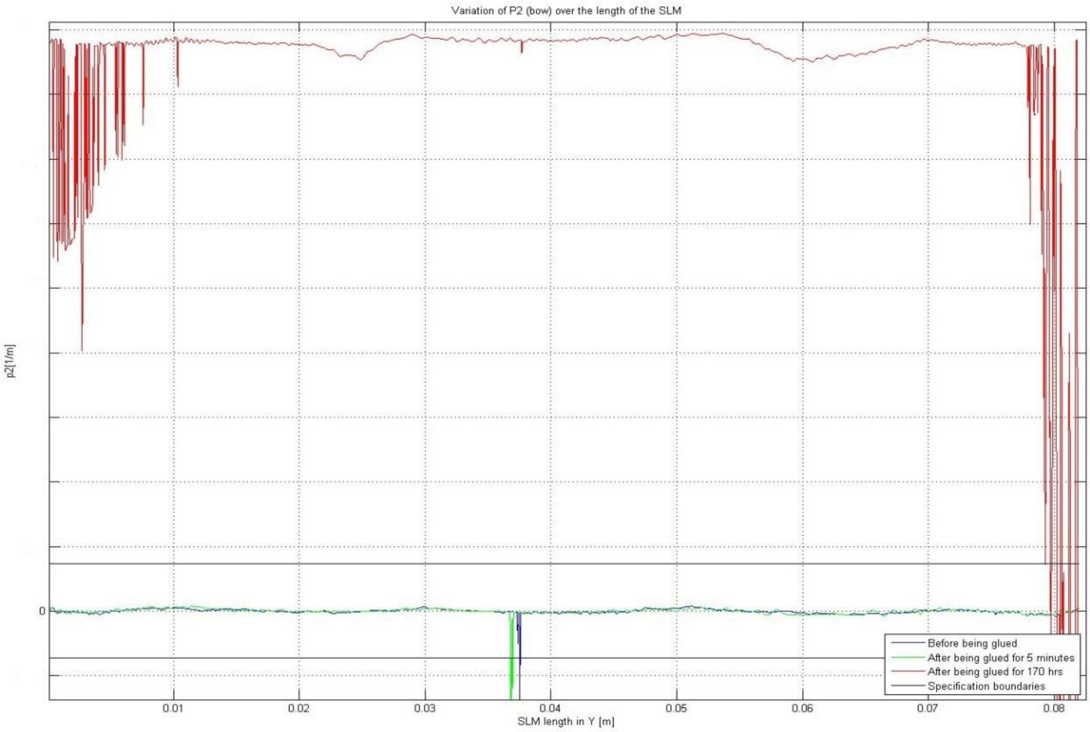

Figure 50   The plot above shows the parameter P2 before and after the SLM had been glued.

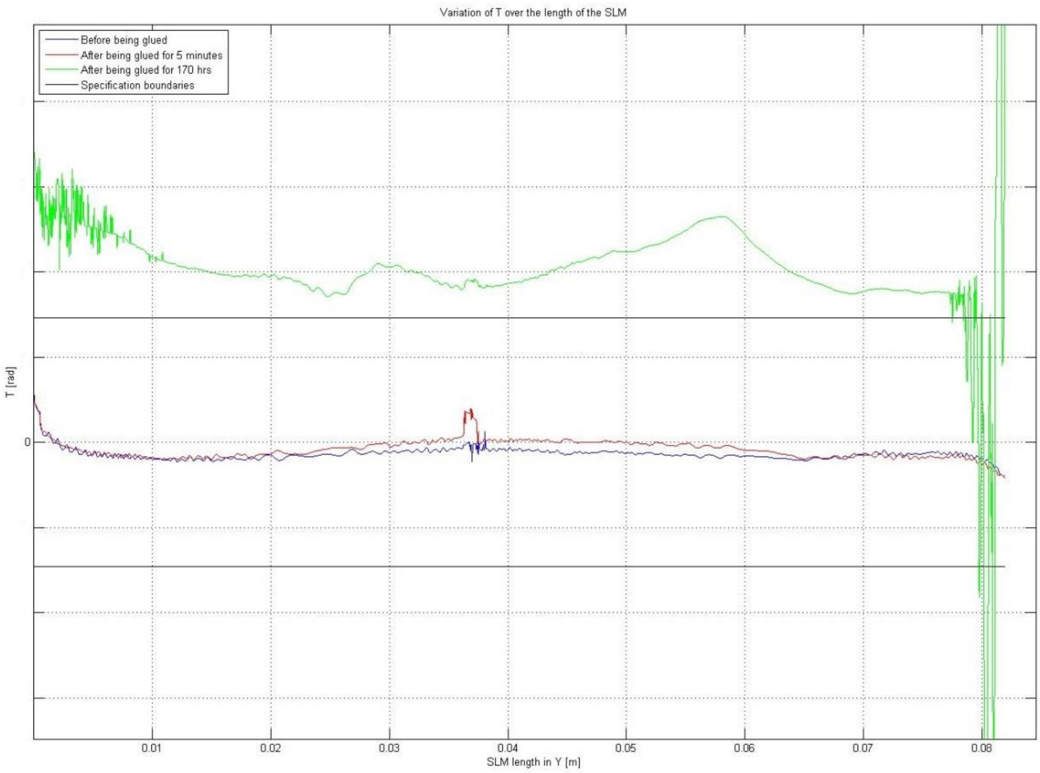

Figure 51 ***The plot above shows the parameter T before and after the SLM had been glued.***

SLM chip VC_2962_10_02

For the chip VC_2962_10_02 several measurements were preformed that did not result in correct readings. This lead to only one reading for said chip.

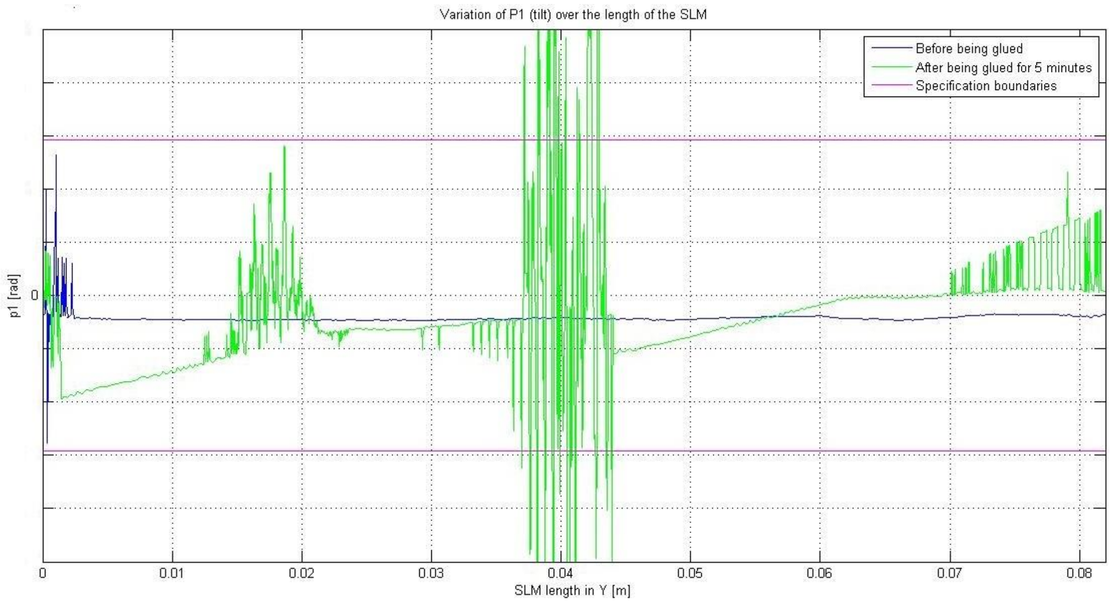

Figure 52 ***The plot above shows the parameter P1 before and after the SLM had been glued.***

