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IMPLEMENTATION OF A CANTILEVER DEFLECTION MEASUREMENT FOR A DO-IT-YOURSELF ATOMIC FORCE MICROSCOPE

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ABSTRACT

Saara Haikka: Implementation of a cantilever deflection measurement for a do-it-yourself atomic force microscope
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Atomic force microscopes (AFM) provide nanoscale imaging of both conducting and insulating surfaces in real space. The current AFMs are expensive and bulky systems with restricted access to them. In order to lower the price and simplify the design, optical pickup units (OPU) are utilized. OPUs are low-cost and small and they enable fast nanoscale measurements. Linear range of the focus error signal, provided by the OPU, is proportional to the distance between the objective lens and the sample and can be exploited as a detection method in AFM.

Do-it-yourself AFM is being constructed for teaching purposes, and the aim of this work was to determine the sensitivity of a commercial OPU for measuring a distance change. Measurements were performed by vertically moving the OPU in the vicinity of its working distance. A piece of foil with a cover glass on top was used as a reflective surface. The focus error signal was calculated from the data for detecting the linear range. In addition, a DVD topography was measured.

However, the experimental setup proved to be inadequate for such small-scale measurements. The working area of the OPU could not be detected form the results and the sensitivity failed to be determined. The results also include a selection of a cantilever for this application which requires durable tip and a reflective coating.

Keywords: Atomic force microscope (AFM), optical pickup unit (OPU), cantilever

TIIVISTELMÄ

Saara Haikka: Tee-se-itse atomivoimamikroskoopin taipumamittauksen toteutus
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Atomivoimamikroskooppi (AFM) mahdollistaa sekä johtavien että eristävien materiaalien pintojen kuvantamisen nanomittakaavassa normaaliolosuhteissa. Nykyiset AFM-laitteet ovat kalliita ja tilaa vieviä laitteita, joihin on rajoitettu pääsy. Edullista ja yksinkertaisempaa atomivoimamikroskooppia suunniteltaessa hyödynnetään CD/DVD-levyjen lukemiseen tarkoitettuja optisia lukupäitä (OPU). OPU:t ovat pienikokoisia ja edullisia ja ne mahdollistavat nopeat nanomittakaavan mittaukset. Lukupään tuottaman tarkennusvirhe-signaalin lineaarinen alue on suoraan verrannollinen OPU:n objektiivin ja mitattavan kohteen väliseen etäisyyteen. Kyseistä lineaarista aluetta voidaan siten käyttää mittaamaan AFM:n ulokepalkin poikkeamaa ja määrittämään näytteen pinnanmuotoja.

Yliopistossa ollaan rakentamassa Tee-se-itse AFM:ää opetustarkoitukseen, joten tämän työn tavoitteena on määrittää kaupallisen OPU:n herkkyys etäisyyden muutoksen mittaamiseen. Työ jakautuu kirjallisuustutkimusosaan ja mittausosaan. Kirjallisuustutkimuksessa käydään läpi AFM:n ja OPU:n toimintaperiaatteet sekä OPU:n hyödyntäminen osana AFM-laitteistoa. Mittausosassa esitellään rakennettu kokeellinen järjestelmä ja tehdyt mittaukset sekä esitetään ja analysoidaan saadut tulokset.

Mittaukset suoritettiin siirtämällä OPU:a pystysuunnassa sen toimintaetäisyyden läheisyydessä. Heijastavana pintana, ulokepalkin sijasta, käytettiin foliopalaa, jonka päälle asetettiin peitinlasi. Tarkennusvirhe-signaali laskettiin mitatusta datasta lineaarisen alueen tunnistamiseksi. Lisäksi pyrittiin mittaamaan DVD:n pinnanmuotoja.

Kokeellisella järjestelmällä ei kuitenkaan onnistuttu saavuttamaan mittauksia tarpeeksi pienessä mittakaavassa. Tarkennusvirhe-signaalia ei voitu havaita tuloksista, joten OPU:n herkkyyttä ei pystytty määrittämään. Tuloksiin on sisällytetty myös ulokepalkin valinta kyseiseen opetustarkoitukseen, joka vaatii kestävän kärjen ja heijastavan pinnoitteen.

Avainsanat: Atomivoimamikroskooppi (AFM), optinen lukupää (OPU), ulokepalkki

CONTENTS

1. INTRODUCTION

The increasing usage of nanoscale or even atomic scale applications in science and technology expands the demand for imaging at that range. For example, microelectronics is sifting to nanoelectronics. Also, understanding the material properties requires knowledge of the atomic structure. Scanning probe microscopes are widely used for nanoscale imaging providing resolution down to the atomic scale in real space. In these microscopes, the properties of a surface or an interface is detected with a small probe at nanometer or atomic range. The sample surface is scanned so that the surface properties at specified points are measured, and the collected data are presented as an image. [1]

The scanning tunnelling microscope is the first of the scanning probe microscopes where the measured quantity is a tunnelling current between a sample and a metal tip. However, this microscope can be employed only with conducting samples whereas atomic force microscope (AFM) enables imaging also on insulating surfaces. AFM measures the force between the tip and the sample. The forces can be either attractive or repulsive, thus bending the spring like cantilever which includes the tip. The deflection of the cantilever is proportional to the tip-sample force and most of the current AFM systems utilize a reflected laser beam to measure the deflection. [1]

Atomic force microscopes are expensive, and the commonly used beam deflection method makes them bulky and awkward to use. Commercial optical pickup units (OPU) which are used to read data form CDs, DVDs and Blu-ray disks, are being implemented to AFM designs in order to replace the optical detection method. OPUs are compact, low-cost, and lightweight systems providing sub-angstrom displacement sensing. [2][3] Employing these pickup units can greatly simplify the design of AFMs and make them more affordable.

This work is a part of a project that aims to build a do-it-yourself AFM for teaching purposes for the Tampere University. The object of this thesis is to determine the sensitivity of the OPU for detecting the vertical displacement of the cantilever. Theoretical background of AFM and commercial OPUs are discussed in Chapters 2 and 3 including the choice of a cantilever for this application . Chapter 4 describes the experimental setup and the used components in more detail and introduces the conducted measurements. Results are displayed and analyzed in Chapter 5. Finally, Chapter 6 concludes the work and the achieved results.

