KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

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DEVELOPMENT AND INVESTIGATION OF VIBROPAD FOR PERIODICAL MICROSTRUCTURE REPLICATION

Master's Degree Final Project

Supervisor
Prof. habil. dr. Arvydas PALEVICIUS

KAUNAS, 2017

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Industrial Engineering and Management (code 621H77003)

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"Development and Investigation of Vibropad for Periodical Microstructure Replication"

DECLARATION OF ACADEMIC INTEGRITY

____ June 2017
Kaunas

I confirm that the final project of mine, **Senthilkumar Gunasekaran**, on the subject “Development and investigation of vibropad for periodical microstructures replication” is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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Department

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Development and Investigation of Vibropad for Periodical Microstructures Replication.

Approved by the Dean Order No. V25-11-8, 21 April 2017

2. Aim of the project

To design the novel Vibropad for thermal replication of microstructures using high frequency excitation.

3. Structure of the project

1. To design the Vibropad using Solidworks 2017.
2. To analyse the Vibropad using Comsol Multiphysics software to find whether it is capable to vibrate at desired mode.
3. To fabricate vibropad.

4. Requirements and conditions

No specific requirements

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2016 June 13th

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SUMMARY

The vibropad of new construction used for replication of microstructures was proposed in the paper. Upon having set the operating frequencies and having selected the optimal vibropad construction, the work was carried out in accordance with the drawing of vibropad components. The finite element method was applied. The created design will be used in the executive research and development of microstructures in forming and replication technologies carried out by the research group "Microsystems Engineering" of KTU Faculty of Mechanical Engineering and Design.

The replication of master microstructure is produced due its cost. The microstructure is used in all fields nowadays. The periodical microstructures were found by an American astronomer David Rittenhouse. It was not as small as microstructures. The shape, size and its manufacture ways change from its invention y various ways. The replication was done by using several techniques to make it available for all in less cost. The quality of the replication is increased from its invention. Various steps and research taken to provide better quality of replication. The vibropad is one of the device which was introduced to make better replication with thermal imprint technique. The vibropad has its changes in design and quality of replication. The uniform vibration displacement produces better quality of replication is known from previous studies. The uniform vibration displacement is done by using high frequency excitation. The shape and design were done for vibropad to avoid deflection of shape and damage to device during vibrations. The design of vibropad were changed from previous studies since the it had some deflection in shape and quality of the replication can be increased by high frequency excitation of uniform vibrations. So, by providing the uniform vibrations throughout the surface of the polymer, the quality of the replication is increased. The working principle is same as the previous Vibroactive pad but only the process is changed. The polymer is used to be at top of the Vibroactive pad but in this process the vibropad will be at top and polymer will be at bottom. The main change in the design is the heating will be given using external element but in this design the heating element is attached to the vibropad device by designing perfectly to it. The working process of the vibropad device. The finite element analysis for the design of vibropad device simulation is presented. The frequency displacement curves of the device simulation were presented. The paper *also showcases the fabricate parts of heating element and assembled vibropad device. Therefore, the investigation was done on previous studies of vibropad device and it was developed for the better quality of the replication. Even the quality of device is also increased by changing its design and parts due to quality issues.*

Senthilkumar, Gunasekaran. Vibropado naudojamo periodinių mikrostruktūrų antrinimui kūrimas ir tyrimas. *Magistro* baigiamasis projektas / vadovas Habil. dr. Arvydas Palevičius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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SANTRAUKA

Darbe pasiūlytas naujos konstrukcijos vibropadas mikrostruktūrų antrinimui. Atliktas vibropado modeliavimas baigtinių elementų metodu. Nustatyti darbinai dažniai ir parinkta optimali vibropad konstrukcija. Darbo metu buvo atlikti brėžiniai pagal kuriuos pagamintos Vibropado sudedamosios dalys. Sukurtas vibropadas bus panaudotas KTU Mechanikos ir dizaino fakulteto mokslo grupės „Mikrosistemų inžinerija“ vykdomuosiuose moksliniuose tyrimuose tobulinant mikrostruktūrų formavimo ir antrinimo technologijas.

Pagrindinių mikrostruktūrų antrinimas atliekamas dėl kaštų. Šiais laikais mikrostruktūros naudojamos visose srityse. Periodines mikrostruktūras atrado Amerikos astronomas David Rittenhouse. Jos nebuvo tokios mažos kaip mikrostruktūros. Nuo atradimo laikų labai pasikeitė tiek jų forma, tiek dydis ir gamyba. Antrinimas atliekamas, naudojant keletą metodų, kad taptų prieinamas asmenims, turintiems mažesnius išteklius. Nuo atradimo laikų antrinimo kokybė išaugo. Jai gerinti imtasi įvairių veiksmų ir atlikti skirtingi tyrimai. Vibropadas – vienas iš prietaisų, galintis patobulinti antrinimą, naudojant terminių atspaudų techniką. Vibropado antrinimo dizainas ir kokybė pasikeitė. Vienodas vibracijos poslinkis leidžia pasiekti kokybiškesnį antrinimą, kaip žinoma iš ankstesnių tyrimų. Jis gaunamas dėka aukšto dažnio sužadinimo. Vibropado forma ir dizainas sukurti, siekiant išvengti formos nuokrypių ir prietaiso sugadinimo vibracijos metu. Lyginant su ankstesniais tyrimais, vibropado dizainas pasikeitė, nes keitėsi forma, augo antrinimo kokybė dėl aukšto dažnio sužadinimo, naudojamo vienodos vibracijos metu. Taigi vienoda vibracija visame polimero paviršiuje padidina antrinimo kokybę. Taikomas tas pats darbinis principas kaip irf ankstesniam vibroaktyviam padui, pasikeitė tik procesas. Anksčiau polimeras būdavo vibropado viršuje, tačiau šio proceso metu viršuje yra vibropadas, o polimeras lieka apačioje. Pagrindinis dizaino pasikeitimas yra tas, kad kaitinimas, naudojant išorinį elementą, pakeičiamas prie vibropado puikiai prijungiamu kaitinimo elementu. Darbinis vibropado prietaiso procesas. Pateikiama baigtinių elementų analizė, taikoma vibropado prietaiso imitavimo dizainui. Pateikiamos prietaiso imitavimo dažnio nuokrypio kreivės. Be to, darbe pristatomos pagamintos kaitinimo elemento detalės ir surinktas vibropado prietaisas. Taigi tyrimas

atliktas, atsižvelgiant į ankstesnius vibropado prietaiso tyrimus, ir vystytas, siekiant pagerinti antrinimo kokybę. Net ir prietaiso kokybė pakeista, pakeitus dizainą ir dalis, atsižvelgiant į kokybę.

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Introduction

An American astronomer David Rittenhouse made the first periodical microstructure in 1785.It was half-inch-wide. It was not smaller than microstructures which were created by novel technologies. After that, it had many changes from the beginning of invention. There were many changes in size and manufacture ways of periodical microstructure from 1785 but the concept of the microstructure remains the same. Periodical microstructures were used in lasers, sensors, holography, etc. It is hard to live a life without the systems like MEMS and MOEMS. They are used in many fields so to produce high-quality Microsystems and improving the production process, to develop the fabrication technologies. The main requirements of MEMS and MOEMS are high definition, reliability and sensitivity. The standard classical technologies of microstructure fabrication have become inefficient nowadays. The main reason is the cost of the microstructure and the standard process of making microstructures like etching, electroplating and photolithography take a long time.

The replication of periodical microstructures is done in many ways. Using Vibropad is the easy and cost-effective way to produce the replication of periodical microstructures. There are already various process and developments done in making replication of periodical structures using Vibropad. The solution proposed is Replication of microstructure which is made through thermal imprint. Even it has cracked and incomplete replicated of quality related issues. Previous research, papers and studies conclude development of replication of microstructure by the application of high-frequency excitation. There is no technology which ensures the high frequency excitation uniform effect in the replicated microstructure process.

The design of new Vibropad differs from the previous Vibroactive pad. It gives much quality and better output than before. The heating element used to give externally in the previous Vibroactive pad but it has designed internally with Vibropad. The parts have been increased to avoid the deformation in shape and design while vibrations.

This study shows the development of design and fabrication of Vibropad by investigating the previous studies. Keeping the demand and importance of microstructures even the results of previous research's, it is important to implement further investigation and development of Replicated periodical microstructure using Vibropad. So, the thermal imprint process is used because it causes preconditions of high quality and efficiently replicated periodical microstructure

The aim of the work

To design the novel Vibropad for thermal replication of microstructures using high frequency excitation.

Tasks to be performed

To achieve the aim of the work it was important to study the following cases:

1. To design the Vibropad using Solid works 2017.
2. To analyse the Vibropad using Comsol Multiphysics software to find whether it is capable of vibrate at desired mode.
3. To fabricate the Vibropad device.

Problem definition

The microstructure is used in many fields like information processing, medicine, laser technologies, electronics, measurements, optics etc. It is necessary to develop the quality of the microstructures and its fabrication technologies. Classic microstructures technologies are used like etching, electroplating and photolithography have become inefficient. The main reason for developing replicated microstructure is due to the cost of the master microstructure. To produce the microstructure rally takes much longer time so it became hard to produce and sustain its demands in respective fields. There are various methods have been used to replicate the master microstructure it became inefficient due to its cracks and incomplete replication of master microstructure. The quality of the replicated master microstructure faces the problems. The development in the design of Vibropad is done to increase the quality of replicated at less cost. The design of shape and its working model has been changing in various studies and research.

1 Literature review

Based on previous research studies replication of periodical microstructure using a Vibropad device. The device has piezo ceramic materials to make replicated master periodical microstructure by vibrations in the polymer. The device has a heating element at the bottom but the design has been varied before. The design has been changing to produce High-quality replication by reducing the defects. The cost of the microstructure is also reduced by making it effective in a design of Vibropad. The periodical microstructure investigation is done through various research studies.

1.1 Periodical Microstructure

The first periodical microstructure is made in 1785 by David Rittenhouse, an American astronomer. The Microstructure is said to be half-inch by the reports. The periodical microstructure is not small as microstructure during the invention. The periodical microstructure changed in size and manufacture ways from the invention. The microstructure is composed of narrow grooves separated by spaces in-between them. They are in the level of propagating lights wavelength.

By using periodical microstructures, the propagating polychromatic light can be separated into its components. Precise processing regimes should be maintained throughout the manufacturing of microstructure to achieve a good quality of periodical microstructure.

1.2 Replication of master microstructure

Master microstructure is not easy to afford it, they are too costly. So, to make available of the microstructure to its demands in short process need replication of master microstructure. Replication techniques are used, they are either surface replication or extraction replication. The both methods have advantages and disadvantages. They are used according to the materials. Classical fabrication methods like electroplating, etching and photolithography have become inefficient today because of its costs and long-time process. So many techniques were coming like thermal imprint technologies. These thermal imprint technologies use high-frequency excitation. The thermal imprint technologies show incomplete replicated microstructures and cracks in quality related issues. Those issues are due to there is no technology to maintain the uniform effect of high-frequency excitation throughout the replicated microstructure. The quality of the replication of master microstructure is developed much more at studies and research.