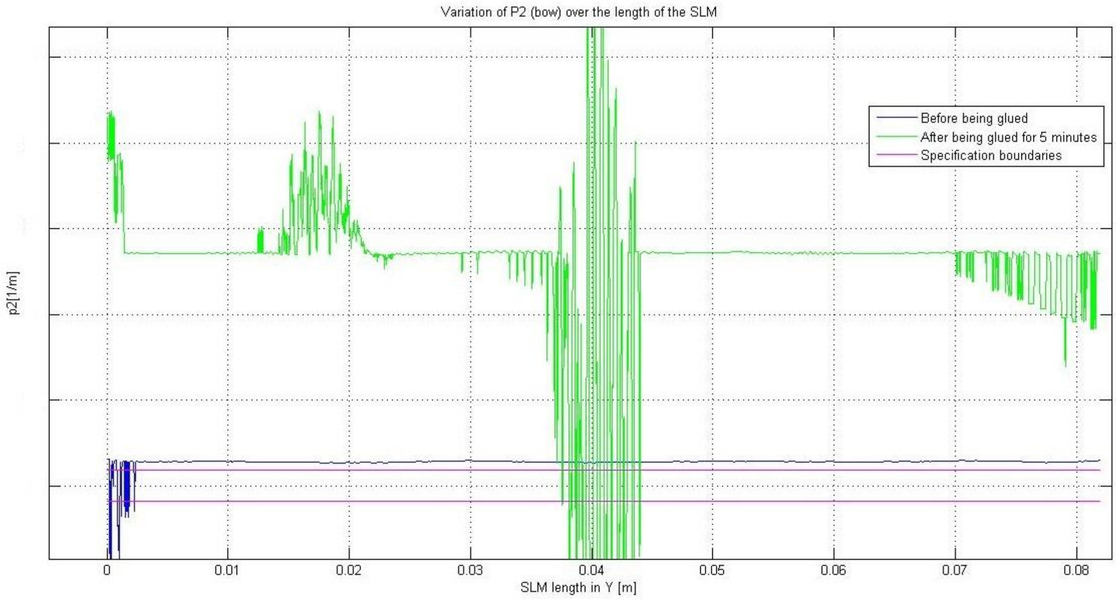

Figure 53 ***The plot above shows the parameter P2 before and after the SLM had been glued.***

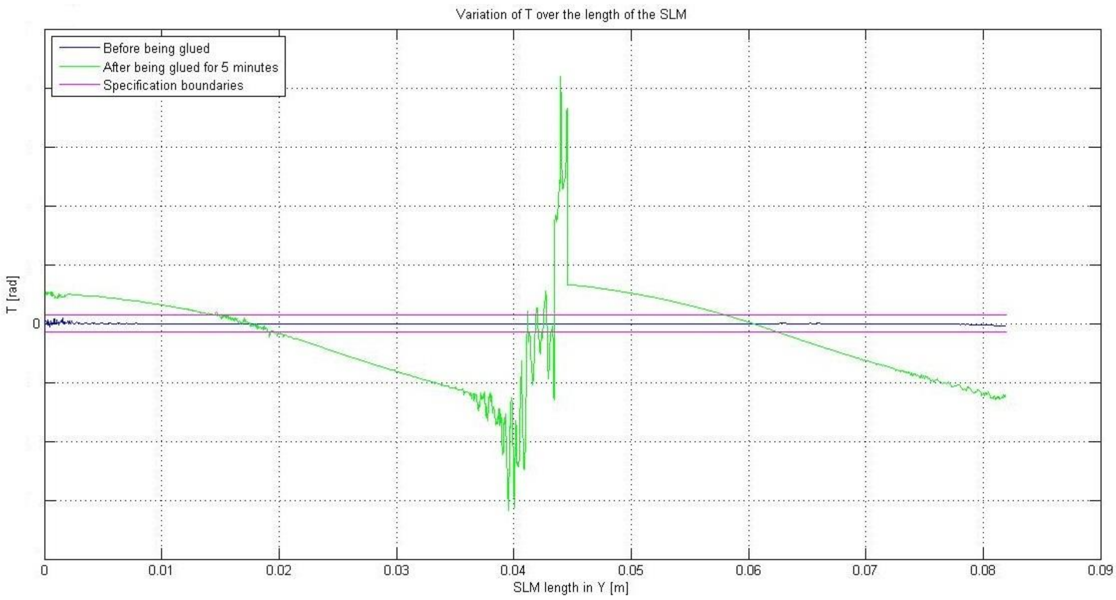

Figure 54 ***The plot above shows the parameter T before and after the SLM had been glued.***

The two SLMs that had the poorest results after the controlled vacuum/glue test were VC_2962_10_02 and VC_2962_10_01. Both of said SLM chips were glued to two of the aluminum blocks with the least plane surfaces. Said blocks had absolute height variations along their surfaces of more than 14µm and 16µm respectively. The results from the CMM measurements can be found in Appendix A.

SLM chip VC_2962_10_05

The block that had the most planar surface was the block used on the SLM VC_2962_10_05. This was also the SLM which had the least drastic changes of its parameters P1, P2 and T. The absolute value between the highest and lowest point on the block used for VC_2962_10_05 was 7µm. Since this SLM varied the least drastically after being glued it was possible to preform several successful measurements to document the curing of the glue over time.

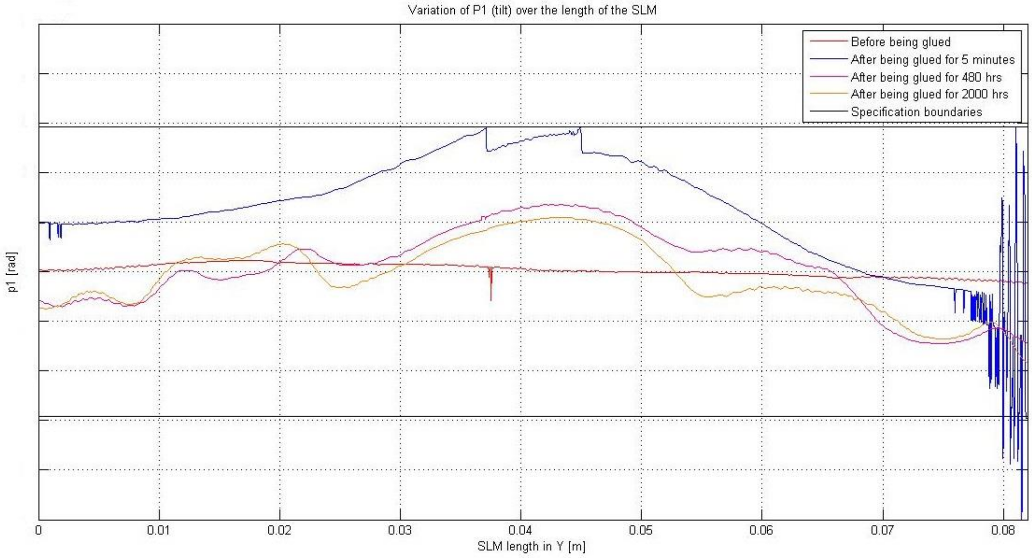

Figure 55 ***The plot above shows the parameter P1 before and after the SLM had been glued.***