2. ATOMIC FORCE MICROSCOPE

Atomic force microscope belongs to the family of scanning probe microscopes (SPM) that form surface images, with resolutions down to nanometer scale, by scanning the sample surface with a small probe. In the AFM, the measured quantity is the force between the tip and the sample. This kind of microscope enables atomic scale imaging of both conducting and insulating samples in real space. [1]

AFM imaging process consists of scanning the sample, feeling the surface of the sample with a cantilever, and detecting the bending of the cantilever. Operating principle and the instrumentation of the microscope is discussed in this chapter. The focus of the methods for detecting the bending of the cantilever is on a beam deflection method for it is the most frequently used method. Cantilevers are also presented in more detail in order to choose proper cantilever for the future purposes of this do-it-yourself AFM.

2.1 AFM instrumentation

AFM detects the surface of a sample with a probe tip by either moving the probe on the sample or the sample underneath the tip. To be able to perform the nanoscale motion that AFM requires, piezoelectric actuators are typically used. The actuators use a converse piezoelectric effect in which an electric field is applied to the piezoelectric material causing it to expand. This deformation is reproducible and such small that subatomic movement can be obtained with voltages in the mV range. The mostly used piezoelectric materials for the actuators are lead zirconate titanate ceramics (PZT) because of their large piezo coefficients and the ability to form ceramics into different shapes. [1][4]

This scanning mechanism allows movement in the three orthogonal directions x, y and z which is controlled with control electronics via three channels. The distance between the tip and sample is determined with a z-channel, and the scanning of the sample is done with x- and y-channels to obtain an image of the sample surface. [4] In this study the sample will be moved while the probe tip stays at the same position.

The tip that ‘feels’ the sample surface is mounted to a flexible cantilever which bends depending on the forces acting between the tip and the sample [4]. Cantilevers are discussed in more detail in section 2.2. The total force between the tip and the sample is a sum of different types of long- and short-range forces [1]. Acting forces can either be repulsive or attractive, and with different samples occur different forces, e.g. in biological systems forces are likely van der Waals force, electrostatic (or Coulombic) force, capillary and adhesive forces, and double layer forces [4].

Atomic force microscopes have different imaging modes in which different forces are involved. The microscope can be either dynamic or static and it can be in contact or not in contact with the sample. In static AFMs the cantilever is not excited to oscillate. In a contact dc (static) mode, also known as the constant force mode, the AFM tip is in direct contact with the sample and the acting forces are repulsive. The tip-sample force is set to a certain setpoint equivalent to a certain deflection of the cantilever. [1][4] Static AFM can also work in a non-contact mode where the acting forces are attractive [1]. In addition, the imaging with the constant force mode of static AFM can be carried out either in air or in a liquid. Using liquid in the imaging process eliminates the capillary forces. [4]

In the dynamic mode, the cantilever is excited to oscillate at a driving frequency close to the resonance frequency of the free cantilever. When the tip interacts with the sample, the resonance frequency changes. Attractive forces cause damping of the oscillating cantilever whereas repulsive forces increase the oscillation. [1]Dynamic AFMs can be further divided into two main types: tapping mode, also called intermittent contact mode, and true non-contact mode. In the tapping mode the amplitude of the oscillation is such large that the tip-sample distance ranges from large distances with insignificant interactions to a contact with the sample with repulsive forces.[1][4] Imaging with tapping mode prevents the tip being trap by capillary forces and it also reduces lateral force on the sample. The tapping can happen in air or in liquid. In a true non-contact AFM, the tip never touches the sample. [4] The driving frequency of the cantilever is not fixed into a certain value, but it sifts according to the tip-sample interactions [1].

The last part of the imaging process is the detection of the cantilever deflection. Laser beam deflection is the most commonly used method for detecting the bending of the cantilever in AFM. The basic layout of the beam deflection method is shown in Fig. 1. A laser beam is targeted to the end of the backside of the cantilever where it reflects into a photodiode which turns the light into an electrical signal. The photodiode can be split into two or four sections. [1][4]]In a split photodiode, where the diode is divided into two parts, the difference in the optical signal of the parts $SA - SB$ is proportional to the angular deflection of the laser beam and thus proportional to the bending of the cantilever. [1] Whereas, in a photodiode with four sections, bending can be achieved by comparing the signals from each quadrant [4]. If beam deflection method is used in an AFM, then usually the sample is scanned instead of the tip. This ensures that the laser beam stays focused on the cantilever. [1]

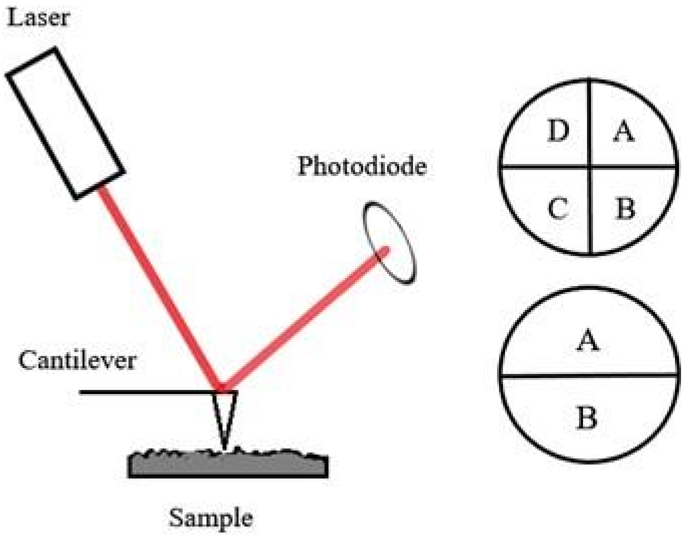


Figure 1. *Beam deflection method is depicted on the left and on the right is two types of photodiode*

In this study the function of the beam deflection method is implemented with a commercial optical pick- up unit (OPU). OPU is discussed in chapter 3.