Microstructure replication using high frequency Vibroactive pad is to analysis practical exploitation of Vibroactive pad. The experiments are done using Mechanical hot imprint. The goal of the paper is to compare the quality of microstructure by using single layer Vibroactive pad and Vibroactive pad

Based on multilayer actuator, the Vibroactive pads are applied in mechanical hot imprint process using Operating frequencies. In polycarbonate surface the microstructures are created by using only process variable is a type of Vibroactive pad. There are three types of quality measurements are performed: measurement of diffraction efficiency, Optical microscopy and atomic microscopy, to examine the quality of replica. [1]

1.3 Polycarbonate used for replication of periodical Microstructures

The polycarbonate is used for replication of periodical microstructures. The application of polycarbonate was analysed in 2013 by janusas G. and Narijauskaite B. It was stated that polycarbonate is the material which will be suitable for replication of periodical microstructures due to its physical properties,

- Strength
- Ability to withstand scratches
- Easily cleaned
- Usability in high temperatures

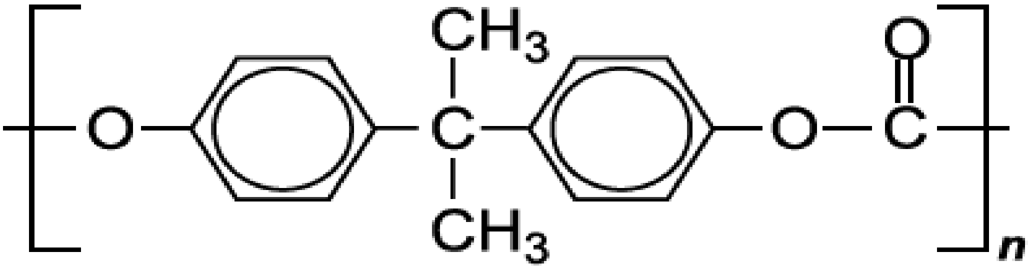


Figure 1 Chemical structure unit of Polycarbonate. [1]

1.4 High-frequency excitation

Using High-Frequency Vibration Excitation is the experiment where the periodical microstructure is developed, the main part is a sensor which bio-sense such as analysis of concertation of microparticles in the biological environment. Using the method of a hot imprint, the diffraction grating is produced. The paper deals with analysis and comparison quality of the microstructures methods, with and without high-frequency excitation [5]. There are three types of measurements in this experiment: Measurement of diffraction efficiency, optical microscopy and atomic force microscopy to analyse the replica quality. During the experiment, periodic lamellar microstructure analyse of the period is 4 µm. diffraction measurement analysis was performed using laser and photodiode BPW-34. The optical microscope is used to find out the images of magnified surface view, by allowing bubbles of residual gas defect and distortions. When atomic microscopy is performed to obtain surface parameters like depth, period, surface roughness and obtain the view of created microstructure [5].

Influence of High-Frequency Excitation into Quality of the Replicated Microstructure is used to analysis the surface relief diffraction grating was fabricated and investigated. The analysis research purpose was to determine the collection of parameters, which influence the diffraction efficiency positively. Ultrasonic thermal embossing was selected with different manufacturing regimes (time, pressure and temperature) for the replication process. Analysis results showing the increase of periodical microstructure quality with the help of high-frequency oscillations during manufacturing. The replication process efficiency is improving due to the combination of pressing time, pressure, temperature and vibrations [3].

Experimental and modelling means for analysis and replication periodical microstructures is to find out their operating frequencies. Application of precise microstructures are in various areas, they are laser industry, electronic-microfluidic devices. The precise periodic microstructures are produced by several processes. The process of hot imprint and many challenges related with quality of microstructure were also performed simultaneously. The exploitation of ultrasonic excitation in the process of the mechanical hot imprint is the solution for the quality issues. Vibroactive pad of well dynamic analysis is presented [4].

1.5 Thermal Imprint technique

Microstructures replication using high-frequency excitation is determined the quality of microstructure by hot imprint process created in the polycarbonate. Microstructures are replicated using hot imprint with and without high-frequency excitation. During the quality investigation diffraction efficiencies were measured to find the best optical quality of microstructure. It will determine high-frequency excitation. The process parameters contain temperature, excitation frequency, the force of mechanical load and duration of hot imprint process. The paper contains main characteristics of Vibropad.

High-Frequency Excitation for Thermal Imprint of Microstructures into a Polymer, the main objective is to attain the formation of microstructures using high-frequency microstructure in this paper. High-frequency excitation in thermal embossing process helps to fill gaps of the stamp by a polymer. The quality and accuracy of replica will be increased by an external factor. This method does not need complex or costly developments or experimental setup and it can be applied in most thermal imprint equipment’s [6].

1.6 Microstructure replication methods

In the replication of microstructures, various methods are used. Such as Ultrasonic hot embossing technology, Microinjection moulding thermal imprint.

1.6.1 Ultrasonic hot embossing technology

UHE is largely used adopted process. In this process using Ultra Sonically-Assisted Tool (UAT), the master microstructure is embossed into the polymer film. This method is easy to use and automate, very rapid and available at low cost. The duration of the process will be in the range of several seconds. The difference between thermal imprint method and UHE is that heating in UHE is generated by ultrasound.

In UHE process, UAT moves towards polymer, the ultrasonic excitation is applied in it and UAT is retracted. In-between friction heat is developed from the heating tool. The heat melts in the polymer and adapts to shape of the tool. At last, we can remove the replicated microstructure from the tool. The process is explained in a simplified way in figure 2,

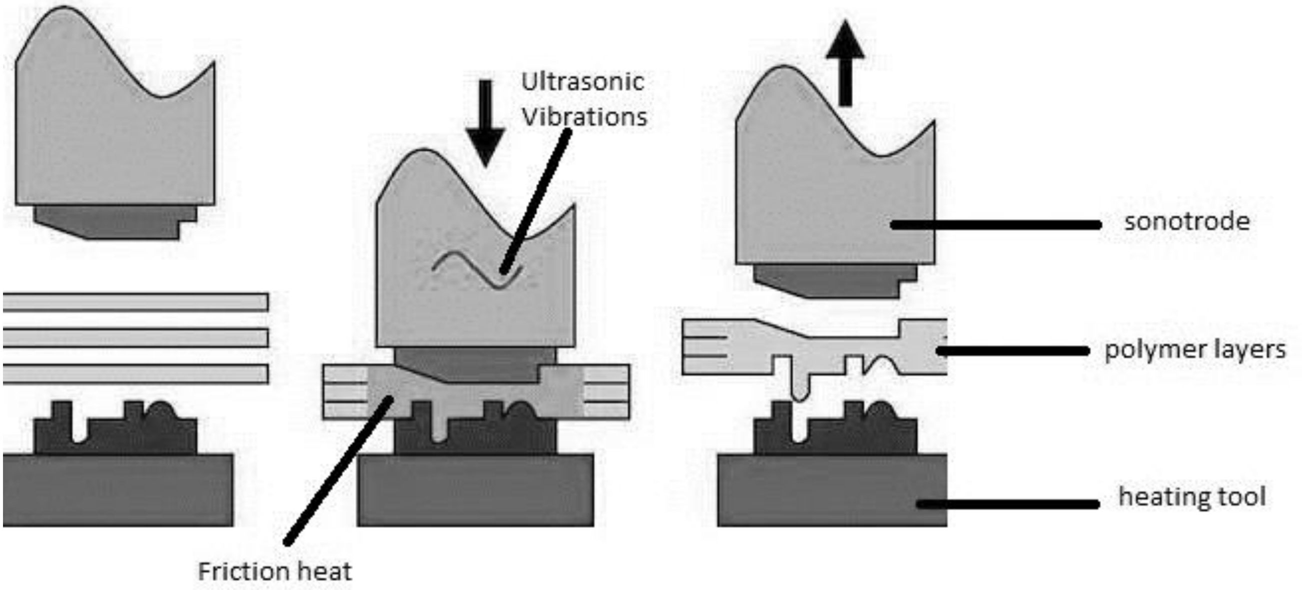


Figure 2. Ultrasonic hot embossing technology process [3]

1.6.2 Microinjection moulding

Microinjection moulding is a variothermal replication technology for fabricating the replicated microstructures. It used to fabricate from medium to large outputs. The microinjection moulding process is by melting the polymer in palettization unit and the molten polymer is injected into the clamped microstructure. Afterwards, the molten polymer was cooled and the part which is finished is moulded. It delivers high injection speed in this technique. In this technique, the material freezes into mould shape. It is a cyclic process.

This method is for large parts and not for replicating micro parts. The process will take several minutes per part. The microinjection moulding process is explained in figure 3,

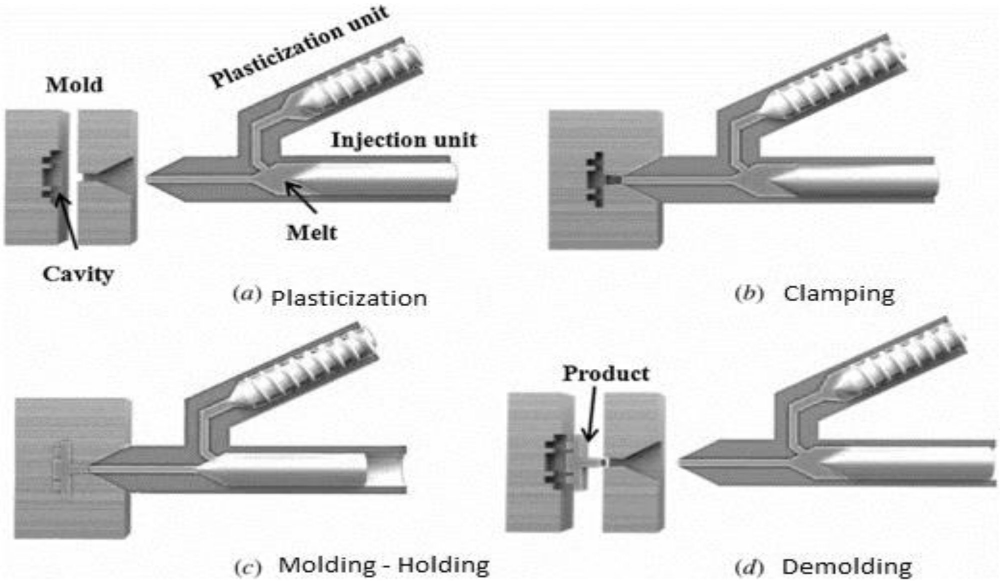


Figure 3. Microinjection moulding process. [3]

1.6.3 Thermal imprint

Thermal imprint is one of the technologies used for replication of microstructures. This process is straightforward, low-cost, well developed and efficient one. This process is a prospective method for replicating the microstructures of high aspect ratio. The process consists of four stages:

a. Heating
b. Imprinting
c. Cooling
d. Demoulding (worgull, heu et al.2008; Kolew, Munich et al.2010)

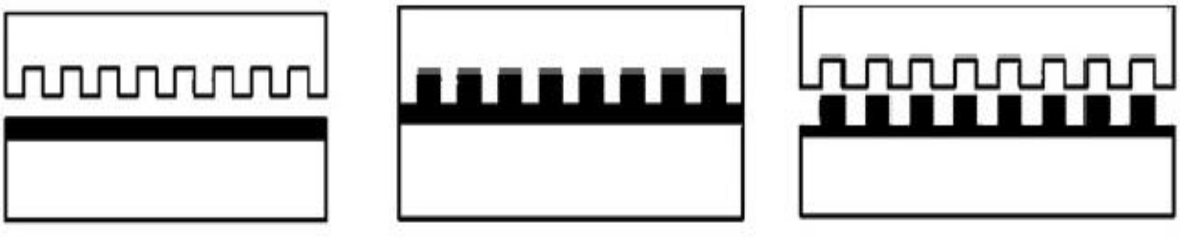


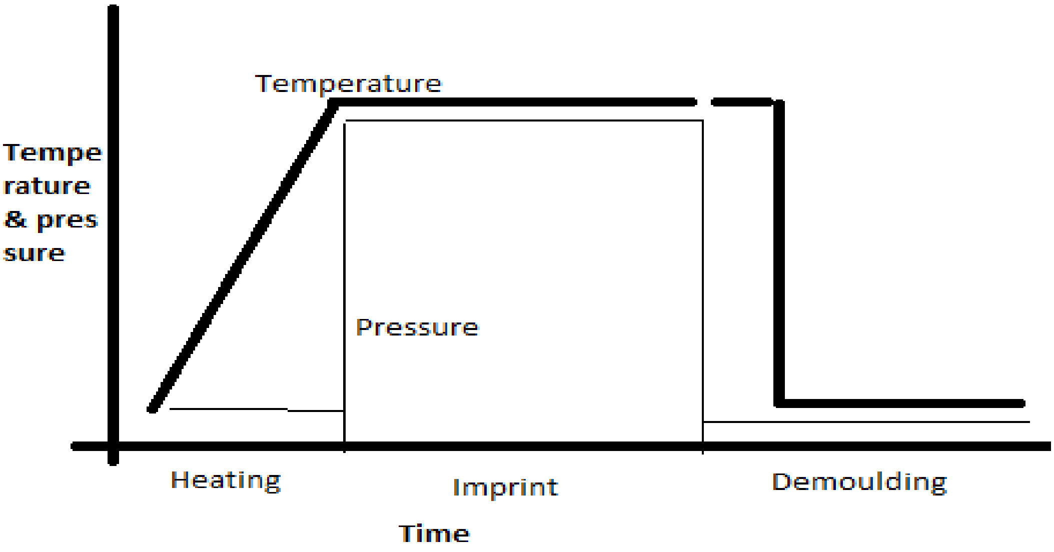
Figure 4. The thermal imprint of heating between the master microscope and polyunsaturated.