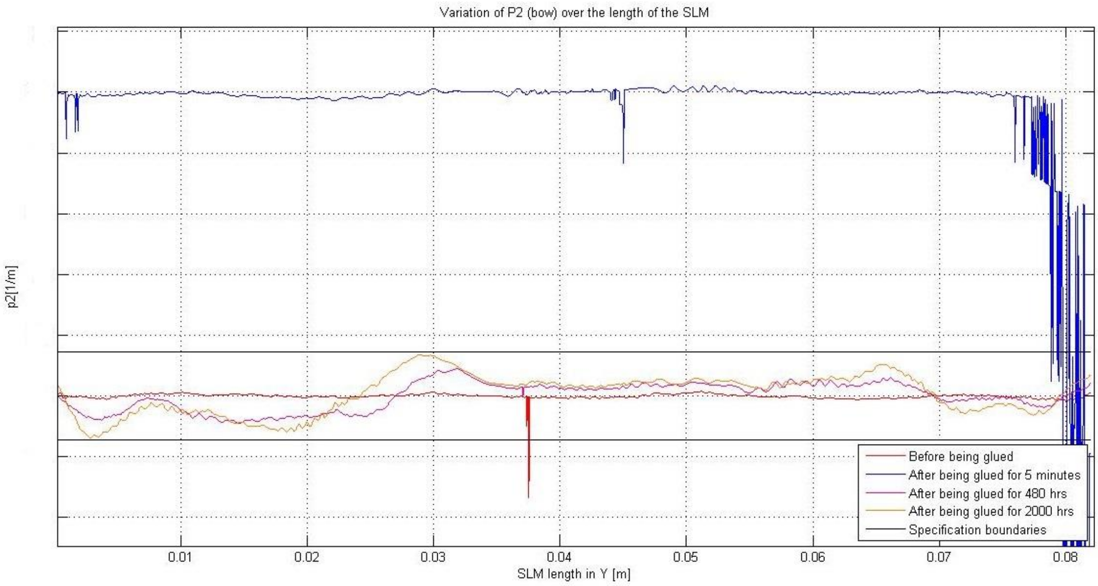

Figure 56 ***The plot above shows the parameter P2 before and after the SLM had been glued.***

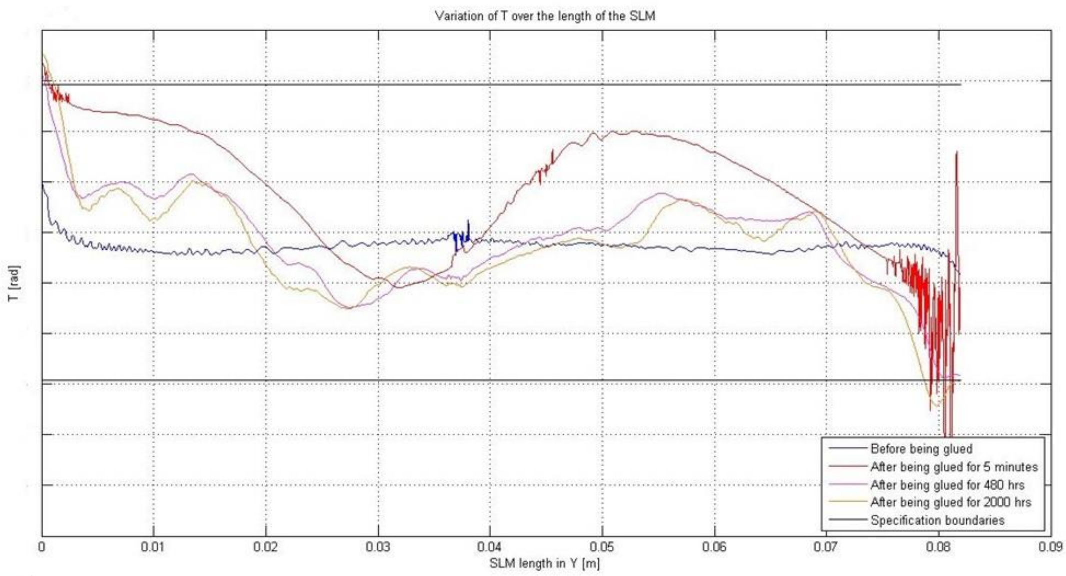

Figure 57 ***The plot above shows the parameter T before and after the SLM had been glued.***

The results over time showed that the SLM in large kept the shape it got upon being bonded to the aluminum block. The large value of P2 in the measurement after five minutes (red) can be due to the poor measurement results at the outer edge that can be seen in the parameters of P1 and T as well.

Conclusions and Recommendations for Future Work

When the project commenced there were two clear goals. The first was to see if it would be possible to improve the global planarity of the Spatial Light Modulator used in the LDI. The second goal of the project was to establish an accurate method to measure the SLM's at the Micronic Mydata HQ without having to send them to the manufacturer for control measurements and also to control the results of the first goal.

With an ambition to improve the global planarity of the SLM the goal could not be obtained when the surface the SLM was to be glued upon had a less planar surface than the SLM itself. The test performed showed that the more un-plane the surface the SLM was to be glued upon the worse the planarity of the SLM became. If any future work would be done to further investigate the possibilities of improving the global planarity it would be essential to have surfaces that would be extremely flat and have a better planarity than the SLM themselves. Of the materials available in-house at the Micronic Mydata HQ there are quartz glass tiles that are extremely planar. Brief attempts were made to try to setup a method using quartz glass tiles that were unsuccessful. In order to be successful with such experiments it would be necessary to drill very precise holes and cavities in the quartz glass which is very difficult. The reference used to decide using the one-hole vacuum setup experimented on the SLM used in the Sigma which has different dimensions than the SLM used in the LDI. Because of said difference between the SLM of the LDI and Sigma it might also be interesting to investigate whether the number of holes or slits used to force the LDI's SLM via vacuum towards the surface might be better with another setup than just one hole.

It can be concluded concerning the established measuring method that the method could in a correct manner approximately represent the characteristics of the parameters P1, P2 and T when enough measurement samples had been taken to obtain the mean values.

In regards to the parameter P1 it is not absolutely certain that the established method could correctly represent said parameter. With only one SLM as a reference and no other known measurable objects it is difficult to know how correct the measurements are. Since the SLM that was used as reference for the measurements was not glued to a ceramic as is the norm it may have behaved differently than usual. This could mean that the SLM did not have the same twist as when it was measured by IPMS. The propeller tests showed that with a provoked twist the same tilt could be measured in a repeated manner. Even though the results did coincide with the simulated results it is still not sure whether the simulated results were correctly achieved in physical form. This leaves room for further investigation.

If there still exists an ambition to utilize the interferometer at the Micronic Mydata HQ more tests could be run to see whether or not it can correctly read minor angular variations. The method established to measure an LDI SLM has been documented and can easily be repeated by following the instructions [13]. Further improvements to the data merging code would be to write in a loop that would take in the samples from ten measurement sets and extract the mean values of desired parameters. This would lead to a very long analysis time but would be advantageous since at the moment the analysis time is still quite long and to obtain the mean values has to be repeated several times.

Appendix

Appendix A

Second Block SLM VC_2962_04_06

pc-dmis	DETALJNAMN : Klos planhet		april 04, 2013	09:51
	VERSIONSNR. :	SERIENR. : 2	STATISTIK-ANT. : 1	