Other methods to detect the cantilever deflection are either optical or electrical in their nature. Interferometry is another optical detection scheme, and it has a high sensitivity, but in practice it is the most difficult. [1][4] The backside of the cantilever is the mirror of the optical laser interferometer [1] and the phase sift of the laser beam describes the deflection [4]. Piezoresistive detection method is an electrical way of detecting the bending of the cantilever. In this method the cantilever is coated with a piezoresistive layer whose resistance changes when the cantilever bends. [1][4] This change can be measured by using a Wheatstone bridge, where the cantilever is one of the resistors. Another electrical method is to use piezoelectric cantilevers which can be used as sensor and actuator simultaneously. The cantilever has two electrodes of which one excites the cantilever and other detects the voltage caused by piezoelectric effect when the cantilever is bend. This method is used in dynamic AFMs. [1]

2.2 Cantilevers in AFM

Cantilever is an important part of the AFM. It is the piece of the microscope that interacts with the sample and detects the tip-sample forces. In general, the cantilever-tip setting is fabricated of silicon or silicon nitride which are both hard and wear resistant materials, and ideal for micro-fabrication. Cantilevers are often coated with another material according to the detecting method, for the optical laser beam deflection the back of the cantilever is coated with a reflective material to improve the reflectivity. [2]

There are certain requirements for cantilevers. Forces between the atoms in the sample are in the range of nanonewtons therefore much larger forces between the tip and the sample can break the bonds between the surface atoms and thus damage the sample surface. [1] According to Hooke's Law

$$F = ks \tag{1}$$

the force F of the bending cantilever depends on the spring constant k of the cantilever and on the cantilever displacement s [4]. This gives us a requirement that cantilever should have a small spring constant in order to prevent too high tip-sample forces. Also, small spring constant leads to a bigger displacement and thus to a better force sensitivity. [1]

Other requirement is a high resonance frequency, preferably >>10 kHz, for implementing high scan speed. The cantilever should be able to follow the surface topography by moving to the corresponding height at every position. The cantilever can be seen as a harmonic oscillator which can respond to an external motion with a gain of one and with no phase shift, only if the excitation frequency is much smaller than the resonance frequency of the harmonic oscillator, i.e., the cantilever. From the basic equation for a harmonic oscillator

$$\omega_{cant} = \frac{\sqrt{k}}{m} \tag{2}$$

it can be seen that the resonance frequency ω_{cant} and the spring constant k are in opposition. Thus, with a small cantilever mass the requirements of high resonance frequency and small spring constant are met. These requirements are for both static and dynamic AFMs. [1]

To Table 1., is collected different contact mode AFM probes available including their length, resonance frequency, and force constant. Force constant is another term for spring constant, it describes the stiffness of the spring The do-it-yourself AFM which is being developed is going to be used for teaching purposes so the priority is a durable tip which can be used for multiple applications. Therefore, all unique probes with extra sharps tips are excluded and the recommended ones are in bold in the table.

Table 1. *Available contact mode AFM probes. L is the length of the cantilever, C is the force constant, and F is the resonance frequency.*

	L (µm)	C (N/m)	F (kHz)	Probe	Coating
CONT [13]	450	0.2	13	Pointprope® Silicon/Standard	-
CONTR [13]	450	0.2	13	Pointprobe® Silicon/Standard	Reflex (aluminum)
Arrow™ CONT [13]	450	0.2	14	Arrow™ Silicon/Arrow	-
Arrow™ CONTR [13]	450	0.2	14	Arrow™ Silicon/Arrow	Reflex (aluminum)
ZEILR* [13]	450	1.6	27	Pointprobe® Silicon/Standard	Reflex (aluminum)
CONTSC [13]	225	0.2	25	Pointprobe® Silicon/ Standard	-
CONTSCR [13]	225	0.2	25	Pointprobe® Silicon/ Standard	Reflex (aluminum)
PPP-CONTR [14]	450	0.2	13	PointProbe® Plus/Stantard	Reflex Aluminum
PPP-CONT [14]	450	0.2	13	PointProbe® Plus/Stantard	-
PPP-CONTSCR [14]	225	0.2	25	PointProbe® Plus/Stantard	Reflex Aluminum
PPP-CONTSC [14]	225	0.2	25	PointProbe® Plus/Stantard	-
PPP-ZEILR* [14]	450	1.6	27	PointProbe® Plus/Stantard	Reflex Aluminum
PPP-LFMR [14]	225	0.2	23	PointProbe® Plus/Stantard	Reflex Aluminum

PPP-CONTAuD [14]	450	0.2	13	PointProbe® Plus/Stantard	Gold
PP-RT-CONTR [14]	**450**	**0.2**	**13**	**Rotated**	**Reflex Aluminum**
HQ:CSC17/Al BS [15]	**450**	**0.18**	**13**	**Rotated**	**Reflex Aluminum**
Contact-G [16]	450	0.2	13	Rotated	-
ContAl-G [16]	**450**	**0.2**	**13**	**Rotated**	**Reflex Aluminum**
ContGD-G [16]	450	0.2	13	Rotated	Gold

*for Zeiss Veritek AFMs

OPUs are adjusted to read data form highly reflective surfaces so the chosen probe should have reflective coating to optimize the conditions. Gold and aluminum backside coatings are available for better reflectivity from which the aluminum is more affordable. Rounded or rotated tips are good for low-wearing imaging which is important for this application where the focus is on teaching.

Rotated tips that have the aluminum coating have all the same resonance frequency, but the force constant can be chosen between 0.2 N/m or 0.18 N/m. With the C = 0.2 N/m the probe focuses a bigger force to the sample and can cause damage to fragile samples. However, the application of this AFM will be at teaching so the probe with better availability and more affordable can be chosen not focusing on the force constant.

3. COMMERCIAL OPU

Optical pickup unit, also known as optical head, is used to read information stored on reflective digital disks e.g., CDs, DVDs, and Blu-ray disks. The digital data are recorded as binary values using either the topography of the disk as pits and lands or using different reflective properties of different spots on the disk. The width of the data tracks varies from 800 nm for a CD to 150 nm for a Blu-ray where the decrease of the width increases the capacity.[5] In order to read the data, the OPU must maintain a focus on the disk data layer surface, covered by a polycarbonate film, as the high-speed rotation causes vibration to it [6]–[8].