The above picture indicates thermal imprint process of heating the master microstructure and polyunsaturated. The first image indicates embossing process, second one indicates moulding and it is released.

This process starts at ambient temperature. The master microstructure is imprinted into the polymer by preheating the polymer in melting temperature. The pressure of imprinting will be applied for some time which is necessary for forming a microstructure on the polymer. Afterwards, the polymer and master microstructure are cooled down and then moulded in the process.

The graph will be presented below which represents the temperature and pressures vs time. The time includes the heating, imprinting and moulding period of the process.

The outputs of production usually range from several thousand from the single of fabricated parts. Microstructures can be replicated by using master microstructure and employing various configurations of the polymer.



Graph 1. Thermal imprint process – temperature & pressure vs time. [5]

There are three types of possible variations in thermal imprint process. The plate-to-plate (P2P), roll-to-plate (R2P), roll-to-roll (R2R). These three possible variations are used in the thermal imprint process. They were represented in figure 4 below,

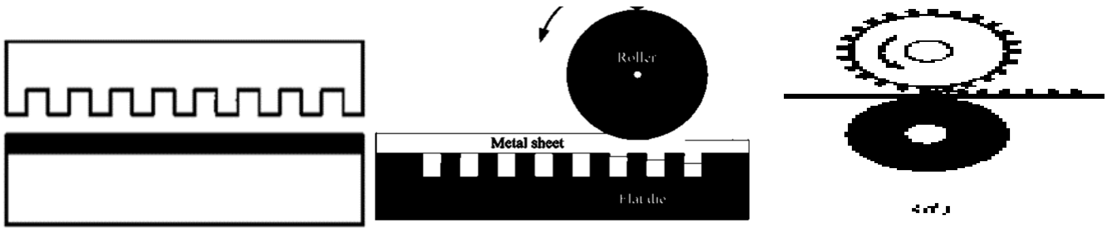


Figure 5. Types of possible variations. [5]

The thermal imprint process is better one from other techniques but the disadvantage of the thermal imprint process is potential damage to the replicated microstructure. When the heating and embossing of the process is done, the polymer used to have combination of stress and strain. The moulding is done at last after the deformation were recovered while the stress in the polymer is relaxed. The contact of master microscope and the polymer is done throughout the process.

The moulding requires accurate control of temperature, force to neglect defects in microstructures and alignment precisely. To improve the results high frequency vibratory, rubber and gas are used to improve the results. The vacuum will be applied during the replicated process. The vacuum will be initiated when the foil is placed in the thermal imprint. Then it will lead to the gas absence in between the microstructure and polymer.

The high-frequency excitation in the process used to reduce the imprint pressures, it allows uniform vibration to vibropad and it will also decrease the process time. It also enhances the vibration flow of microstructure of molten polymer. By using the high-frequency excitation, we can eliminate possible damage in the replication of master microstructure.

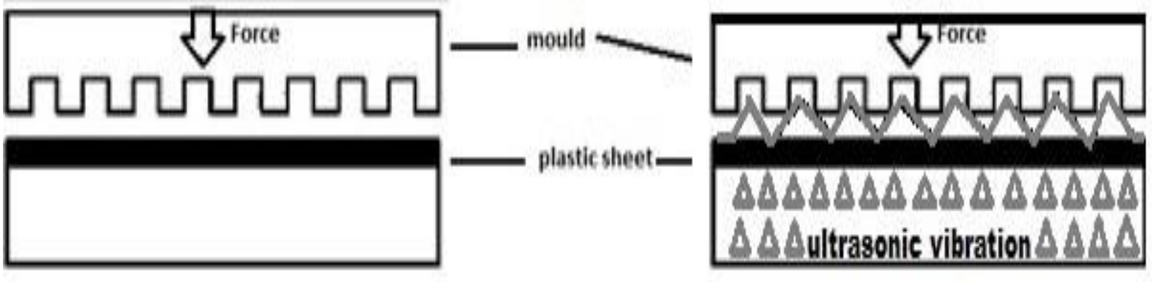


Figure 6. ultrasonic vibration flow in microstructure.

The figure 6 indicates that force will be applied to the microstructure, At first without frequency and with frequency excitation. The ultrasonic vibration is applied with high-frequency excitation is done.

From above microstructure techniques, the thermal imprint is widely used and better one. The thermal imprint and UHE are economic methods. We can make in a cost of 10,000 euros. Thermal imprint and UHE are not complicated when compared to microinjection. Replicating large features are done in microinjection moulding and complex parts are done by UHE and thermal imprint.

1.7 Replication Microstructure quality

Investigation of Dependency of Microstructure Quality on Vibration Mode is to investigate the quality of microstructure created on polycarbonate using hot imprint process and changing vibration parameters.to make successful of this investigation, it is successfully applying in research and industry. Before it was revealed high-frequency excitation, made from aluminium and piezoceramic (PZT-4) with the usage of the Vibroactive pad which affects the quality of the microstructure. The investigation finds out which of them influences the quality of created microstructure best. The experiment of qualitative analysis is performed using optical microscope [2].

2 Existing Vibroactive pad device

Vibroactive pad is a device which is used for producing replicated periodical microstructure using thermal imprint. The vibropad is developed and fabricated by thermal imprint process technique. Vibroactive pad has been changing its design from previous research studies. The Vibroactive pad device model is different from previous studies.

The Vibroactive pad operated based on the inverse piezoelectric effect. The Inverse piezoelectric is defined as “converting AC voltage to harmonic mechanical displacements”. The vibropad purpose is to stimulate the flowing of preheated polymer towards the master microstructure to produce and increase the replication quality.

The Vibropad device is used since it gives better results in the experiment than using other methods in replication of microstructures. Existing Vibroactive pad device have been shown in figure 7 as follows,

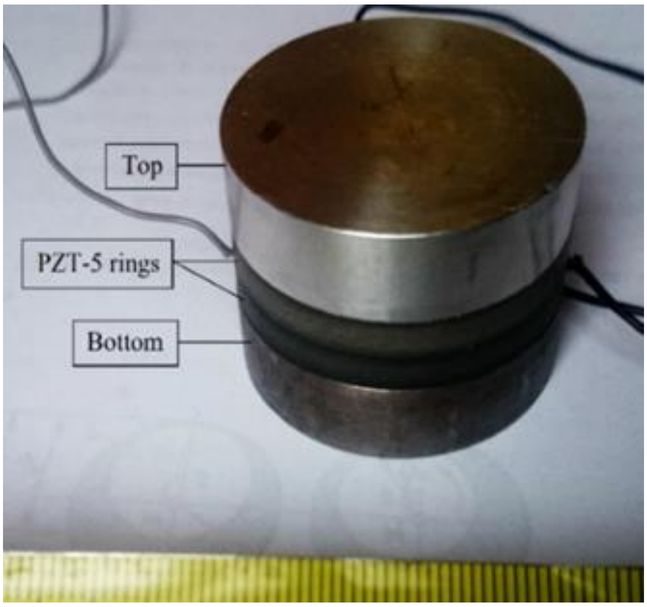


Figure 7. Existing Vibroactive pad device. [1]

The Vibroactive pad is a replication of microstructures device which is 32.5mm height and 40mm diameter. The Vibroactive pad Piezo ceramic rings in-between two stainless parts. It has two PZT-5 rings in the device. The principle of the Vibropad device is inverse piezoelectric “converting AC voltage to harmonic mechanical displacements”. The PZT-5 helps the Vibroactive to vibrate in high frequency when AC is given to piezoceramic rings.

The process of the Vibroactive pad is a simple and easy process. The Vibropad will be at the bottom. The top surface of the Vibropad will have polycarbonate which is used to give replicated microstructure. The master microstructure will above of this with the heating plate. The heating is given externally. The vibropad used to vibrate when AC is given to piezoceramic rings. The heating plate gives high temperature to get better mould and polycarbonate will deliver better and high quality of replicated microstructure of master microstructure. The high-frequency excitation is attained at a specific frequency. In existing pre- stressed Vibroactive it is attained at 7Khz, which is the high-frequency excitation. At this frequency uniform displacement vibrations are attained where the surface of Vibroactive will equally punch the polycarbonate without any defects. It results as the replica have better quality at this frequency is attained in experimentally. During the process, the vibropad will vibrate with polycarbonate, master microstructure and heating plate. The existing Vibroactive pad process is shown in figure 8 as follows,

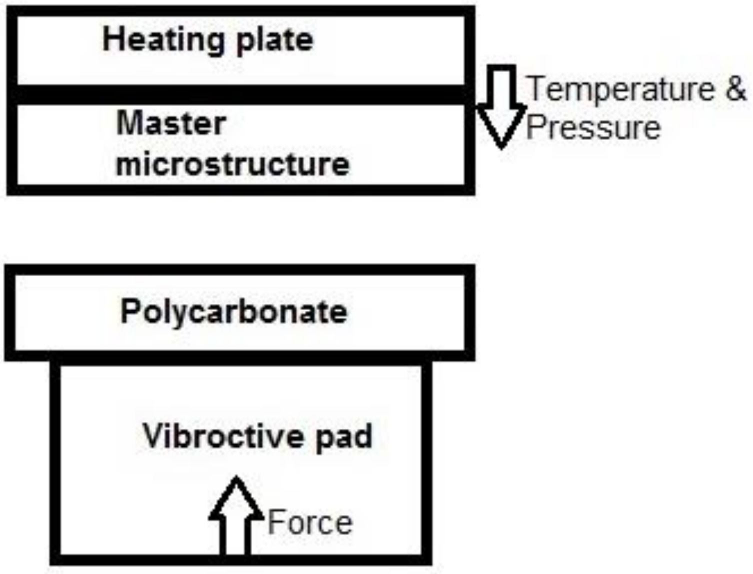


Figure 8. Vibroactive pad process

The previous study of Vibroactive pad attained better quality replication of master microstructure. Even it had minor cracks it gave high quality of replica than previous studies. The quality of reliction for this research has been proved experimentally too that using Vibroactive pad gives high quality of replicated microstructure of master microstructure. But the structure of Vibroactive pad is complicated in the process even it looks simple. It can be made simple by making changes in design and structure.