FCFPLAN1	MM	⏥ 0.01

Element	MÄTT	NOMINELLT	+TOL	-TOL	AVV
PLAN3	0.0086	0.0000	0.0100		0.0086

ELEMENT	MÄTPKTR	MÄTT X	Y	Z	VEKTOR I	J	K	AVV
PLAN3	1	4.935	4.958	-0.002	-0.000	-0.000	1.000	0.004
	2	15.094	4.980	-0.002	-0.000	0.000	1.000	0.005
	3	25.093	4.976	-0.003	-0.000	0.000	1.000	0.003
	4	35.099	5.023	-0.005	-0.000	0.000	1.000	0.002
	5	45.088	4.987	-0.004	-0.000	0.000	1.000	0.002
	6	55.084	4.983	-0.005	-0.000	0.000	1.000	0.002
	7	65.090	4.965	-0.004	-0.000	0.000	1.000	0.002
	8	75.093	4.964	-0.004	-0.000	0.000	1.000	0.003
	9	85.088	5.001	-0.003	-0.000	0.000	1.000	0.003
	10	4.910	9.997	-0.006	-0.000	0.000	1.000	0.001
	11	15.078	10.001	-0.005	-0.000	0.000	1.000	0.001
	12	25.084	10.002	-0.006	-0.000	0.000	1.000	0.001
	13	35.098	10.011	-0.007	-0.000	0.000	1.000	-0.001
	14	45.089	9.967	-0.007	-0.000	0.000	1.000	-0.000
	15	55.082	9.973	-0.006	-0.000	0.000	1.000	0.000
	16	65.084	10.014	-0.007	-0.000	0.000	1.000	-0.000
	17	75.093	9.978	-0.006	-0.000	0.000	1.000	0.000
	18	85.092	10.001	-0.008	-0.000	0.000	1.000	-0.002
	19	4.911	14.988	-0.007	-0.000	0.000	1.000	-0.000
	20	15.079	14.985	-0.007	-0.000	0.000	1.000	-0.001
	21	25.085	14.995	-0.007	-0.000	0.000	1.000	-0.001
	22	35.098	14.988	-0.007	-0.000	0.000	1.000	-0.001
	23	45.081	14.985	-0.007	-0.000	0.000	1.000	-0.001
	24	55.083	14.990	-0.007	-0.000	0.000	1.000	-0.001
	25	65.094	15.000	-0.007	-0.000	0.000	1.000	-0.001
	26	75.086	15.006	-0.006	-0.000	0.000	1.000	-0.000
	27	85.081	14.977	-0.008	-0.000	0.000	1.000	-0.002
	28	4.913	17.496	-0.008	-0.000	0.000	1.000	-0.001
	29	7.091	17.497	-0.008	-0.000	0.000	1.000	-0.001
	30	9.091	17.483	-0.006	-0.000	0.000	1.000	-0.000
	31	11.102	17.472	-0.006	-0.000	0.000	1.000	0.000
	32	13.096	17.478	-0.006	-0.000	0.000	1.000	0.000
	33	15.086	17.476	-0.007	-0.000	0.000	1.000	-0.001
	34	17.094	17.501	-0.007	-0.000	0.000	1.000	-0.001

1 för 3

35	19.095	17.485	-0.007	-0.000	0.000	1.000	-0.001	
36	21.089	17.475	-0.007	-0.000	0.000	1.000	-0.000	
37	23.094	17.467	-0.007	-0.000	0.000	1.000	-0.000	
38	25.095	17.478	-0.008	-0.000	0.000	1.000	-0.001	
39	27.089	17.470	-0.007	-0.000	0.000	1.000	-0.000	
40	29.100	17.462	-0.006	-0.000	0.000	1.000	-0.000	
41	31.099	17.473	-0.007	-0.000	0.000	1.000	-0.001	
42	33.090	17.476	-0.007	-0.000	0.000	1.000	-0.001	
43	35.091	17.479	-0.007	-0.000	0.000	1.000	-0.001	
44	37.089	17.466	-0.007	-0.000	0.000	1.000	-0.001	
45	39.094	17.466	-0.008	-0.000	0.000	1.000	-0.002	
46	41.099	17.500	-0.008	-0.000	0.000	1.000	-0.002	
47	43.090	17.478	-0.008	-0.000	0.000	1.000	-0.002	
48	45.090	18.013	-0.007	-0.000	-0.000	1.000	-0.001	
49	47.089	17.465	-0.007	-0.000	0.000	1.000	-0.001	
50	49.092	17.464	-0.007	-0.000	0.000	1.000	-0.001	
51	51.082	17.463	-0.007	-0.000	0.000	1.000	-0.001	
52	53.087	17.465	-0.006	-0.000	0.000	1.000	-0.000	
53	55.096	17.494	-0.007	-0.000	0.000	1.000	-0.001	
54	57.098	17.480	-0.007	-0.000	0.000	1.000	-0.001	
55	59.090	17.470	-0.007	-0.000	0.000	1.000	-0.001	
56	61.084	17.467	-0.007	-0.000	0.000	1.000	-0.001	
57	63.085	17.494	-0.007	-0.000	0.000	1.000	-0.001	
58	65.088	17.480	-0.007	-0.000	0.000	1.000	-0.001	
59	67.087	17.470	-0.006	-0.000	0.000	1.000	-0.000	
60	69.094	17.467	-0.006	-0.000	0.000	1.000	-0.000	
61	71.103	17.501	-0.007	-0.000	0.000	1.000	-0.001	
62	73.105	17.475	-0.007	-0.000	0.000	1.000	-0.001	
63	75.099	17.469	-0.006	-0.000	0.000	1.000	-0.000	
64	77.094	17.475	-0.007	-0.000	0.000	1.000	-0.001	
65	79.097	17.482	-0.007	-0.000	0.000	1.000	-0.001	
66	81.098	17.485	-0.007	-0.000	0.000	1.000	-0.001	
67	83.086	17.478	-0.008	-0.000	0.000	1.000	-0.002	
68	85.092	17.500	-0.008	-0.000	0.000	1.000	-0.002	
69	4.918	19.998	-0.008	-0.000	0.000	1.000	-0.002	MIN
70	15.080	20.002	-0.008	-0.000	0.000	1.000	-0.002	
71	25.090	19.977	-0.007	-0.000	0.000	1.000	-0.001	
72	35.100	19.977	-0.008	-0.000	0.000	1.000	-0.002	
73	45.090	19.985	-0.007	-0.000	0.000	1.000	-0.001	
74	55.080	19.986	-0.007	-0.000	0.000	1.000	-0.001	
75	65.093	19.987	-0.006	-0.000	0.000	1.000	-0.000	

2 för 3

76	75.087	19.985	-0.007	-0.000	0.000	1.000	-0.001	
77	85.086	20.001	-0.006	-0.000	0.000	1.000	-0.000	
78	4.917	24.992	-0.007	-0.000	0.000	1.000	-0.000	
79	15.083	24.989	-0.006	-0.000	0.000	1.000	0.000	
80	25.083	24.984	-0.007	-0.000	0.000	1.000	-0.001	
81	35.099	24.986	-0.007	-0.000	0.000	1.000	-0.001	
82	45.093	24.986	-0.008	-0.000	0.000	1.000	-0.002	
83	55.093	24.985	-0.006	-0.000	0.000	1.000	-0.000	
84	65.097	24.986	-0.006	-0.000	0.000	1.000	0.000	
85	75.087	24.992	-0.004	-0.000	0.000	1.000	0.002	
86	85.093	24.988	-0.005	-0.000	0.000	1.000	0.001	
87	4.925	29.988	-0.003	-0.000	0.000	1.000	0.003	
88	15.088	29.987	-0.004	-0.000	0.000	1.000	0.003	
89	25.091	29.984	-0.004	-0.000	0.000	1.000	0.002	
90	35.101	29.983	-0.005	-0.000	0.000	1.000	0.001	
91	45.089	29.990	-0.005	-0.000	0.000	1.000	0.001	
92	55.088	29.987	-0.004	-0.000	0.000	1.000	0.001	
93	65.095	29.984	-0.002	-0.000	0.000	1.000	0.004	
94	75.081	29.986	-0.000	-0.000	0.000	1.000	0.005	
95	85.089	29.988	0.001	-0.000	0.000	1.000	0.007	MAX

3 för 3

Third Block SLM VC_2962_04_04

pc-dmis	DETALJNAMN : Klos planhet		april 04, 2013	09:57
	VERSIONSNR. :	SERIENR. : 3	STATISTIK-ANT. :	1