Most of the OPUs use the astigmatism principle, where rays propagate in perpendicular planes with different foci, as a focusing method. A laser diode on the optical head emits a laser beam which is first reflected by a beam splitter, then collimated, and finally gets focused onto the surface of the disk by an objective lens moved by a voice coil motor. The reflected beam passes through the beam splitter plate, and then impinges onto a photo detector integrated chip (PDIC).[2], [3], [5]–[11] The optical path of the laser beam is depicted in Figure 2.

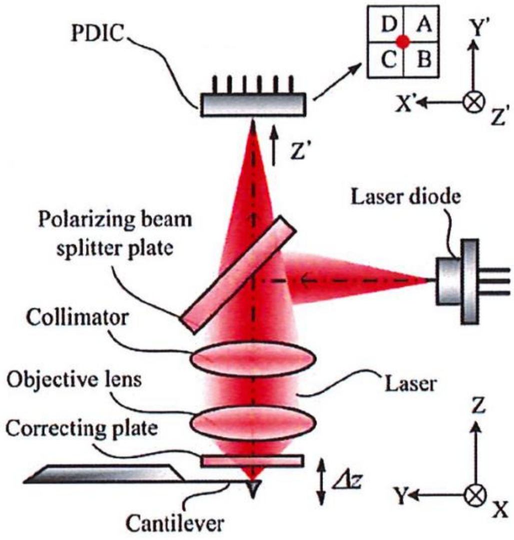


Figure 2. *Optical path of the laser beam starting from the laser diode and ending up on the PDIC.*[8]

The PDIC is composed by four quadrant photodiodes (A, B, C, D) which each have a current preamplifier assigned to them. When the disk is precisely at the focus point of the laser beam, the beam forms a circle on the PDIC, otherwise when the surface is slightly higher or lower than the focus, it forms an elliptical shape. This shape change of the laser beam can be detected by the focus error signal (FES) using the outputs of each photodiode in the PDIC:

$$FES = (A + C) - (B + D) \tag{2}$$

The focus error signal and the laser beam on the PDIC are displayed in the Figure 3. FES is zero when the target is at the focus of the objective lens, negative when the distance from the lens increases, and positive when near to the lens. This relationship is shown in the Figure 3 as a well-known S-curve. If the target moves out of the linear region, the laser beam covers all photodiodes equally causing the FES to reach 0 again. The FES is used via control system to maintain the objective lens at the correct focus by changing its position with the voice coil motor. [2], [3], [5]–[11]

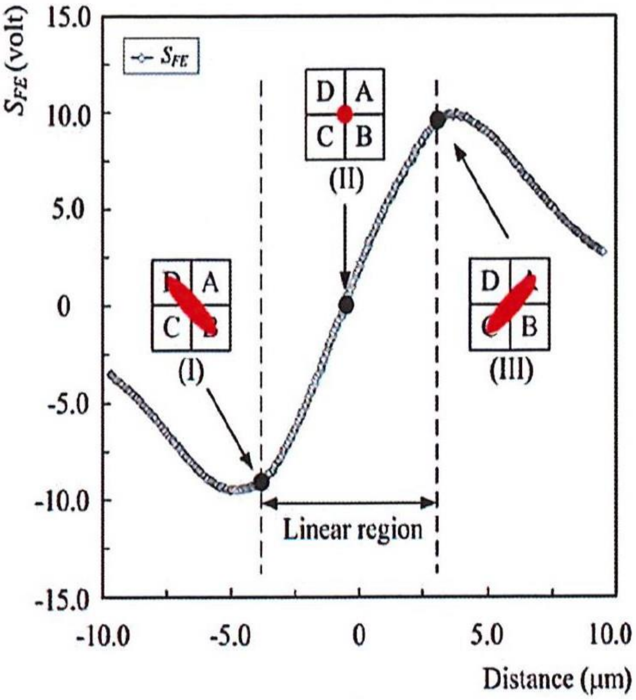


Figure 3. *The S-curve of the FES as a function of the distance between the optical disk and the OPU, and the shape of the laser beam on the photodetector.* [8]

The linear region of the measured FES is proportional to the distance between the target and the OPU, as shown in Figure 3. Thus, the FES can be used in this region to measure the height and the vertical displacement of an object surface, such as AFM cantilever, with high sensitivity. In addition, commercial optical heads have affordable prices, they are small, lightweight, and compact, and they are capable of nanoscale measurements, explaining why they are vastly utilized in do-it-yourself AFMs. [2], [3], [5]–[11]

Commercial OPUs have originally been optimized to measure signals from the highly reflecting surfaces of digital disks which can cause challenges to nonstandard uses of the OPUs [5]. Different surface materials have different reflectivities and may produce different S-curves [10].

4. MATERIAL AND METHODS

4.1 Experimental setup

The experimental setup consists of an optical pickup unit, XYZ-positioning table with 0.01 mm accuracy, driver electronics, and a reflective surface. The measurements were done with Simulink Real-Time that uses a separate target PC and a host PC connected through Ethernet for real-time measurements. The driver board is connected to the target PC with DAQ (NI CB-68LP). The setup is shown in Figure 4.