3 Piezo ceramic rings

Piezo ceramic rings are used in Vibropad device. There are many types of PZT rings. The Piezo ceramic have their own properties as follows,

3.1 Piezo mechanical effects

Piezo actuators like stacks, benders, tubes, rings make use of deformation of electro-active PZT-ceramics. The lead, zirconia, titanite were the materials used in PZT. The deformations are used to produce force or motions. The conversion of electricity into mechanical by piezo material was the principle when it was introduced. The basic piezoelectric single layer element is shown in figure as follows,

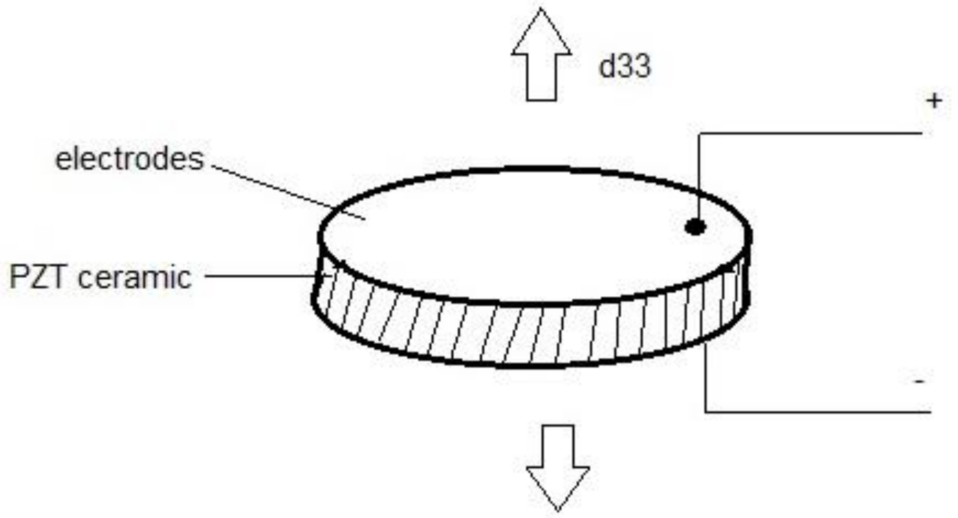


Figure 9 Piezoelectric single layer element.

The deformation will be created when the piezo material is charged by applying a voltage.

Piezo Stack rings are used to make use of increased thickness of ceramic in the direction of applied electric field. The total strokes will be equivalently increased for several layers of the multilayer structure. The d33 mode is used in the vibropad device. Which is sued to vibrate when the voltage is given. The figure shows d33 as follows,

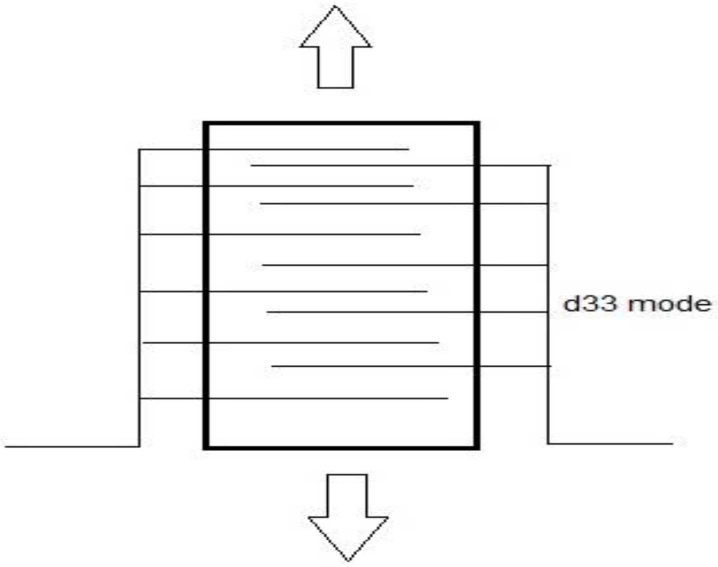


Figure 10. The PZT d33 mode.

3.2 Stacked piezo ring actuators:

Piezo actuators were used in past for the precision qualities positioning tasks. But now it has been used in many fields than the past. The new fields of applications are dynamic actuated mechanics like valves and fuel injection devices or vibration generating devices. It has been known that there are the variety of applications are there in general type of actuator. [30]

There is the main parameter to adopt a perfect piezo material for each process. The PZT is selected according to their application. The application is,

- Selection of proper piezo ceramic material according to their process. The proper PZT material achieves strain, stroke temperature range and energy balance etc.
- Preparing efficient structure of stacks and highly reliable like vibration resistant electrode.
- Packing of ceramic rings and stacks like preloading according to rules and dynamic application in heat management.

The ring stacks with a centre hole:

The need of ring stacks structures is,

- The mechanical part feed up is needed and the accessible system is needed.
- By enlarging the diameter of ring stacks, we can increase the bending stiffness. It can be done without the need of increasing the operating the volume of ceramic. The ring structure of piezo material provides cooling performance due to access of inner and outer surface.

The ring stacks structures is shown in figure 11 as follows,

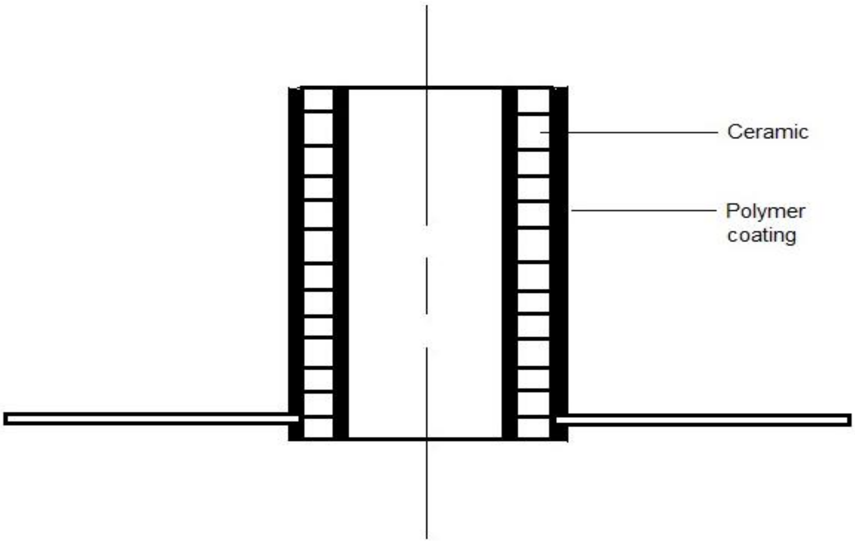


Figure 11. The ring stacks structures of Piezoceramic.

The energy or power balance of piezo actuator basic principle is to be converting the electrical energy into mechanical energy like vibrations. The formula for calculating the electrical energy as follows,

P = ½ CU2

Where C- actuator capacitance and U- applied voltage.

The PZT adapted has a material like standard ceramic and HS/HT ceramic. It shows the dielectric constant is low with high strain. These materials have a high temperature operating and high stability. PZT ceramic is not selected for energy aspects as criteria alone, it has other things too.

The power optimisation, the piezo actuator can deliver high displacement along with high force to achieve the transfer of high mechanical energy.

The high mechanical energy can be transferred into the mechanical structure. It can provide high mechanical output with a input of high electrical energy.

PZT ceramics will be the future in the solid-state actuation. Other thigs than ceramic cannot compete due to technical and cost issues. PZT ceramic materials have stack manufacturing in which it covers a large variety of applications. Piezo stack can be operated with unipolar and semi-bipolar voltage signals. The analysis is always needed to know the correct voltage polarity while connecting the piezo to a power supply.

Semi bipolar results are better than the unipolar results in piezo materials. It has wider total voltage, stroke increase and energy density. Hard material can withstand high counter fields. The hard materials are ceramic materials. The pre-stress or pre-load is applied in various applications of PZT. It means the application of force which means vibrations or compression of stacks.

The properties of piezoceramics which state the stability of piezo actuators in high temperatures. It can withstand high temperatures which made it as important use for many industrial aspects since it shows only a few changes in properties as result.

The reliability and lifetime of piezo actuators are depending on inherent features. The inherent features are coatings and materials. But not only this also it depends on the electrical and mechanical coupling strong qualities.

To dynamic load operations, the force of actual balance can be done. Within the actuator force detection will be achieved. A small part of the ceramic stack is separated from a whole part. The part which is separated will be electrically separated and it was used to contact charge or supply of voltage detecting purposes. Therefore, it will be delivering the force variations in the stack. The special casing also covered to piezo stacks sometimes to avoid damages, the materials used for covering are INVAR, aluminium, titanium and much more.

The piezo mechanical performance will be same for both high and low voltage systems. The low voltage actuators are used for small and medium size elements for cross sections. We should always the electronic driving for selecting piezo actuators. Prototype manufacturing is easier for the high voltage elements than the low voltage elements. Piezo materials can be easily implemented. The layer structure is to determine the electrical capacitance. A large number of elements will be used for low voltage actuators. But the charge required for both high and low voltage actuator is same even the results differ.

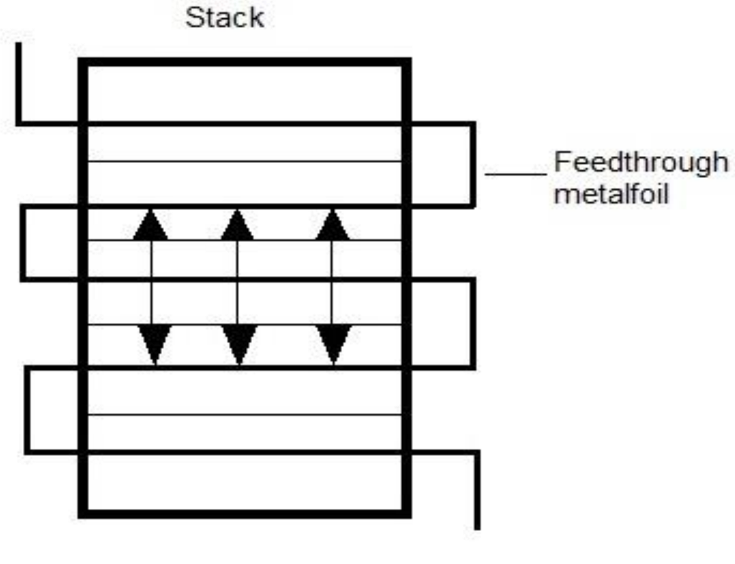


Figure 12. The surface supply electrode for high voltage.

The mounting procedures for ring actuators: the principle for ring actuators is same for stacks actuators. The requirement for the ring actuator is only to prevent mechanical damage or attack on the inner side of the rings. This is must check for better results. This is needed for both bare rings and actuators.[30]

3.3 Fabrication of ring type piezo actuators

PZT were fabricated using powders of PZT by tape casing methods. A well dispersed PZT materials were made using slurry due to the use of require amount of PZT powder, organic solvents, dispersant binder, plasticisers. It will have combined and ball milling will be done for 72 hours to make it perfect. By changing the parameters green tapes of the thickness of $20\mu m$ and $200\mu m$ such as clearance of blade, the speed of casting, the slurry viscosity. The process of tape casting technique in PZT is the powder of calcined PZT is slurry formulated then it will be tape casting of flurry. It was covered with green sheets. When green sheets are done the printing of electrode will be achieved. The laminations of layers and vacuum is sealed in it with compressed. The cutting and cofiring of layers. It will be taken to drawing of terminal and poling process and ML device is achieved slowly.