FCFPLAN1	MM	⏥ 0.01			
Element	MÄTT	NOMINELLT	+TOL	-TOL	AVV
PLAN3	0.0096	0.0000	0.0100		0.0096

ELEMENT	MÄTPKTR	MÄTT X	Y	Z	VEKTOR I	J	K	AVV
PLAN3	1	4.931	4.982	-0.002	0.000	0.000	1.000	0.005 MAX
	2	15.087	5.018	-0.003	-0.000	0.000	1.000	0.004
	3	25.090	4.995	-0.003	-0.000	0.000	1.000	0.004
	4	35.094	4.982	-0.004	-0.000	0.000	1.000	0.003
	5	45.088	4.998	-0.006	-0.000	0.000	1.000	0.001
	6	55.093	4.995	-0.005	-0.000	0.000	1.000	0.002
	7	65.084	4.975	-0.004	-0.000	0.000	1.000	0.003
	8	75.098	5.010	-0.003	-0.000	0.000	1.000	0.003
	9	85.089	5.007	-0.003	-0.000	0.000	1.000	0.003
	10	4.915	9.996	-0.007	-0.000	0.000	1.000	0.000
	11	15.081	10.007	-0.005	-0.000	0.000	1.000	0.002
	12	25.088	10.014	-0.005	-0.000	0.000	1.000	0.002
	13	35.090	9.976	-0.007	-0.000	0.000	1.000	-0.000
	14	45.094	10.003	-0.006	-0.000	0.000	1.000	0.001
	15	55.088	10.007	-0.006	-0.000	0.000	1.000	0.000
	16	65.092	9.971	-0.005	-0.000	0.000	1.000	0.001
	17	75.108	10.007	-0.005	-0.000	0.000	1.000	0.001
	18	85.090	9.983	-0.006	-0.000	0.000	1.000	0.000
	19	4.911	14.987	-0.009	-0.000	0.000	1.000	-0.003
	20	15.084	15.027	-0.007	-0.000	0.000	1.000	-0.001
	21	25.087	15.005	-0.005	-0.000	0.000	1.000	0.001
	22	35.091	15.018	-0.007	-0.000	0.000	1.000	-0.001
	23	45.085	14.977	-0.005	-0.000	0.000	1.000	0.000
	24	55.080	15.002	-0.005	-0.000	0.000	1.000	0.000
	25	65.089	15.005	-0.005	-0.000	0.000	1.000	0.000
	26	75.102	14.992	-0.006	-0.000	0.000	1.000	-0.001
	27	85.091	14.973	-0.009	-0.000	0.000	1.000	-0.004 MIN
	28	4.905	17.504	-0.010	-0.000	0.000	1.000	-0.004
	29	7.085	17.520	-0.009	-0.000	0.000	1.000	-0.003
	30	9.088	17.514	-0.009	-0.000	0.000	1.000	-0.003
	31	11.107	17.517	-0.007	-0.000	0.000	1.000	-0.001
	32	13.091	17.518	-0.007	-0.000	0.000	1.000	-0.001
	33	15.097	17.486	-0.009	-0.000	0.000	1.000	-0.003
	34	17.087	17.496	-0.007	-0.000	0.000	1.000	-0.001

1 för 3

35	19.095	17.507	-0.006	-0.000	0.000	1.000	-0.000
36	21.089	17.513	-0.006	-0.000	0.000	1.000	-0.000
37	23.093	17.515	-0.006	-0.000	0.000	1.000	-0.000
38	25.096	17.481	-0.006	-0.000	0.000	1.000	-0.000
39	27.090	17.504	-0.005	-0.000	0.000	1.000	0.001
40	29.095	17.510	-0.007	-0.000	0.000	1.000	-0.001
41	31.094	17.511	-0.006	-0.000	0.000	1.000	-0.001
42	33.095	17.484	-0.005	-0.000	0.000	1.000	0.000
43	35.092	17.492	-0.005	-0.000	0.000	1.000	0.000
44	37.098	17.501	-0.006	-0.000	0.000	1.000	-0.001
45	39.095	17.508	-0.007	-0.000	0.000	1.000	-0.002
46	41.091	17.509	-0.006	-0.000	0.000	1.000	-0.001
47	43.084	17.508	-0.006	-0.000	0.000	1.000	-0.001
48	45.091	18.020	-0.005	0.000	0.000	1.000	0.000
49	47.093	17.464	-0.007	-0.000	0.000	1.000	-0.002
50	49.086	17.466	-0.006	-0.000	0.000	1.000	-0.001
51	51.085	17.485	-0.006	-0.000	0.000	1.000	-0.001
52	53.089	17.495	-0.007	-0.000	0.000	1.000	-0.002
53	55.085	17.503	-0.006	-0.000	0.000	1.000	-0.001
54	57.094	17.510	-0.008	-0.000	0.000	1.000	-0.003
55	59.097	17.511	-0.005	-0.000	0.000	1.000	0.000
56	61.096	17.482	-0.005	-0.000	0.000	1.000	0.000
57	63.091	17.492	-0.006	-0.000	0.000	1.000	-0.001
58	65.092	17.499	-0.006	-0.000	0.000	1.000	-0.001
59	67.098	17.506	-0.006	-0.000	0.000	1.000	-0.001
60	69.105	17.511	-0.005	-0.000	0.000	1.000	-0.000
61	71.107	17.485	-0.006	-0.000	0.000	1.000	-0.001
62	73.103	17.492	-0.006	-0.000	0.000	1.000	-0.001
63	75.112	17.503	-0.006	-0.000	0.000	1.000	-0.001
64	77.101	17.509	-0.006	-0.000	0.000	1.000	-0.001
65	79.095	17.500	-0.006	-0.000	0.000	1.000	-0.001
66	81.099	17.510	-0.007	-0.000	0.000	1.000	-0.002
67	83.089	17.502	-0.007	-0.000	0.000	1.000	-0.002
68	85.092	17.510	-0.007	-0.000	0.000	1.000	-0.002
69	4.911	19.998	-0.009	-0.000	0.000	1.000	-0.003
70	15.092	19.978	-0.007	-0.000	0.000	1.000	-0.001
71	25.088	20.009	-0.006	-0.000	0.000	1.000	-0.001
72	35.093	20.007	-0.007	-0.000	0.000	1.000	-0.002
73	45.099	19.997	-0.006	-0.000	0.000	1.000	-0.001
74	55.088	19.970	-0.005	-0.000	0.000	1.000	-0.000
75	65.089	20.000	-0.007	-0.000	0.000	1.000	-0.002

2 för 3

76	75.089	19.981	-0.006	-0.000	0.000	1.000	-0.001
77	85.084	19.989	-0.007	-0.000	0.000	1.000	-0.002
78	4.909	24.998	-0.005	-0.000	0.000	1.000	-0.000
79	15.087	24.981	-0.004	-0.000	0.000	1.000	0.000
80	25.093	24.997	-0.003	-0.000	0.000	1.000	0.001
81	35.095	25.010	-0.003	-0.000	0.000	1.000	0.001
82	45.085	25.008	-0.004	-0.000	0.000	1.000	-0.000
83	55.081	24.975	-0.003	-0.000	0.000	1.000	0.001
84	65.091	25.001	-0.003	-0.000	0.000	1.000	0.001
85	75.089	25.001	-0.002	-0.000	0.000	1.000	0.001
86	85.098	24.993	-0.004	-0.000	0.000	1.000	-0.001
87	4.913	29.988	-0.001	-0.000	0.000	1.000	0.003
88	15.096	30.024	0.000	-0.000	0.000	1.000	0.004
89	25.088	29.985	-0.001	-0.000	0.000	1.000	0.003
90	35.090	29.996	-0.001	-0.000	0.000	1.000	0.003
91	45.093	30.006	-0.001	-0.000	0.000	1.000	0.003
92	55.086	30.016	-0.001	-0.000	0.000	1.000	0.003
93	65.094	30.015	0.000	-0.000	0.000	1.000	0.003
94	75.086	30.018	0.001	-0.000	0.000	1.000	0.004
95	85.100	29.991	0.002	-0.000	0.000	1.000	0.005

3 för 3

Fourth Block SLM VC_2962_10_02

pc•dmis	DETALJNAMN : Klos planhet		maj 07, 2013	10:10
	VERSIONSNR. :	SERIENR. : 4	STATISTIK-ANT. :	1