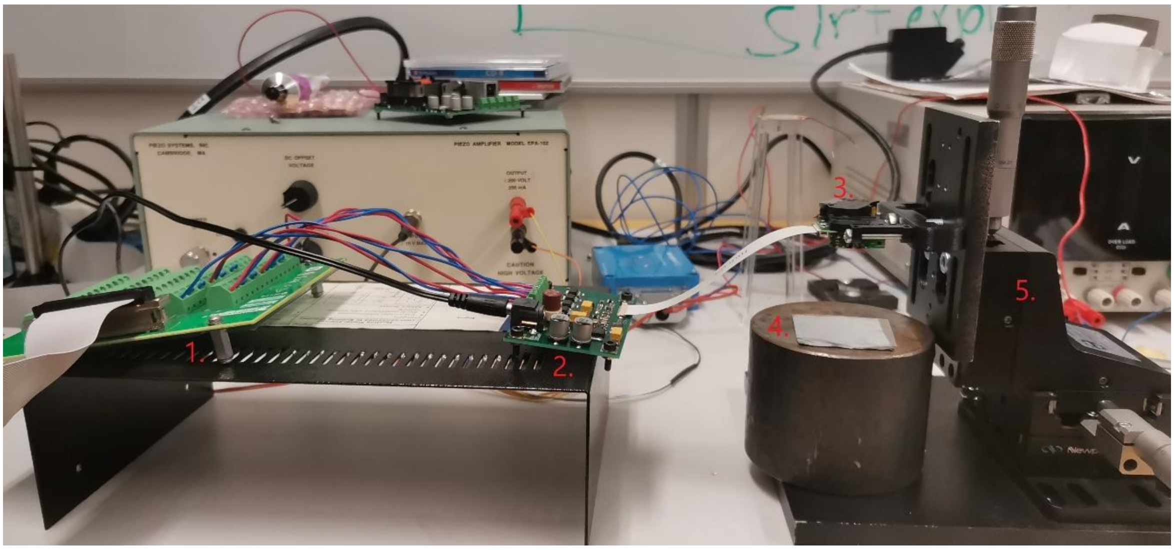


Figure 4. *The experimental setup: 1. DAQ, 2. in-house made driver electronics, 3. commercial OPU, 4. piece of foil with a cover glass, 5. XYZ-positioning table.*

In this study, the detection method of the AFM instrumentation was implemented without cantilevers or piezoelectric actuators. An optical CD/DVD pickup unit (SF-HD65, SANYO electric Co.) was used in order to replace the beam deflection system in AFM to detect the cantilever deflection. The OPU was chosen because of the availability of its datasheet which was utilized e.g. in the building of the driver electronics and choosing the measurement distances. The pickup unit can be used for reading DVDs and CDs, so the laser diode emits light at the wave lengths of 650 nm and 790 nm. The laser beam of 650 nm was used in this experiment for it is in range of visible light.

Movement of the voice coil motor was prevented in the pickup driver electronics. Working distance of the OPU when using the wavelength of 650 nm is 1.6–2.77 mm and the linear region of the S-curve is 6 µm according to the datasheet [12]. Working distance is the distance between objective lens and the target being measured. Calculated FES signal is negative when the target is closer than the focus. In Figure 5 is a photograph of the OPU where we can see the laser diode that emits the light, the lenses and mirror that guide the beam, and the photo diode where the beam lastly impinges on. The voice coil motor, that changes the position of the objective lens, is also visible.

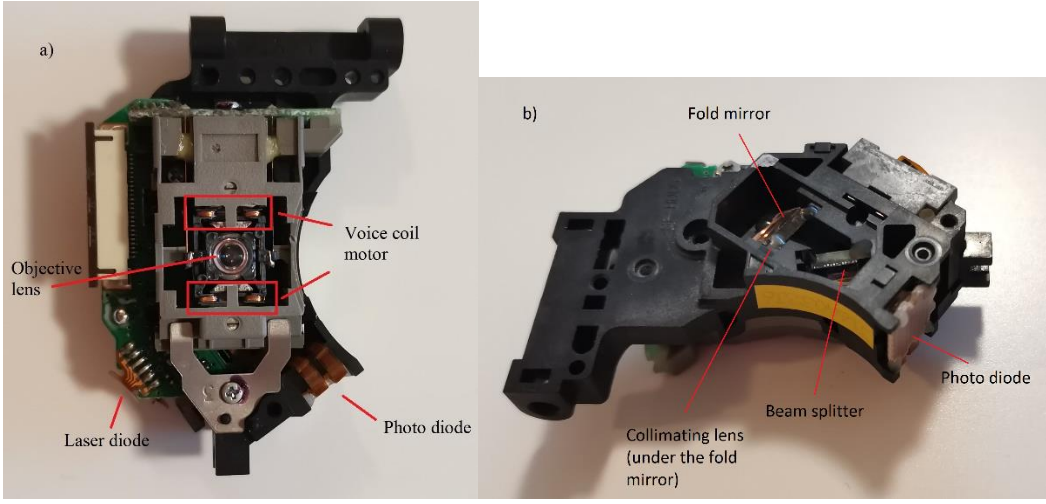


Figure 5. *Figure 5. A photograph of the used OPU form the a) top view and b) bottom view. The optical bath of the laser beam starts form the laser diode, it reflects from the beam splitter and fold mirror, and goes through the collimating lens and then the objective lens to the CD. From the CD the beam reflects back through the lenses and the fold mirror directs it through the beam splitter to the photo diode.*

The driver board for the optical head was already existing. It has the laser diode driver and the photodiode post-amplifiers. Bandwidth of the photodiode amplifiers is approximately 500 kHz. In normal conditions the output signal should be around 0–2.5 V. The photo outputs of the driver correspond to the photodiodes a–d on the OPU. The barrel plug connector was used as a power input. In order to reduce crosstalk and noise, the photodiode channels were measured differentially, only even-numbered DAQ channels were used, and the odd number channels were shorted to ground.

A DVD and a piece of foil were used as the reflective surfaces instead of the cantilever. A cover glass was placed on top of the foil to correspond the projective layer of the DVD. A piece of paper was placed on top of the setup to prevent the surrounding light to reflect to the PDIC and causing noise.

4.2 Measurements

The measurements were conducted with Simulink Real-Time, a real-time control system in MATLAB. A sine wave was used to drive the optical head. Sampling frequency of 100 Hz was first employed but it led the measured output signal to oscillate between the real values and zero. Different frequencies were tried and with 50 Hz the gained signal was coherent, thus the sampling frequency was set to 50 Hz.