The green tapes thickness will be $80\mu m$. The laminated stacks are placed one over the other using uniaxial stacking machine. The stack is used to isopressed for 5 minutes in 30 Mpa. The stack will be levelled to have parallel surface. The soldering of wires will be done by two terminals. It will have silicon bath for 20 degrees Celsius for 45 minutes and they were forced were characterised.

The working principle of ring fabricated actuator is the design is for flow control of liquid. The substrate will be glued for the inverted position of the actuator. In the stacks, there will be a gap between the substrate and middle rod. It facilitates the flow of fluid.

The fabrication of ring actuator has three parts in it, they are:

An active PZT ring stack which will be prepared usually with 70 layers. The stacks will be in an annular shape. In central there was rod in the middle which will be cylindrical PZT rod. The Circular base will have 10 layers usually, it will be an inactive circular base. The PZT base is used to facilitate the displacement of active ring actuator. The active regions in the stacks will be poled and an electrode at kilo volts and the measuring of displacement will be done respectively. [31]

The results of fabricated PZT ring type will be done. By displacement of fabricated ML stacks and ring, actuator will be measured without the use of mechanical load. There will be an increase in voltage and displacement. The piezo multilayer stacks are prepared by tapes on it. In the piezo flow of liquid is expected at last.

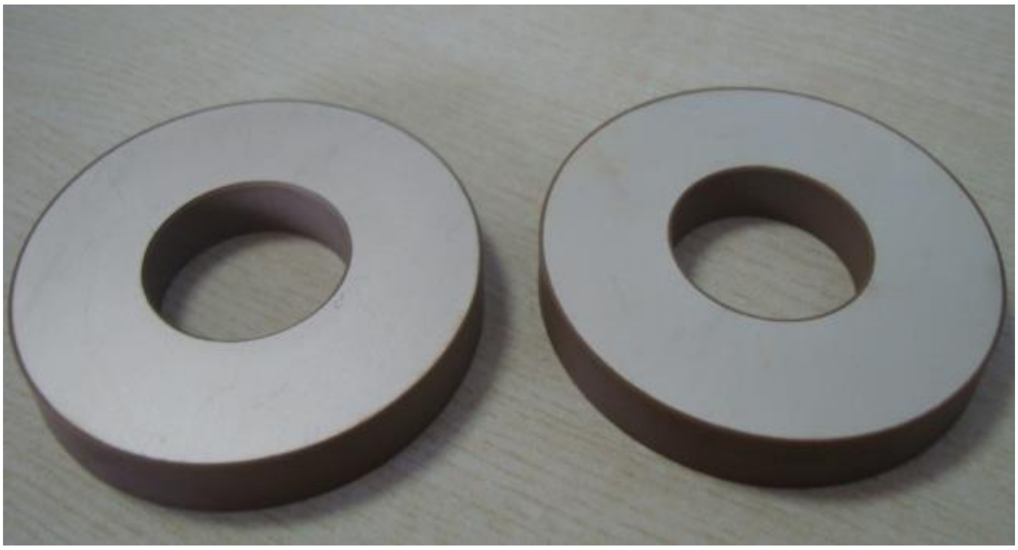


Figure 13. Fabrication of standard Ring stack of piezoceramic [31]

The characters of PZT-4n which is used in new Vibropad device:

- high electromechanical coupling factors (k).
- high mechanical quality factor (Qm).
- high stability / low dissipation factor.
- compatible with high voltages / high mechanical loads.

The available types of PZT-4 in recent times are PZT Type-4 (Navy-I), Type-5A (Navy-II), Type-8 (Navy-III), Type-5J (Navy-V), and Type-5H(Navy-VI). PNS-PZT and PMN-PT are the recent addition to the list. PZT Type-4 has a low dielectric loss, high mechanical quality factor (Qm), reasonably good coupling coefficient and high mechanical and electrical strain properties. This material is suitable for high power ultrasonic applications, acoustic projectors etc. PZT materials can be processed into various forms such as bulk ceramics, thin films, and fibres. [30]

The resistivity of the PZT-4 ceramics remained relatively constant between -150 and 50°C. PZT-5 does not positive results as PZT-4 it was decreasing in resistivity. The PZT-4 specimen exhibited a change in the rate of expansion at approximately 310°C, whereas the PZT-5A and PZT-5H ceramics exhibited similar changes at 350 and 170°C respectively. the PZT-4 ceramics possessed the highest average MOR (Modulus of Rupture) value, followed by the PZT-5A, PLZT-9/65/35, and PZT-5H compositions, respectively. The PZT-4 specimens also exhibited strong piezoelectric resonances above room temperature. [31]

4 Design of Vibropad

Vibropad is a device which is used for producing replicated periodical microstructure using thermal imprint. The Vibropad is developed and fabricated by thermal imprint process technique. Vibropad has been changing its design from previous research studies. The Vibropad device model is different from previous studies. The quality of the replica is increased, the main change from the previous studies is the heating element is attached to the Vibropad it will be placed at the bottom of the Vibropad device itself. The working principle is same from previous studies but the working process is changed.

The Vibropad is designed using the 3D CAD Solid Works 2017 software. The basic model is drawn according to the dimensions. Each part is drawn and then they were assembled as a device. The main part of the device is piezoceramic rings (PZT-4). The construction was fixed through stainless steel screw. The new design to the Vibropad is the heating element is fixed to the Vibropad.

The design of Vibropad is done using Solid Works software. The Vibropad device structure is changed from existing Vibroactive pad. The design is done according to results of the previous study. The Vibropad device has many parts in the new design from previous existing Vibroactive device but we can see Vibropad as three parts by neglecting the subparts. The Vibropad is designed using the 3D CAD Solid Works 2017 software.

4.1 The main parts of Vibropad device

There are many parts in Vibropad device. The design of Vibropad is presented here. The main parts of the Vibropad device are only presented here. Only some of the minor parts were neglected. The Vibropad is designed using the 3D CAD Solid Works 2017 software. The basic model is drawn according to the dimensions. Each part is drawn and then they were assembled as a device. The design is done according to results of the previous study.

To avoid deflection of shape in a vibropad device while vibrating at high speed, the two extra parts were specially designed for it. These two parts will be made of stainless steel and placed on top of the device which is top of piezoceramic rings (PZT-4). The top parts were different from each other in diameter to avoid heavy force in the device, which may damage device due to heavy force. The Top two parts were drawn in mm. To withstand the pressure, temperature and force the top two parts were designed. The designed two parts are shown in figure 14 as follows,

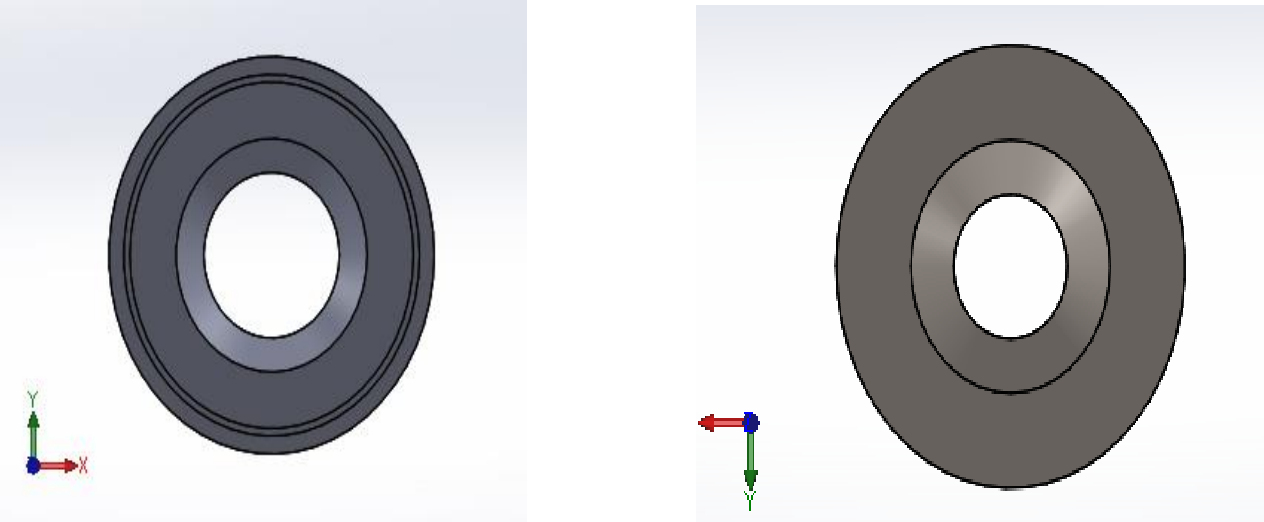


Figure 14. The first two parts of the vibropad device.

After two parts on top, we will have piezoceramic rings (PZT-4). The piezoceramic rings (PZT-4) will be placed in the middle of the device. There are 4 piezoceramic rings (PZT-4). The reason for placing 4 PZT-4 rings is for high vibrations will make the process faster and reduce the time of replication process. The piezoceramic has their own materials of ceramic. The piezoceramic rings were drawn in mm. The piezoceramic rings (PZT-4) will be shown in figure 15 as follows,

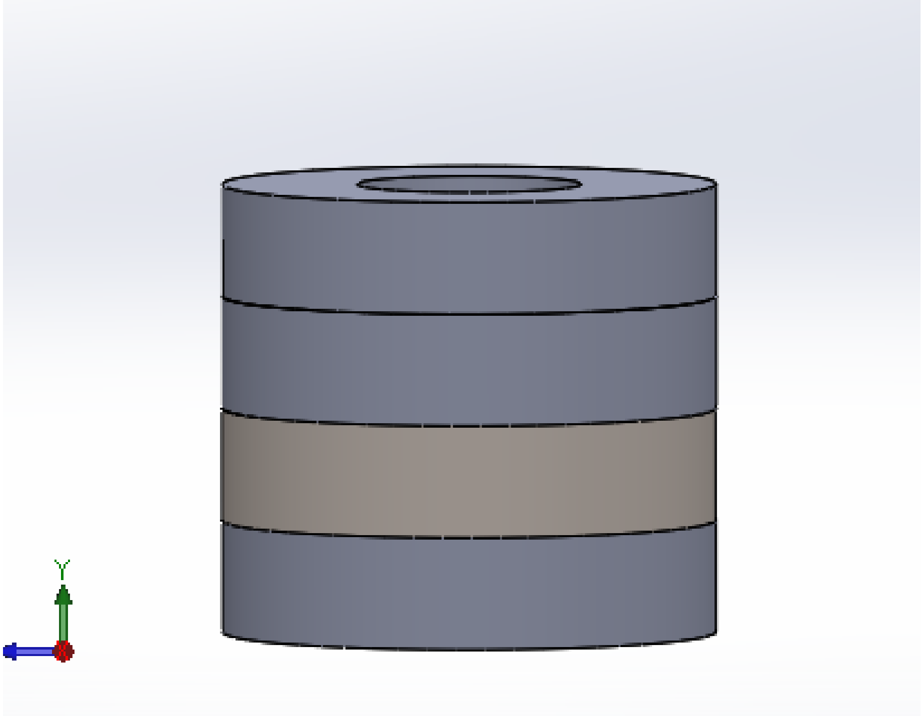


Figure 15. The piezoceramic rings (PZT-4)