FCFPLAN1	MM	▱ 0.01			
Element	MÄTT	NOMINELLT	+TOL	-TOL	AVV
PLAN3	0.0138	0.0000	0.0100		0.0138

ELEMENT	MÄTPKTR	MÄTT X	Y	Z	VEKTOR I	J	K	AVV
PLAN3	1	4.962	4.986	-0.004	0.000	0.000	1.000	0.006
	2	15.102	4.986	-0.004	0.000	0.000	1.000	0.006
	3	25.090	4.993	-0.006	0.000	0.000	1.000	0.004
	4	35.085	4.993	-0.008	0.000	0.000	1.000	0.003
	5	45.089	4.986	-0.008	0.000	0.000	1.000	0.003
	6	55.081	4.987	-0.011	0.000	0.000	1.000	0.000
	7	65.084	4.987	-0.007	0.000	0.000	1.000	0.004
	8	75.092	4.987	-0.004	0.000	0.000	1.000	0.007
	9	85.085	4.995	-0.005	0.000	0.000	1.000	0.007
	10	4.904	10.007	-0.007	0.000	0.000	1.000	0.002
	11	15.096	9.980	-0.008	0.000	0.000	1.000	0.002
	12	25.078	9.987	-0.008	0.000	0.000	1.000	0.001
	13	35.088	9.984	-0.009	0.000	0.000	1.000	0.001
	14	45.093	9.981	-0.011	0.000	0.000	1.000	-0.000
	15	55.079	9.990	-0.011	0.000	0.000	1.000	-0.001
	16	65.095	9.987	-0.008	0.000	0.000	1.000	0.003
	17	75.089	9.987	-0.008	0.000	0.000	1.000	0.002
	18	85.087	9.988	-0.010	0.000	0.000	1.000	0.001
	19	4.914	15.005	-0.010	0.000	0.000	1.000	-0.002
	20	15.088	14.976	-0.008	0.000	0.000	1.000	0.001
	21	25.089	14.986	-0.010	0.000	0.000	1.000	-0.001
	22	35.082	14.987	-0.010	0.000	0.000	1.000	-0.001
	23	45.095	14.992	-0.013	0.000	0.000	1.000	-0.003
	24	55.089	14.980	-0.013	0.000	0.000	1.000	-0.004
	25	65.091	14.970	-0.009	0.000	0.000	1.000	0.001
	26	75.091	14.993	-0.010	0.000	0.000	1.000	0.000
	27	85.093	14.994	-0.011	0.000	0.000	1.000	-0.001
	28	4.907	17.495	-0.010	0.000	0.000	1.000	-0.002
	29	7.085	17.534	-0.011	0.000	0.000	1.000	-0.002
	30	9.093	17.531	-0.010	0.000	0.000	1.000	-0.002
	31	11.100	17.520	-0.009	0.000	0.000	1.000	-0.000
	32	13.093	17.535	-0.010	0.000	0.000	1.000	-0.002
	33	15.093	17.523	-0.011	0.000	0.000	1.000	-0.002
	34	17.103	17.507	-0.010	0.000	0.000	1.000	-0.002

1 för 3

35	19.090	17.508	-0.010	0.000	0.000	1.000	-0.001	
36	21.076	17.517	-0.008	0.000	0.000	1.000	0.000	
37	23.087	17.476	-0.010	0.000	0.000	1.000	-0.001	
38	25.094	17.508	-0.010	0.000	0.000	1.000	-0.002	
39	27.093	17.515	-0.010	0.000	0.000	1.000	-0.001	
40	29.081	17.502	-0.008	0.000	0.000	1.000	0.000	
41	31.098	17.530	-0.011	0.000	0.000	1.000	-0.002	
42	33.097	17.519	-0.011	0.000	0.000	1.000	-0.003	
43	35.079	17.521	-0.011	0.000	0.000	1.000	-0.002	
44	37.089	17.506	-0.009	0.000	0.000	1.000	-0.000	
45	39.101	17.517	-0.011	0.000	0.000	1.000	-0.002	
46	41.096	17.504	-0.012	0.000	0.000	1.000	-0.002	
47	43.091	17.532	-0.013	0.000	0.000	1.000	-0.004	
48	45.095	18.028	-0.010	0.000	0.000	1.000	-0.001	
49	47.097	17.476	-0.014	0.000	0.000	1.000	-0.005	
50	49.092	17.502	-0.015	0.000	0.000	1.000	-0.005	
51	51.092	17.523	-0.015	0.000	0.000	1.000	-0.006	MIN
52	53.090	17.530	-0.015	0.000	0.000	1.000	-0.005	
53	55.092	17.506	-0.012	0.000	0.000	1.000	-0.003	
54	57.090	17.506	-0.013	0.000	0.000	1.000	-0.003	
55	59.089	17.504	-0.013	0.000	0.000	1.000	-0.004	
56	61.097	17.508	-0.013	0.000	0.000	1.000	-0.003	
57	63.094	17.504	-0.009	0.000	0.000	1.000	0.000	
58	65.091	17.500	-0.011	0.000	0.000	1.000	-0.001	
59	67.088	17.479	-0.010	0.000	0.000	1.000	-0.001	
60	69.103	17.512	-0.010	0.000	0.000	1.000	-0.000	
61	71.102	17.490	-0.010	0.000	0.000	1.000	-0.001	
62	73.094	17.506	-0.011	0.000	0.000	1.000	-0.001	
63	75.108	17.521	-0.010	0.000	0.000	1.000	-0.001	
64	77.109	17.501	-0.011	0.000	0.000	1.000	-0.001	
65	79.086	17.531	-0.010	0.000	0.000	1.000	-0.001	
66	81.093	17.532	-0.011	0.000	0.000	1.000	-0.001	
67	83.095	17.518	-0.011	0.000	0.000	1.000	-0.002	
68	85.092	17.531	-0.014	0.000	0.000	1.000	-0.004	
69	4.911	20.018	-0.010	0.000	0.000	1.000	-0.002	
70	15.081	19.966	-0.009	0.000	0.000	1.000	-0.001	
71	25.097	19.990	-0.010	0.000	0.000	1.000	-0.002	
72	35.084	19.982	-0.011	0.000	0.000	1.000	-0.002	
73	45.081	19.976	-0.012	0.000	0.000	1.000	-0.003	
74	55.094	19.985	-0.013	0.000	0.000	1.000	-0.004	
75	65.078	19.992	-0.008	0.000	0.000	1.000	0.001	

2 för 3

76	75.095	19.981	-0.009	0.000	0.000	1.000	0.000	
77	85.092	19.987	-0.011	0.000	0.000	1.000	-0.001	
78	4.920	25.003	-0.007	0.000	0.000	1.000	0.000	
79	15.088	24.981	-0.006	0.000	0.000	1.000	0.002	
80	25.095	24.985	-0.007	0.000	0.000	1.000	0.000	
81	35.090	24.985	-0.007	0.000	0.000	1.000	0.001	
82	45.078	24.971	-0.009	0.000	0.000	1.000	-0.000	
83	55.092	24.985	-0.010	0.000	0.000	1.000	-0.002	
84	65.077	24.984	-0.006	0.000	0.000	1.000	0.003	
85	75.091	24.992	-0.006	0.000	0.000	1.000	0.002	
86	85.090	24.991	-0.007	0.000	0.000	1.000	0.002	
87	4.908	30.006	0.001	0.000	0.000	1.000	0.007	
88	15.091	29.975	-0.001	0.000	0.000	1.000	0.006	
89	25.091	30.001	-0.003	0.000	0.000	1.000	0.004	
90	35.093	29.986	-0.003	0.000	0.000	1.000	0.004	
91	45.089	29.997	-0.004	0.000	0.000	1.000	0.004	
92	55.083	29.980	-0.008	0.000	0.000	1.000	0.000	
93	65.089	29.979	-0.005	0.000	0.000	1.000	0.003	
94	75.086	29.983	-0.001	0.000	0.000	1.000	0.007	
95	85.090	29.988	-0.000	0.000	0.000	1.000	0.008	MAX

3 för 3

Fifth Block SLM VC_2962_10_02

pc•dmis	DETALJNAMN : Klos planhet		maj 07, 2013	10:15
	VERSIONSNR. :	SERIENR. : 5	STATISTIK-ANT. : 1	