The first series of measurements were conducted in order to determine the operating distance and sensitivity of the OPU. The optical head was first attached to a stand where the reflecting object was moved in vertical direction by hand. However, the movement was not as subtle and precise as needed. Consequently, the OPU was mounted to a XYZ-positioning table. Here the location of the object was fixed at certain level and the OPU was moved by manually rotating the vertical controller knob. A piece of foil with a cover glass on top, was used as a reflective surface in these measurements. The distance between the foil and the objective lens of the OPU was set to the operating distance according to the datasheet approximately. The measurements were performed by moving the OPU carefully in vertical direction and reading the change of the distance from the controller knob. Starting the measurement and the movement was done at the same time. The data was analyzed between the measurements to locate the linear region of the S-curve of the FES.

Another set of measurements aimed to measure the profile of a DVD. The optical head was positioned to the previously estimated operating distance. The DVD was moved horizontally so that its radius was scanned.

5. RESULTS AND ANALYSIS

The voltages were obtained from each quadrant A–D of the PDIC and used to calculate the FES with (A+C) – (B+D). Measurements were first conducted with different sampling frequencies: 1 kHz, 500 Hz, 200 Hz, and 50 Hz. Larger frequencies caused oscillation to the signal, so the sampling frequency was set to 50 Hz. The noise with the higher sampling frequencies is most likely caused by the background radiation of the power grid. The FESs obtained with different frequencies are displayed on Figure 6.

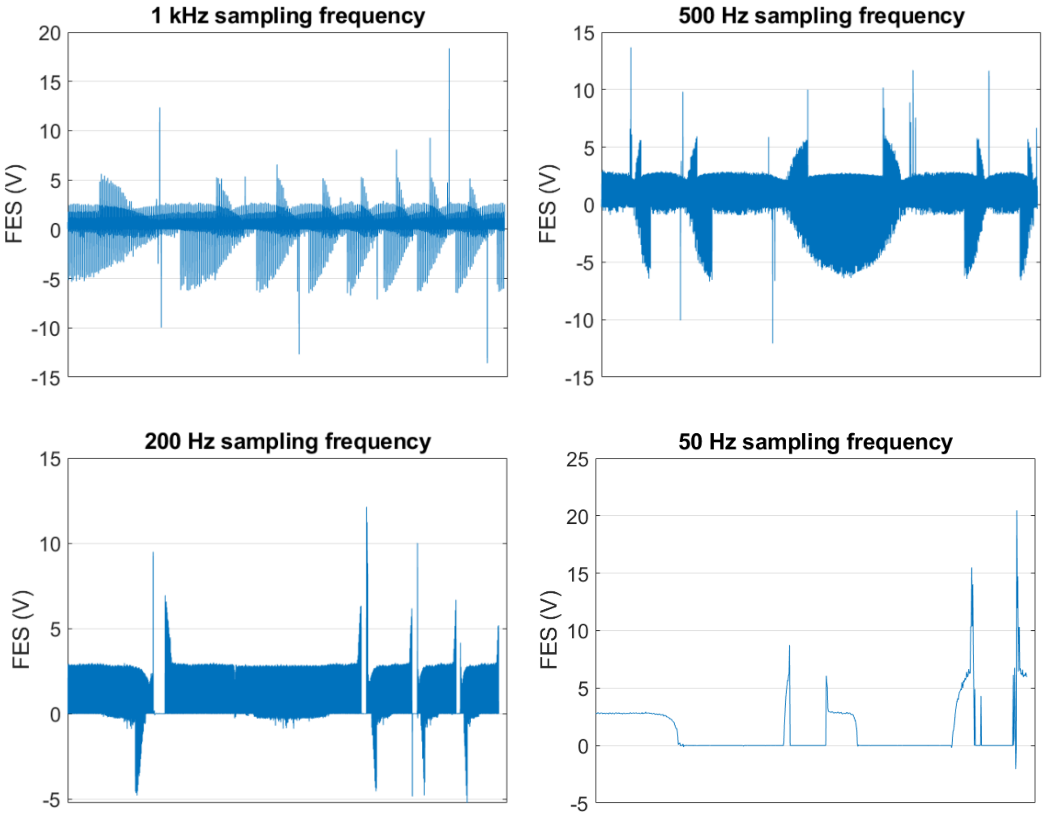


Figure 6. *Focus error signals with different sampling frequencies. With 50 Hz the obtained signal was coherent.*

A large number of measurements at different distances were performed aiming to find the S-curve in the FES. However, the S-curve could not be detected from the signals. Figure 6 depicts the calculated FES for six of the measurements where the distance *d* between the OPU and the sample was moved approximately from 1.6 mm to 2.77 mm according to the working distance of the device.