The last part of the device is heating plate. The heating plate will be placed at the bottom of the device. The heating changes the whole design from existing Vibroactive pad. As we know, in a previous device the heating plate will be external parts but in this model, the design has been done by keeping the heating plate along with device itself. In the design, heating plate has the complicated parts. It has been drawn into two parts Top and Bottom using Solidworks software. Then they were attached with small miniature screws. The heating plate has two parts but will be a single part by assembling them. The bottom of the heating plate has the complicated design, it has gap for inserting the heating wire. There will be two blocks of a whole to allow the heating wire. The heating wire is inserted during the process due to supply and initiates heat to the plate. The heating plate will be made of stainless steel and it can withstand high temperature given to it. It has been given high thickness to the heating plate since it will be the bottom of the device which will be in contact with the polymer in the process of replication. The designing of the part has been done to withstand the fast vibrations and temperature given to it. The material can be changed while experimenting according to the temperature given to it. The heating plate parts were drawn in mm. The designed part of heating plate has been shown as two parts separately in figure 16 as follows,

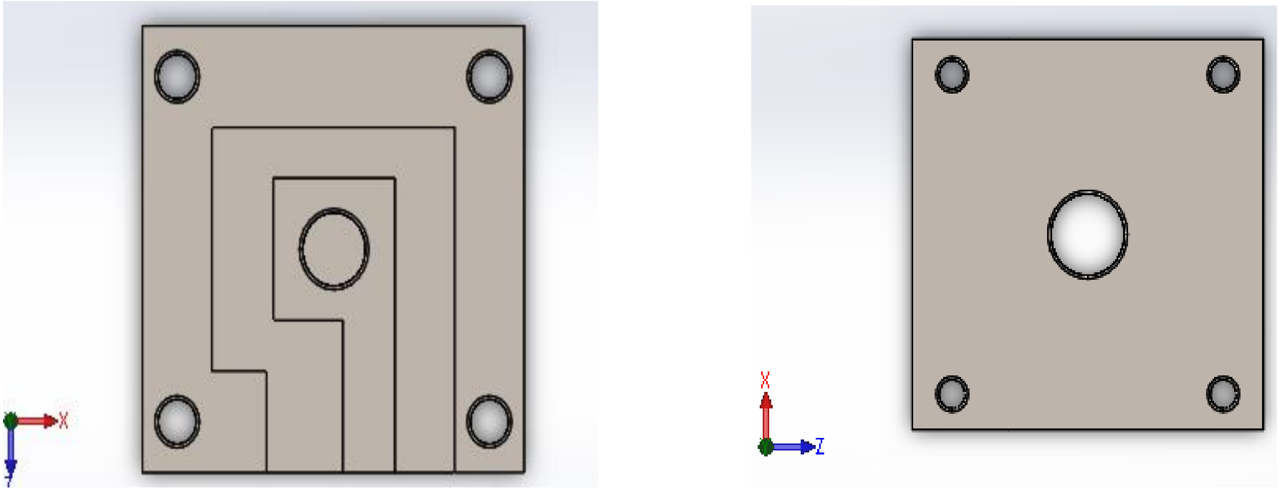


Figure 16. Parts of the heating plate.

4.2 Vibropad device assembly view

The heating plate of two parts has been assembled using standard screws. The heating part was drawn in mm. The heating part assembly is done by fixing them by option mating and locking them. The coincident option is used for mating the heating plate parts. The centre bolt is used to insert at the end of the heating part. The bolt connects the heating plate and other parts. they were attached with small miniature screws. Bolt fix the parts of the vibropad device. The design of assembled part has been shown in figure 17 as follows,

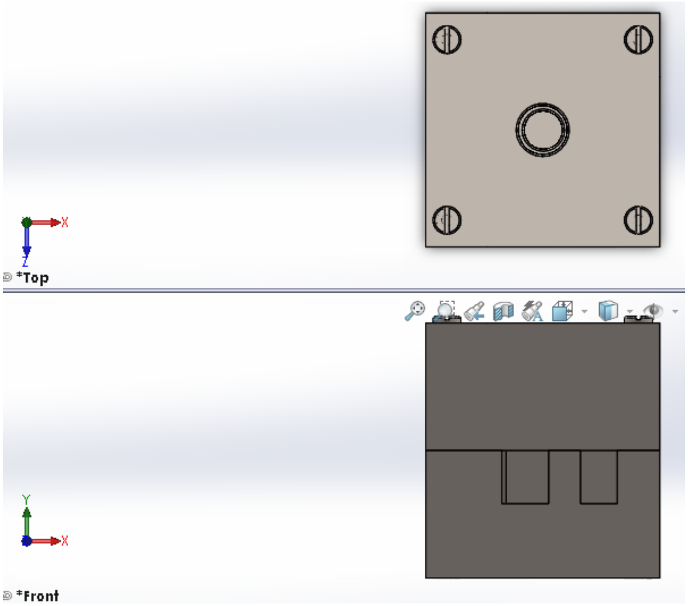


Figure 17. The assembly of the heating plate.

The Three Main parts of the vibropad device will be assembled orderly. The assembling of the vibropad device will be done by making use of the long screw. The standard screw has been selected and inserted. The long screw is placed in the middle of the device. It will be at the bottom of the heating plate. The vibropad device assembled is shown in figure as follows,

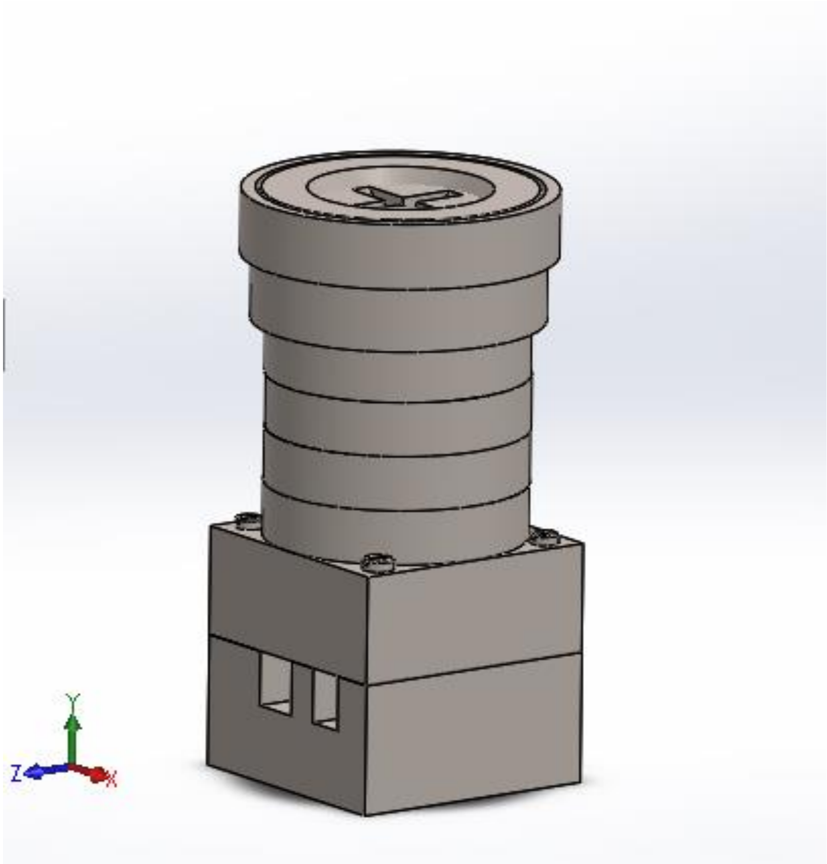


Figure 18. The assembly of Vibropad device using Solidworks.

4.3 Dimensions of vibropad device

The Designing of vibropad is done using Solidworks 2017 software. The dimension was given to each part having some changes from the previous device and its results. The heating plate is complicated part and has complicated dimensions too. The block which is used to inserting a heating wire is easily visible. The top part does not have any special structures inside so it has only height and width nothing much. So, the bottom part of the heating plate has only complicated structures inside for inserting the heating wire. The dimensions of the parts will be in mm. The dimensions of the heating plate bottom part will be shown in figure 19 as follows,

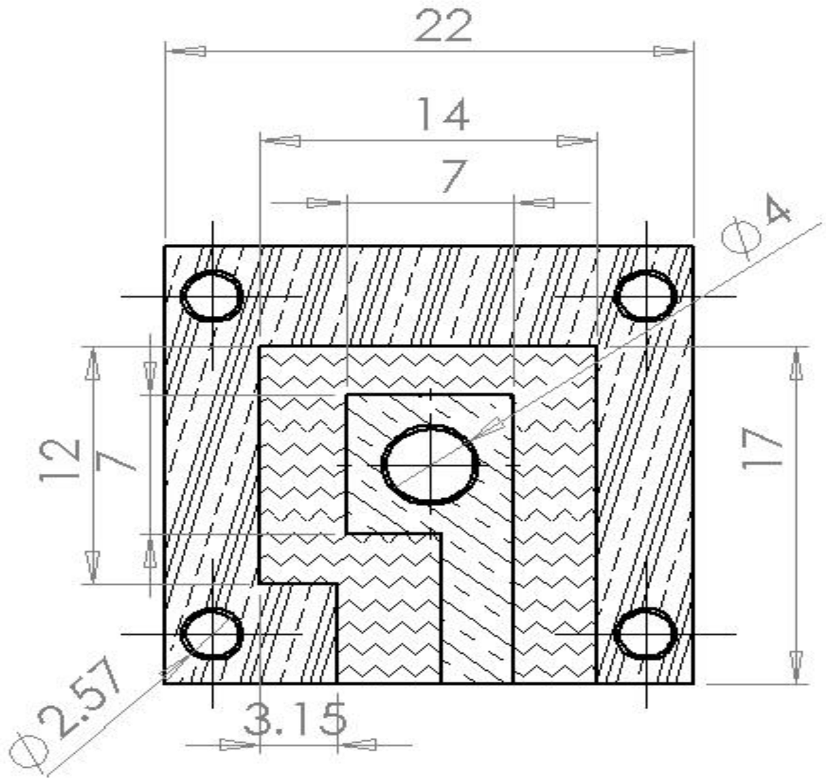


Figure 19. The dimensions of the heating part in vibropad. (in mm)

The dimensions of assembled Vibropad device is shown in figure 20. It clearly shows the stainless Top part is marked as 1 and 2 respectively. The 3 shows the 4 piezoceramic rings (PZT-4) and 4 shows the heating plate part. The dimensions were marked for each part. All parts were drawn in mm. The part 1 diameter is 26mm respectively. The small screws were used to fix the heating element parts in figure 19. The gap in heating element is for inserting a wire which transfers heat to the device. A long screw is fixed in the middle to get fixed of all parts in a vibropad device. Each part was hatched differently to show the difference between them. The 2d diagram was drawn using Solidworks 2017 software. Each part has been made in respective materials of stainless steel, aluminium, piezoceramic rings and screws are made of stainless steel.