FCFPLAN1	MM	▱ 0.01			
Element	MÄTT	NOMINELLT	+TOL	-TOL	AVV
PLAN3	0.0163	0.0000	0.0100		0.0163

ELEMENT	MÄTPKTR	MÄTT X	Y	Z	VEKTOR I	J	K	AVV
PLAN3	1	4.943	4.978	-0.003	0.000	-0.000	1.000	0.010 MAX
	2	15.093	4.987	-0.003	-0.000	-0.000	1.000	0.010
	3	25.091	4.994	-0.010	-0.000	-0.000	1.000	0.003
	4	35.077	4.988	-0.013	-0.000	-0.000	1.000	0.000
	5	45.095	4.999	-0.013	-0.000	-0.000	1.000	-0.000
	6	55.088	5.002	-0.010	-0.000	-0.000	1.000	0.004
	7	65.081	4.992	-0.006	-0.000	-0.000	1.000	0.007
	8	75.091	4.989	-0.007	-0.000	-0.000	1.000	0.007
	9	85.090	5.003	-0.005	-0.000	-0.000	1.000	0.009
	10	4.910	10.019	-0.010	-0.000	-0.000	1.000	0.002
	11	15.094	9.984	-0.008	-0.000	-0.000	1.000	0.004
	12	25.086	9.993	-0.014	-0.000	-0.000	1.000	-0.001
	13	35.087	9.994	-0.016	-0.000	-0.000	1.000	-0.003
	14	45.093	10.006	-0.018	-0.000	-0.000	1.000	-0.005
	15	55.097	9.983	-0.014	-0.000	-0.000	1.000	-0.001
	16	65.082	9.996	-0.011	-0.000	-0.000	1.000	0.003
	17	75.097	9.980	-0.011	-0.000	-0.000	1.000	0.002
	18	85.095	9.990	-0.012	-0.000	-0.000	1.000	0.002
	19	4.906	15.010	-0.013	-0.000	-0.000	1.000	-0.001
	20	15.094	15.000	-0.011	-0.000	-0.000	1.000	0.001
	21	25.080	14.985	-0.015	-0.000	-0.000	1.000	-0.003
	22	35.082	14.995	-0.017	-0.000	-0.000	1.000	-0.005
	23	45.092	14.991	-0.016	-0.000	-0.000	1.000	-0.003
	24	55.097	14.986	-0.015	-0.000	-0.000	1.000	-0.003
	25	65.075	14.983	-0.014	-0.000	-0.000	1.000	-0.001
	26	75.087	14.982	-0.014	-0.000	-0.000	1.000	-0.001
	27	85.093	14.987	-0.014	-0.000	-0.000	1.000	-0.000
	28	4.914	17.495	-0.013	-0.000	-0.000	1.000	-0.001
	29	7.089	17.536	-0.012	-0.000	0.000	1.000	-0.001
	30	9.084	17.514	-0.011	-0.000	0.000	1.000	0.001
	31	11.105	17.515	-0.013	-0.000	0.000	1.000	-0.001
	32	13.092	17.536	-0.012	-0.000	0.000	1.000	-0.001
	33	15.102	17.542	-0.011	-0.000	0.000	1.000	0.001
	34	17.093	17.542	-0.009	-0.000	0.000	1.000	0.003

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35	19.093	17.543	-0.010	-0.000	0.000	1.000	0.002	
36	21.096	17.520	-0.012	-0.000	0.000	1.000	-0.000	
37	23.091	17.529	-0.014	-0.000	0.000	1.000	-0.002	
38	25.091	17.513	-0.014	-0.000	0.000	1.000	-0.003	
39	27.082	17.538	-0.015	-0.000	0.000	1.000	-0.003	
40	29.098	17.539	-0.016	-0.000	0.000	1.000	-0.004	
41	31.093	17.517	-0.017	-0.000	0.000	1.000	-0.004	
42	33.091	17.508	-0.017	-0.000	0.000	1.000	-0.005	
43	35.093	17.522	-0.017	-0.000	0.000	1.000	-0.005	
44	37.093	17.518	-0.019	-0.000	0.000	1.000	-0.006	MIN
45	39.090	17.504	-0.018	-0.000	0.000	1.000	-0.006	
46	41.089	17.521	-0.018	-0.000	0.000	1.000	-0.006	
47	43.103	17.516	-0.019	-0.000	0.000	1.000	-0.006	
48	45.092	18.017	-0.017	0.000	-0.000	1.000	-0.005	
49	47.091	17.485	-0.017	-0.000	0.000	1.000	-0.005	
50	49.093	17.517	-0.018	-0.000	0.000	1.000	-0.005	
51	51.088	17.513	-0.014	-0.000	0.000	1.000	-0.002	
52	53.096	17.508	-0.015	-0.000	0.000	1.000	-0.003	
53	55.093	17.533	-0.016	-0.000	0.000	1.000	-0.003	
54	57.094	17.513	-0.014	-0.000	0.000	1.000	-0.001	
55	59.085	17.510	-0.013	-0.000	0.000	1.000	-0.001	
56	61.087	17.534	-0.013	-0.000	0.000	1.000	-0.000	
57	63.085	17.541	-0.014	-0.000	0.000	1.000	-0.001	
58	65.083	17.514	-0.013	-0.000	0.000	1.000	-0.001	
59	67.095	17.513	-0.011	-0.000	0.000	1.000	0.002	
60	69.097	17.520	-0.010	-0.000	0.000	1.000	0.003	
61	71.097	17.498	-0.012	-0.000	0.000	1.000	0.000	
62	73.093	17.513	-0.015	-0.000	0.000	1.000	-0.002	
63	75.103	17.512	-0.015	-0.000	0.000	1.000	-0.002	
64	77.089	17.527	-0.014	-0.000	0.000	1.000	-0.001	
65	79.098	17.501	-0.015	-0.000	0.000	1.000	-0.002	
66	81.100	17.513	-0.014	-0.000	0.000	1.000	-0.001	
67	83.097	17.525	-0.013	-0.000	0.000	1.000	-0.000	
68	85.094	17.517	-0.013	-0.000	0.000	1.000	-0.000	
69	4.906	20.005	-0.012	-0.000	-0.000	1.000	-0.001	
70	15.083	19.982	-0.011	-0.000	0.000	1.000	0.001	
71	25.077	19.991	-0.015	-0.000	0.000	1.000	-0.003	
72	35.085	19.999	-0.017	-0.000	0.000	1.000	-0.006	
73	45.086	19.993	-0.018	-0.000	0.000	1.000	-0.006	
74	55.089	19.991	-0.015	-0.000	0.000	1.000	-0.003	
75	65.085	19.992	-0.013	-0.000	0.000	1.000	-0.000	

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76	75.096	19.980	-0.014	-0.000	0.000	1.000	-0.002
77	85.096	19.990	-0.014	-0.000	0.000	1.000	-0.001
78	4.914	25.002	-0.007	-0.000	-0.000	1.000	0.004
79	15.086	24.980	-0.007	-0.000	0.000	1.000	0.004
80	25.090	24.970	-0.003	-0.000	0.000	1.000	0.008
81	35.093	24.994	-0.014	-0.000	0.000	1.000	-0.002
82	45.093	24.991	-0.015	-0.000	0.000	1.000	-0.003
83	55.086	24.995	-0.012	-0.000	0.000	1.000	0.000
84	65.096	24.994	-0.009	-0.000	0.000	1.000	0.003
85	75.086	24.988	-0.010	-0.000	0.000	1.000	0.003
86	85.084	24.979	-0.008	-0.000	0.000	1.000	0.004
87	4.918	30.012	-0.002	-0.000	-0.000	1.000	0.008
88	15.083	29.984	-0.001	-0.000	0.000	1.000	0.010
89	25.093	29.981	-0.007	-0.000	0.000	1.000	0.003
90	35.096	29.987	-0.012	-0.000	0.000	1.000	-0.001
91	45.085	29.989	-0.011	-0.000	0.000	1.000	-0.000
92	55.084	29.986	-0.009	-0.000	0.000	1.000	0.003
93	65.091	29.980	-0.005	-0.000	0.000	1.000	0.006
94	75.096	29.990	-0.008	-0.000	0.000	1.000	0.004
95	85.096	29.988	-0.005	-0.000	0.000	1.000	0.007

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Seventh Block SLM VC_2962_10_05

pc-dmis	DETALJNAMN : Klos planhet		maj 20, 2013	10:34
	VERSIONSNR. :	SERIENR. : 7	STATISTIK ANT. : 1	