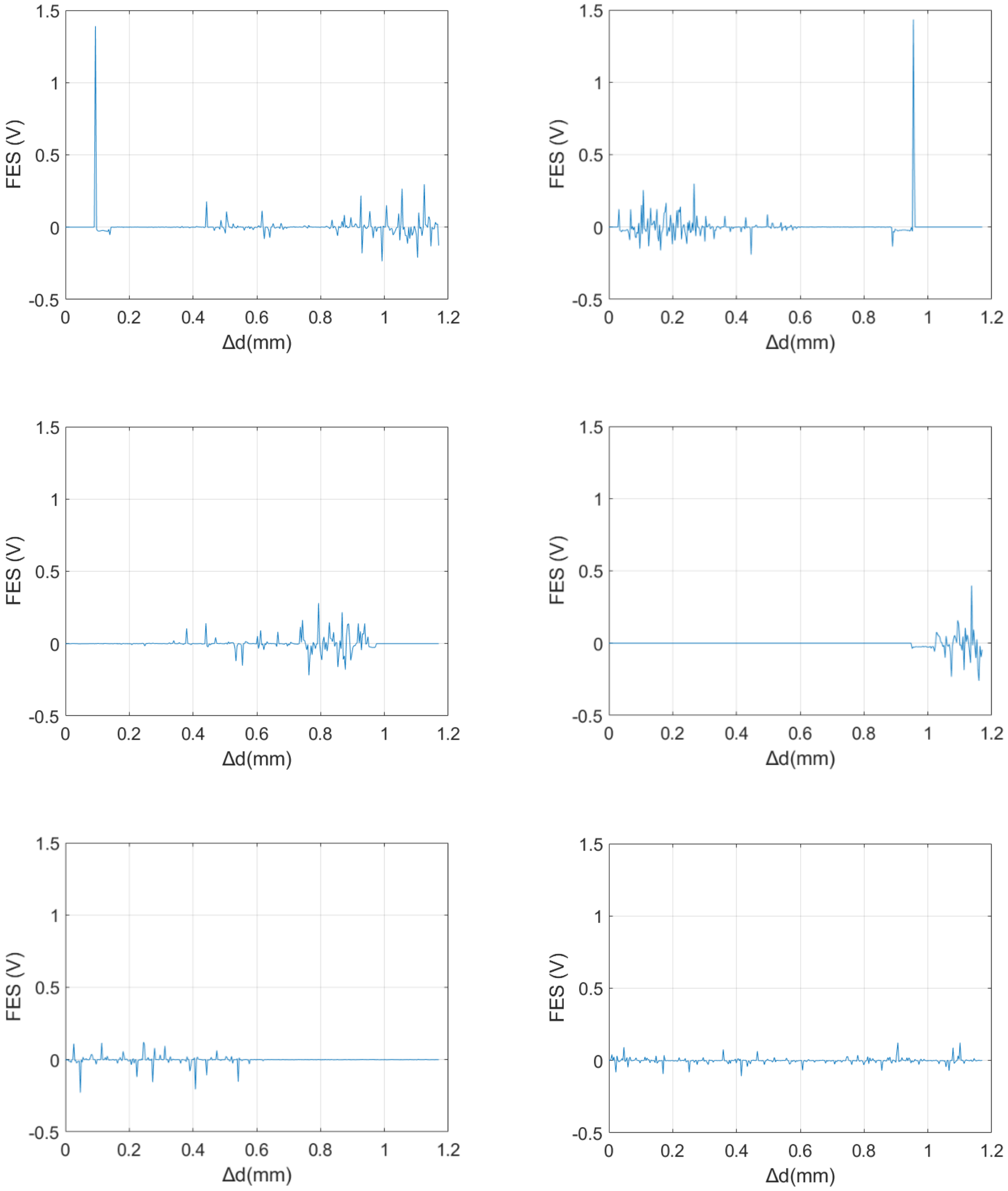
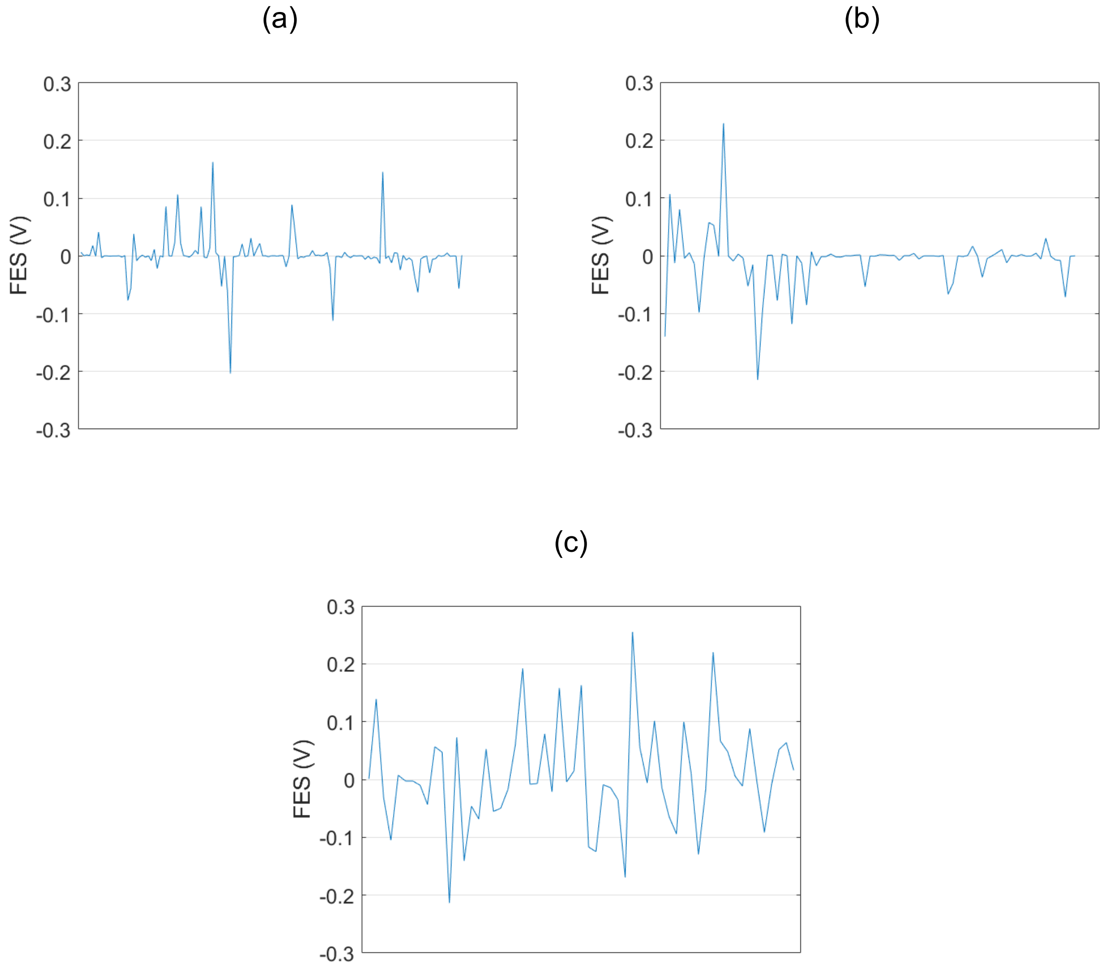


Figure 7. *Calculated FES as a function of a change in the distance d between the OPU and the sample.*

From the Figure 7 can be seen that the signal is not reproducible even though the circumstances remain the same. The S-curve, which should be located on the working distance, cannot be detected either.

The accuracy of the XYZ-table is 0.01 mm = 10 µm so the movement of the OPU may not be small enough to measure the 6 µm linear region of the S-curve. The vertical controller knob was rotated at a slow and steady pace, but differences occur between the measurements. The starting distance between the OPU and the sample was measured with a ruler which is not accurate enough to determine the exact position. In addition, starting the measurement and starting the movement are not perfectly synchronized. These can explain the difficulties with the reproducibility and the detection of the S-curve.