The 2d diagram was drawn using Solidworks 2017 software. Each part has been made in respective materials of stainless steel, aluminium, piezoceramic rings and screws are made of stainless steel. The dimensions for designing the vibropad device is shown in figure 20 as follows,

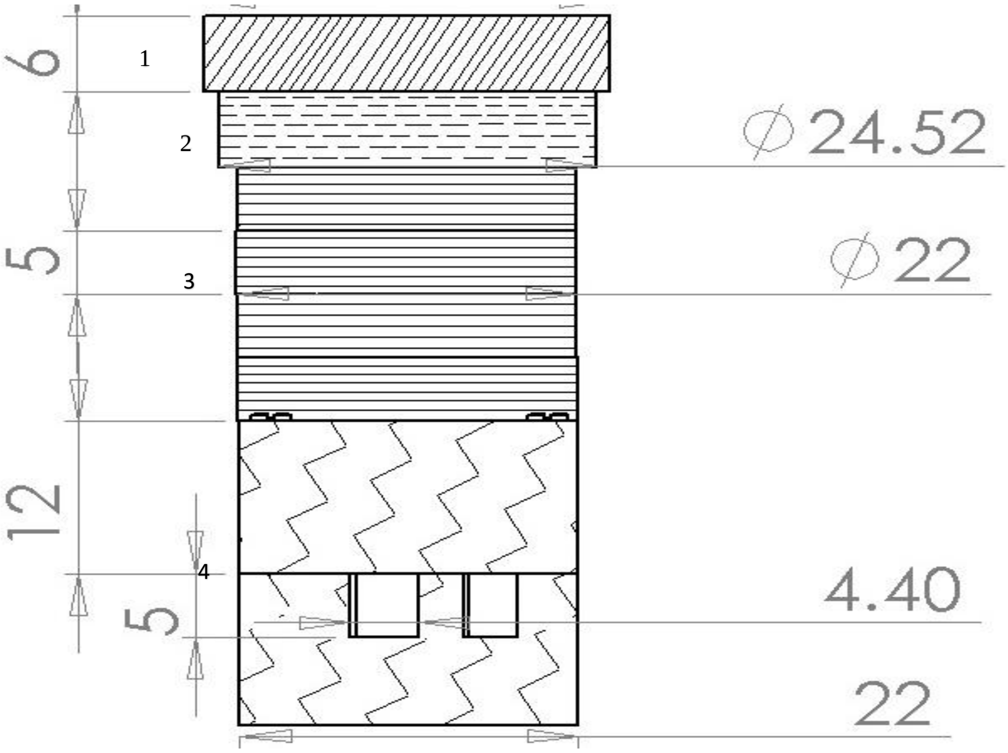


Figure 20. The dimensions of Vibropad device. (in mm)

5 Simulation of Vibropad

The vibropad operated on the basis of multilayer actuator in the centre and aluminium frame of construction. The aluminium frame is used to increase the operating area, protect the pad against the mechanical load and possibilities of actuator damage.

The vibropad is developed and fabricated for thermal imprint process technique. Vibropad has been changing its design from previous research studies. The vibropad device model is different from previous studies. The quality of the replica is increased, the main change from the previous studies is the heating element is attached to the vibropad it will at the bottom of the device. The working principle is same from previous studies but the working process is changed. The vibropad device model is designed using Solidworks software.

The Vibropad operated based on the inverse piezoelectric effect. The Inverse piezoelectric is defined as “converting AC voltage to harmonic mechanical displacements”. The vibropad purpose is to stimulate the flowing of preheated polymer towards the master microstructure to produce and increase the replication quality.

The task or objective of the vibropad device is to generate uniform vibration displacements at every point of the bottom operating surface.

The vibration displacement should be uniformly distributed to replication otherwise the quality of the replication will be poor. 1 represents polymer and 2 represents the vibropad device. The first vibration mode at first, second vibration mode and at last vibration mode equally transmitted between surface polymer. The Figure 21 explains the uniform vibration in contact between the vibropad and polymer.

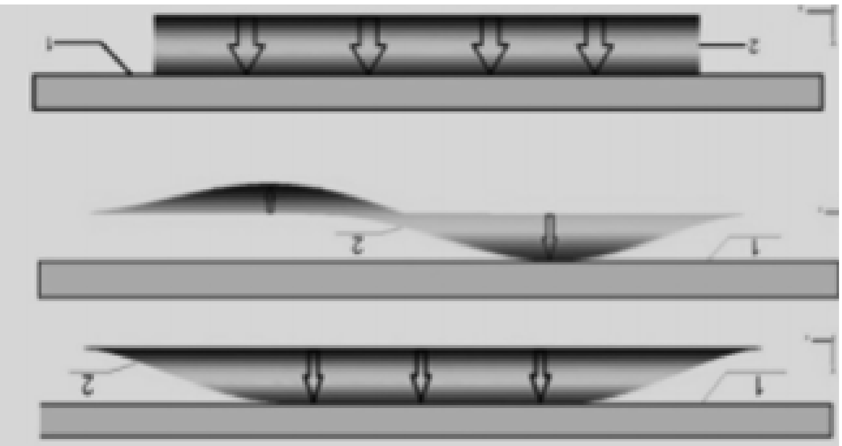


Figure 21. contact pattern between vibropad and polymer.

The operating surface with full contact with the polymer is used in the process for better quality. The vibropad device has a heating element at the bottom when the polymer is placed below it and the heating wire is inserted into the gaps of the heating material. Then, the piezoceramic ring (PZT-4) will vibrate at high-frequency excitation. Due to High stress in it, the replication of the master microstructure is done.

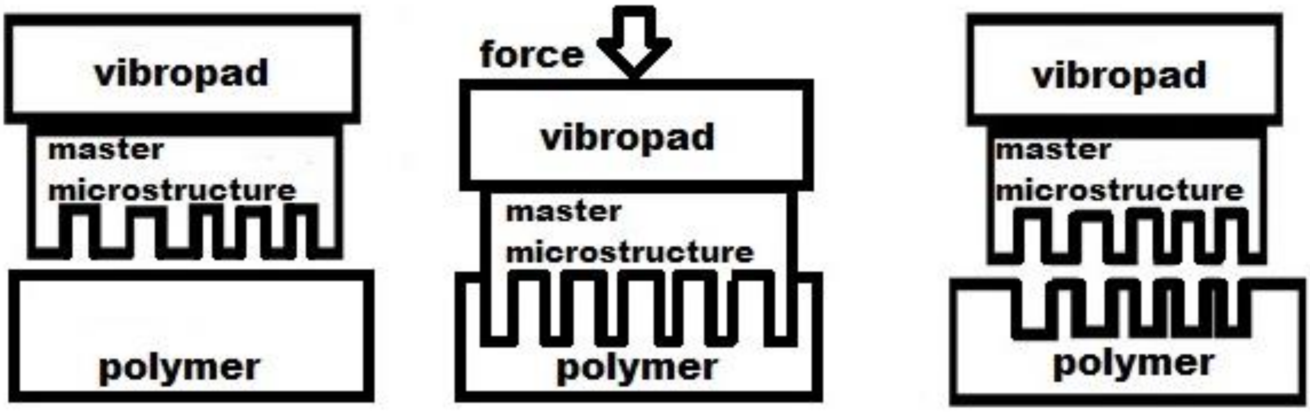


Figure 22. The process of replication using master microstructure in high-frequency excitation.

The operating process in the system required to generate the operating deflection shape. They were done after the unstressed and pre-stressed devices of frequency response analysis. The pre-stressed device allows in a system as follows: The device is analysed to determine displacement in corresponding to the applied thermal imprint stress statically. The pre-stressed device frequency analysis is performed. The Comsol Multiphysics software is used to determine FEA (Finite Element Analysis). To verify the model and uniform displacement vibrations, the fabrication and experimental analysis are carried out.

The geometry of devices was designed correspondingly,

- The outer diameter of the PZT-4 ring is 22mm. The outer diameter of the device design should be corresponding to the rings because deflection of shapes can be avoided.
- The other two top parts were 26 and 24 mm of the outer diameter. The deflection of a shape or damage to shape of its design is avoided because of its parts.
- The heating element was made into two parts with small rectangle hole in the middle of the right face of its design. It will be in the bottom part. The dimensions were in figure 14 for heating element part.

The geometry of the device and its material should be selected in the conditions which can withstand in its application. The device should withstand the 600 KPa of pressure and it will transfer the vibrations to the polycarbonate. The design of the Vibropad contains 4 piezoceramic rings in-between the two stainless parts at the top of it and Heating material at the bottom which are fastened by a bolt. The heating material itself screwed into 4 screws to attach two halves'.

From the previous studies, the design has been changed. The previous research study has a prototype, the Vibroactive pad contains PZT-5 in-between the two stainless parts and another Vibroactive pad contains PZT-4 in between the two stainless parts.

The parts were increased in this newly designed model to avoid the deflection in shape of the device. They will transfer the vibrations to the ceramic rings.

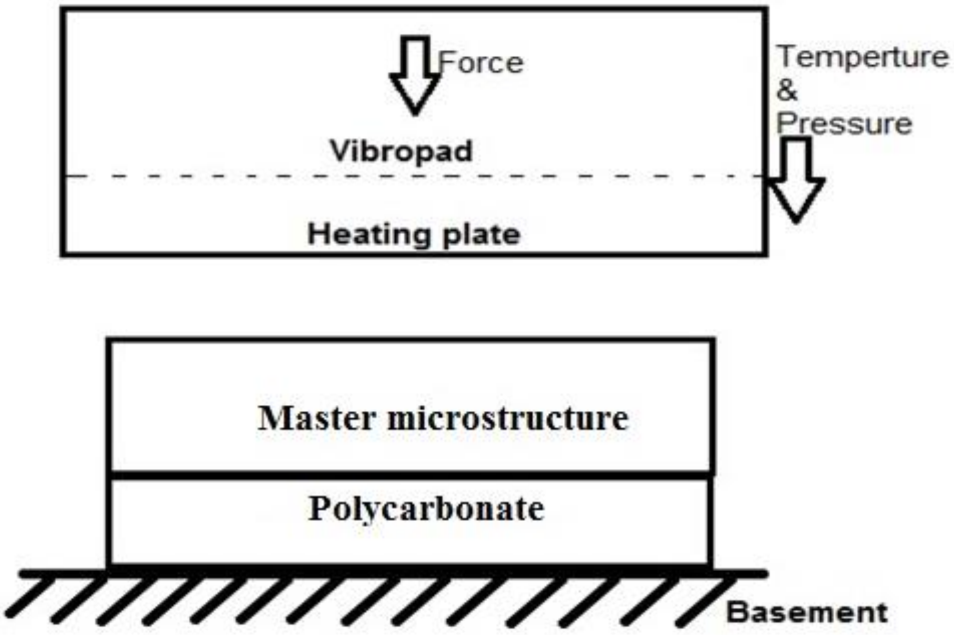


Figure 23. The replication process by high-frequency excitation using vibropad.

The simulation of the vibropad device is explained in a simple way by above figure 19. Due to force is given to the vibropad device, it will undergo stress and it gives high-frequency excitation and Piezoceramic rings give vibrations. Due to uniform displacement vibrations by high-frequency excitation and the heating element in the vibropad device will make high-quality replication of master microstructure in a polymer. It will take few minutes to produce high-quality replication of master microstructure using this method.

The application of several piezo- ceramic rings resulted in multilayer effects. The multilayer effects mean the layers causes high amplitudes. The velocity of pre-heated polymer flow will be increasing by higher force and amplitude. It will lead to high-quality replication of microstructure.

The development from the previous Vibroactive pad were as follows,

- The heating plate was designed along with the vibropad pad device which was externally supplied in existing device.
- The vibropad will vibrate in contact with master microstructure and polycarbonate in the bottom of the device but previously it is used to vibrate in contact at the top. It makes the process easier than before.
- The vibropad replication equipment uses the hydraulic function before but it uses pressure function, which is used to give pressure and compression by rotating the steering and fixing the device in the equipment.

The vibropad device is a better alternative to the existing Vibroactive pad device.

The cross section view of the vibropad device is shown in figure 24 as follows,

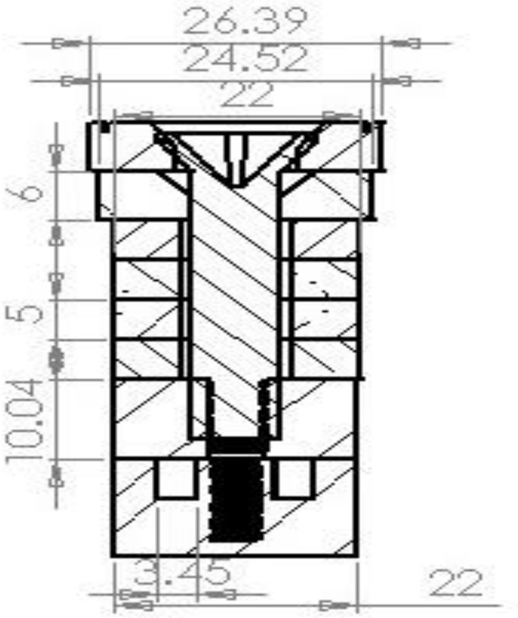


Figure 24. The cross-section view of Vibropad device. (in mm)

The Vibropad device design; it contains two steel parts and four PZT-4 rings (outer diameter – 22 mm, inner diameter – 10 mm, and height – 5 mm). The device is tightened with a bolt.