FCFPLAN1	MM	⏥ 0.01			
Element	MÄTT	NOMINELLT	+TOL	-TOL	AVV
PLAN3	0.0071	0.0000	0.0100		0.0071

ELEMENT	MÄTPKTR	MÄTT X	Y	Z	VEKTOR I	J	K	AVV
PLAN3	1	4.935	4.979	0.001	0.000	0.000	1.000	0.001
	2	15.101	5.004	0.001	0.000	0.000	1.000	0.000
	3	25.078	5.000	0.002	0.000	0.000	1.000	0.002
	4	35.092	4.998	0.003	0.000	0.000	1.000	0.003
	5	45.082	4.996	0.003	0.000	0.000	1.000	0.003
	6	55.099	4.994	0.002	0.000	0.000	1.000	0.002
	7	65.092	4.989	0.001	0.000	0.000	1.000	0.002
	8	75.087	4.987	0.001	0.000	0.000	1.000	0.001
	9	85.091	4.986	-0.002	0.000	0.000	1.000	-0.001
	10	4.906	10.013	-0.000	0.000	0.000	1.000	-0.001
	11	15.094	10.014	0.000	0.000	0.000	1.000	-0.000
	12	25.080	10.005	0.000	0.000	0.000	1.000	0.000
	13	35.086	10.002	0.001	0.000	0.000	1.000	0.001
	14	45.090	10.001	0.001	0.000	0.000	1.000	0.001
	15	55.098	9.995	0.002	0.000	0.000	1.000	0.002
	16	65.088	9.993	0.001	0.000	0.000	1.000	0.001
	17	75.082	9.988	-0.002	0.000	0.000	1.000	-0.001
	18	85.098	9.987	-0.003	0.000	0.000	1.000	-0.003
	19	4.909	15.008	-0.002	0.000	0.000	1.000	-0.002
	20	15.097	15.020	-0.000	0.000	0.000	1.000	-0.001
	21	25.087	14.994	-0.000	0.000	0.000	1.000	-0.000
	22	35.085	14.994	0.002	0.000	0.000	1.000	0.002
	23	45.088	14.994	0.001	0.000	0.000	1.000	0.001
	24	55.100	14.989	0.001	0.000	0.000	1.000	0.001
	25	65.090	14.985	0.001	0.000	0.000	1.000	0.001
	26	75.082	14.983	-0.002	0.000	0.000	1.000	-0.002
	27	85.096	14.983	-0.004	0.000	0.000	1.000	-0.003
	28	4.915	17.503	-0.000	0.000	0.000	1.000	-0.001
	29	7.092	17.508	0.000	-0.000	0.000	1.000	-0.000
	30	9.081	17.507	-0.000	-0.000	0.000	1.000	-0.001
	31	11.100	17.504	-0.001	-0.000	0.000	1.000	-0.001
	32	13.108	17.501	-0.000	-0.000	0.000	1.000	-0.001
	33	15.107	17.502	0.000	-0.000	0.000	1.000	-0.000
	34	17.101	17.500	-0.001	-0.000	0.000	1.000	-0.002

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35	19.093	17.500	-0.002	-0.000	0.000	1.000	-0.002
36	21.087	17.499	-0.001	-0.000	0.000	1.000	-0.002
37	23.086	17.500	0.000	-0.000	0.000	1.000	-0.000
38	25.088	17.497	-0.000	-0.000	0.000	1.000	-0.001
39	27.080	17.498	-0.001	-0.000	0.000	1.000	-0.001
40	29.083	17.497	-0.000	-0.000	0.000	1.000	-0.001
41	31.085	17.497	0.000	-0.000	0.000	1.000	-0.000
42	33.079	17.496	0.001	-0.000	0.000	1.000	0.000
43	35.085	17.497	0.001	-0.000	0.000	1.000	0.001
44	37.085	17.493	0.001	-0.000	0.000	1.000	0.000
45	39.087	17.495	0.001	-0.000	0.000	1.000	0.001
46	41.084	17.494	0.001	-0.000	0.000	1.000	0.000
47	43.098	17.495	0.000	-0.000	0.000	1.000	-0.000
48	45.097	18.036	-0.000	0.000	0.000	1.000	-0.000
49	47.092	17.468	0.001	-0.000	0.000	1.000	0.001
50	49.098	17.476	0.001	-0.000	0.000	1.000	0.002
51	51.098	17.488	-0.000	-0.000	0.000	1.000	0.000
52	53.091	17.486	0.000	-0.000	0.000	1.000	0.001
53	55.096	17.487	0.001	-0.000	0.000	1.000	0.001
54	57.091	17.488	0.001	-0.000	0.000	1.000	0.002
55	59.091	17.487	-0.000	-0.000	0.000	1.000	0.000
56	61.094	17.488	-0.001	-0.000	0.000	1.000	-0.000
57	63.089	17.486	0.001	-0.000	0.000	1.000	0.001
58	65.094	17.487	-0.001	-0.000	0.000	1.000	-0.000
59	67.081	17.485	-0.001	-0.000	0.000	1.000	-0.001
60	69.093	17.486	-0.002	-0.000	0.000	1.000	-0.001
61	71.105	17.486	-0.000	-0.000	0.000	1.000	0.000
62	73.101	17.485	-0.001	-0.000	0.000	1.000	-0.000
63	75.096	17.485	-0.001	-0.000	0.000	1.000	-0.001
64	77.099	17.485	-0.002	-0.000	0.000	1.000	-0.001
65	79.095	17.485	-0.001	-0.000	0.000	1.000	-0.001
66	81.085	17.485	-0.003	-0.000	0.000	1.000	-0.002
67	83.093	17.486	-0.003	-0.000	0.000	1.000	-0.003
68	85.091	17.485	-0.004	-0.000	0.000	1.000	-0.003
69	4.904	19.988	-0.000	0.000	0.000	1.000	-0.001
70	15.091	19.990	-0.001	-0.000	0.000	1.000	-0.001
71	25.085	19.989	0.002	-0.000	0.000	1.000	0.001
72	35.083	19.986	0.002	-0.000	0.000	1.000	0.002
73	45.085	19.983	0.000	-0.000	0.000	1.000	0.000
74	55.092	19.980	-0.000	-0.000	0.000	1.000	-0.000
75	65.087	19.980	0.000	-0.000	0.000	1.000	0.000

76	75.083	20.006	-0.002	-0.000	0.000	1.000	-0.001	
77	85.093	20.001	-0.004	-0.000	0.000	1.000	-0.004	MIN
78	4.910	25.006	-0.001	0.000	0.000	1.000	-0.001	
79	15.087	25.014	-0.000	-0.000	0.000	1.000	-0.001	
80	25.082	25.018	-0.000	-0.000	0.000	1.000	-0.000	
81	35.084	25.009	0.000	-0.000	0.000	1.000	0.000	
82	45.090	24.998	0.002	-0.000	0.000	1.000	0.002	
83	55.092	24.994	0.001	-0.000	0.000	1.000	0.001	
84	65.089	24.992	-0.000	-0.000	0.000	1.000	-0.000	
85	75.090	24.984	-0.000	-0.000	0.000	1.000	0.000	
86	85.088	24.983	-0.001	-0.000	0.000	1.000	-0.000	
87	4.911	29.999	-0.001	0.000	0.000	1.000	-0.002	
88	15.086	30.012	0.000	-0.000	0.000	1.000	-0.000	
89	25.090	30.006	0.001	-0.000	0.000	1.000	0.000	
90	35.078	30.000	0.002	-0.000	0.000	1.000	0.002	
91	45.088	29.996	0.001	-0.000	0.000	1.000	0.001	
92	55.096	29.994	0.002	-0.000	0.000	1.000	0.002	
93	65.083	29.989	0.002	-0.000	0.000	1.000	0.002	
94	75.079	29.984	0.002	-0.000	0.000	1.000	0.003	
95	85.084	29.983	0.003	-0.000	0.000	1.000	0.003	MAX

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