The surface of a DVD was attempted to measure to gain the FES voltages corresponding to the pits even though the sensitivity was not defined. The distance was set to the working distance of 1.67 mm stated in the datasheet and the disc was moved vertically. Figure 7 displays signal obtained from the DVD surface when the same measurement was repeated.


(a)

(b)

(c)

Figure 8. *FES when surface of a DVD is measured.*

Signal (c) is close to expected but again the signal is not reproducible and the position of the OPU could not be determined precisely enough with the ruler.

In addition to errors and difficulties in determining the correct distances, the electronics of the setup can have defects. The output signals of the PIDC quadrants when the OPU is moved vertically are shown in the Figure 8. These signals should remain around 0–2.5 V, and output of 10 V might be possible if the light somehow focuses only to one photodiode.

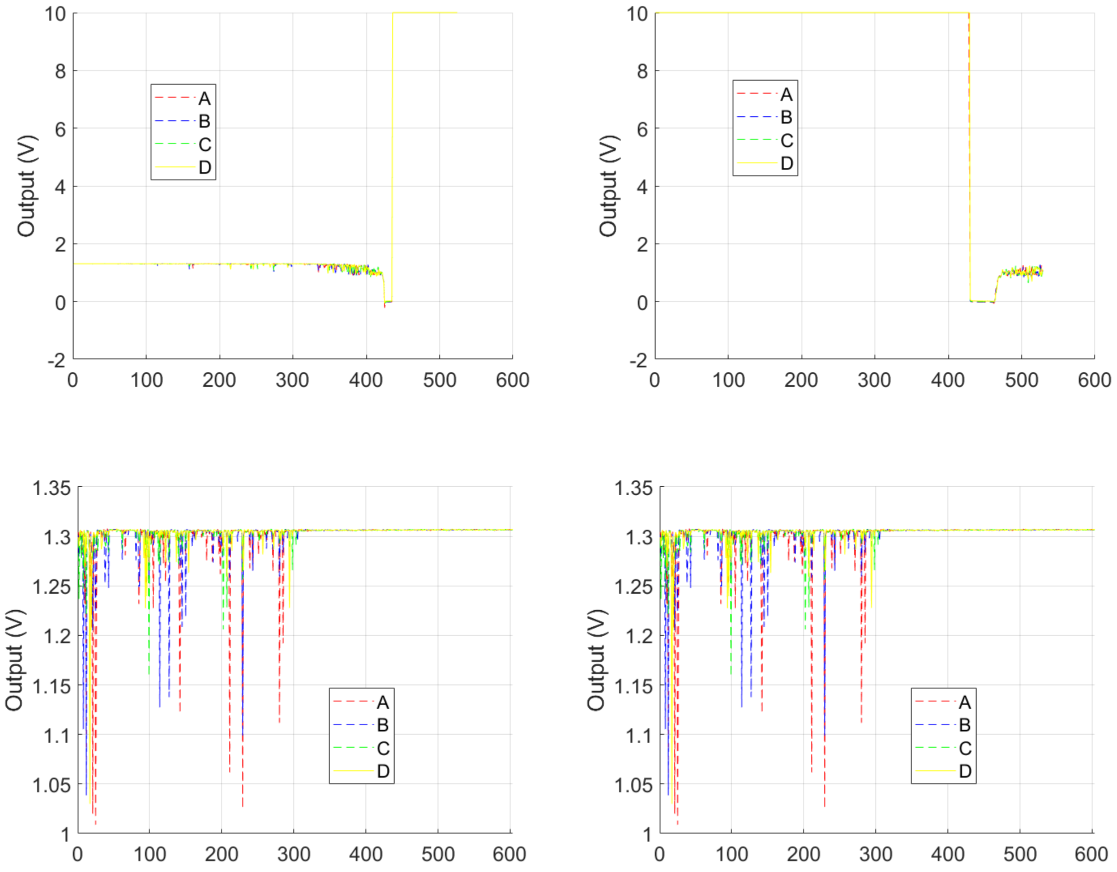


Figure 9. *Output voltages of the PDIC quadrants when the OPU is moved in vertical direction*

The output signal reaches 10 V in all photodiodes at the same time which should not be possible. According to these signals, there can be defects with the electronics e.g. with the driver board or the OPU or with the connection between them. Also, the measurements are conducted with the same circumstances so the output voltages should be the same in each figure.

6. CONCLUSIONS

Commercial OPUs are vastly utilized in do-it-yourself AFMs to measure the deflection of the cantilever. OPUs are low-cost and small and they enable fast nanoscale measurements. Linear range of the focus error signal, provided by the OPU, is proportional to the distance between the objective lens and the sample and can be exploited as a detection method in AFM. The do-it-yourself AFM being constructed is targeted for teaching purposes. This application and the nonstandard use of OPUs gives demands for the cantilever. Durable tip e.g., rotated tip and reflective aluminum coating are required.

In this work the aim was to determine the sensitivity (V/μm) of the OPU for measuring the change in the distance which could then be implemented in do-it-yourself AFM. Also, a surface of a DVD was measured. However, the measurements were not successful, and the aims were not reached.

The measurements were conducted with 50 Hz sampling frequency with Simulink Real-Time. The S-curve could not be detected from the signal when the distance between the OPU and the reflective surface was moved in the vicinity of the working distance. The signal was not reproducible most likely because the starting point could not be determined exactly and because the movement was produced by hand causing differences between measurements. It is also possible that the electronics have defects for at some points the output of all the PDIC quadrants reached 10 V which should not occur. In addition, it is likely that the XYZ-position table could not provide small enough movement to gain data form different points on the linear range.

For future work, to gain proper results, better setup conditions are required. A laser distance sensor could be included in the setup for precise detection of the working distance and for correct measurement of the change in the distance. Also, a position table with better accuracy is needed to provide movement in μm range to detect the linear range of the optical head. Piezo actuators can as well be utilized to produce such small motion.

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