The application of several piezo-ceramic rings results in a multilayer effect, i.e. the superposition of layers causes higher amplitudes. The higher amplitude and force increase the velocity of pre-heated polymer flow which leads to increased replicability (Goldfarb and Celanovic 1997).

5.1 Finite Element Analysis:

The model will be presented in Finite Element Analysis (FEA). The aim of the numerical frequency analysis is to find the frequency at an operating surface of Vibropad. It will vibrate with uniform vibratory displacement at every point of the operating surface.

To calculate the damping of devices, the logarithmic decrement method is used. The bump test and transient ratio were done by determining the damping ratio of a vibropad device. The logarithmic decrement formula for calculating as follows,

$$\delta = \frac{1}{n} \ln(x(t)|x(t + nT) \tag{1}$$

Where, x(t) – amplitude at time (t), x (t + nT) – amplitude at time and n – periods.

The damping ratio will be calculated by using formula as follows,

$$\zeta = \left(\delta \middle| \sqrt{(2\pi)^2} + \delta^2\right) \tag{2}$$

To find higher precision, damping ratio and logarithmic decrement were calculated for various periods; n=1, 5, 10, 15, 20. At last, the results were averaged at table

Device	Average logarithmic decrement	Average damping ratio
Vibropad device	0.38	0.06

Table 1. The logarithmic decrement and damping ratio of the device.

Material	Mass density ρ / Mgm^{-3}	Young's Modulus E / GNm^{-2}	Poisson Ratio ν	Expansion coefficientK^{-1}
Stainless steel	7.5-7.7	$190 - 200$	0.30	$11 * 10^{-6}$
PZT-4	7.7	$7.8 * 10^{10}$	0.31	$4 * 10^{-6}$

Table 2. The properties of materials

Vibropad device described with following parameters: The Vibropad device height h_{con}- 56.05 mm; the piezoceramic rings (PZT-4) height h_{piezo}- 20mm and the diameter of the vibropad device at top- 26.39 diameter; the vibropad device bottom is a heating element which is a box in shape.

In piezoceramic rings (PZT-4), actuation voltage supplied between from top and bottom varies from 5 to 100 V. The material used for other parts are stainless steel. The PZT-4 is used for the metallic part of Vibropad. and the piezoceramic material.

The assumptions which were made for modelling vibropad as follows,

- The top two parts and heating elements were made of stainless steel material and the bolt is made of high tensile steel 4340. Considering as a single element in modelling.
- Instead of using 4 PZT-4 rings(20mm) single PZT-4 rings(20mm) will be used.

2D images of unstressed devices with their corresponding boundary conditions are in Figure 25 as follows,

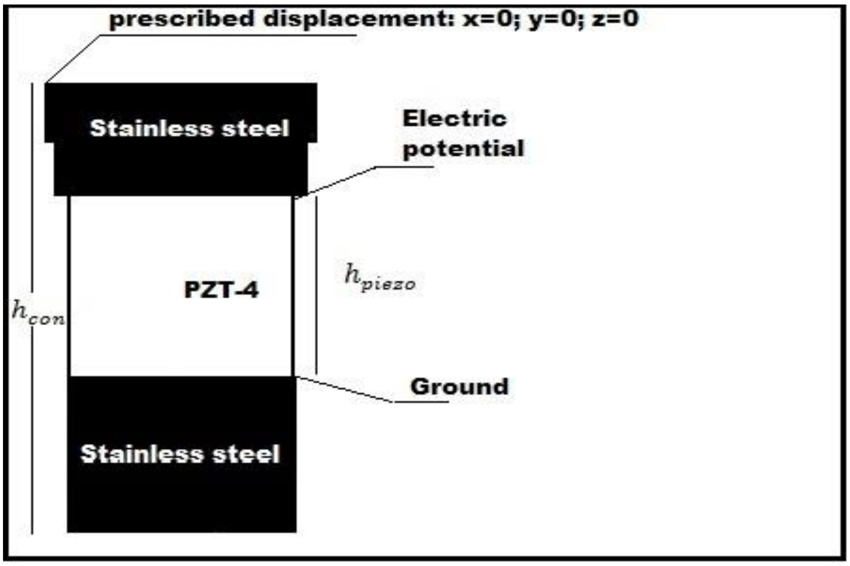


Figure 25. Boundary conditions of unstressed Vibropad.

5.1.1 Constitute equations

The material parameters of piezoelectric of devices were selected as stress charge in the equation. The material parameters for the PZT-4 are used in elasticity matrix- c_e, the coupling matrix – e, and relative permittivity matrix- ε_{rs}. The piezoceramic elements polarisation is considered in the y direction.

The elasticity matrix was characterized by the stress applied to its material and strain response. The relationship of stress- strain throughout the elasticity matrix is expressed as,

$$\sigma = c_e \varepsilon, \tag{3}$$

In this equation, it represents: σ- stress, ε- strain and c_e- elasticity matrix.

The elasticity matrix for PZT-4 follows,

$$c_e = \begin{bmatrix} 1.38996e11 & 7.51791e10 & 7.5001e10 & 0 & 0 & 0 \\ 7.51791e10 & 1.20346e10 & 7.50901e10 & 0 & 0 & 0 \\ 7.50901e10 & 7.50901e10 & 1.10867e11 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2.10526e10 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.10526e10 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.25734e10 \end{bmatrix}$$

The coupling matrix: e represents piezo-coupling matrix which is applied in stress- charge relationship,

$$\sigma = c_e \varepsilon - e^T E,` \tag{4}$$

In this equation: σ- stress, ε- strain and E- electric field.

The coupling matrix for PZT-4 as follows,

$$e = \begin{bmatrix} 0 & 0 & 0 & 0 & 12.7179 & 0 \\ 0 & 0 & 0 & 12.7179 & 0 & 0 \\ -5.20279 & -5.2027 & 15.0804 & 0 & 0 & 0 \end{bmatrix}$$

The relative permittivity matrix: ε_{rS} is applied in constitutive relation of stress and strain-charge forms,

$$D = e\varepsilon + \varepsilon_0 \varepsilon_{rS} E\ , \tag{5}$$

The relativity permittivity matrix of PZT-4 as follows,

$$\varepsilon_{rS} = \begin{vmatrix} 762.5 & 0 & 0 \\ 0 & 919.1 & 0 \\ 0 & 0 & 663.2 \end{vmatrix}$$

The FEA is verified by comparing simulation and experimentation of obtained frequencies. Firstly, the numerical frequency response curves of the centre in the y-direction and four edges points are in unstressed devices were obtained.

The piezoelectric equations were written in the form of nodal displacement $\{U\}$ and nodal electrical potential $\{\phi\}$. For the Unstressed device, force F is equal to zero and nodal electric loads were expressed as $\{Q\}$:

$$\begin{bmatrix} [M_{UU}] & 0 \\ 0 & 0 \end{bmatrix} \left\{ \{\ddot{U}\} \middle| \{\ddot{\phi}\} \right\} + \begin{bmatrix} [C_{UU}] & 0 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} [K_{UU}] & [K_{U\phi}] \\ [K_{U\phi}] & [K_{\phi\phi}] \end{bmatrix} \begin{Bmatrix} U \\ \phi \end{Bmatrix} = \begin{Bmatrix} \{0\} \\ \{Q\} \end{Bmatrix} \tag{6}$$

$$[K_{UU}] = \iiint_{\Omega e} [B_U]^T [C][B_U] dV,$$

$$\left[K_{U\phi}\right] = \iiint_{\Omega e}[B_U]^T[e][B_U]dV,$$

$$\left[K_{\phi\phi}\right] = \iiint_{\Omega e}[B_\phi]^T[\varepsilon]\left[B_\phi\right]dV,$$

$$[M_{UU}] = \rho\iiint_{\Omega e}[N_U]^T[N_U]dV,$$

$$[C_{UU}] = \beta[K_{UU}]$$

In the above equations, it indicates $[K_{UU}]$- mechanical stiffness matrix, $\left[K_{U\phi}\right]$- piezoelectric coupling matrix, $\left[K_{\phi\phi}\right]$-dielectric stiffness matrix, ρ- piezoelectric density, $[N_U]$-matrix of elemental shape functions, $[C_{UU}]$- mechanical damping matrix, $[B_U]$ and $[B_\phi]$- derivatives of Finite element shape functions, [c]- elastic coefficients, [e]- piezoelectric coefficients, $[\varepsilon]$-dielectric coefficient, β-damping coefficient.

The vibropad is excited with harmonic voltage signal and electric potential follows,

$$Q = A\sin\omega, \tag{7}$$

In this equation: A- amplitude and ω- angular frequency- x.

The vibropad of simulated dynamic behaviour, to obtain vibration responses, the unstressed device is solved by frequency response problem:

$$\begin{bmatrix} K_{UU} - \varpi M_{UU} - \varpi^2 M_{UU} & K_{U\phi} \\ K_{\phi U} & K_{\phi\phi} \end{bmatrix} \begin{Bmatrix} \{U\} \\ \{\phi\} \end{Bmatrix} = \begin{Bmatrix} \{0\} \\ \{\phi\} \end{Bmatrix} \tag{8}$$

Validation of FE model

The analysis of unstressed Vibropad,

The finite element analysis is verified by simulated obtained operating frequencies. The centre is numerical frequency response curves y -directional and four points at the edges of the unstressed Vibropad device is obtained.

The numerical frequency curves were marked as points in the device and the displacement field was given. The FE of unstressed device focus is to determine the coincidence of frequency at which frequency response curves. The coincide peaks shows the ODS with uniform displacement vibrations throughout the surface at the analysed points.

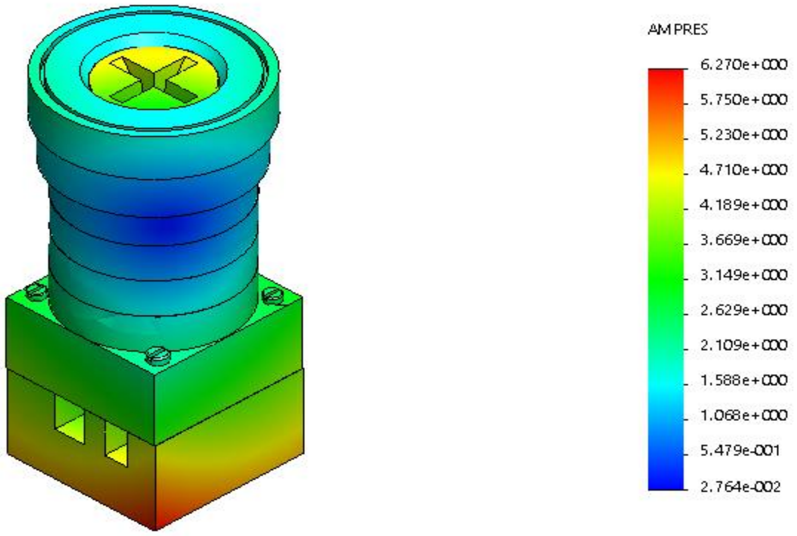
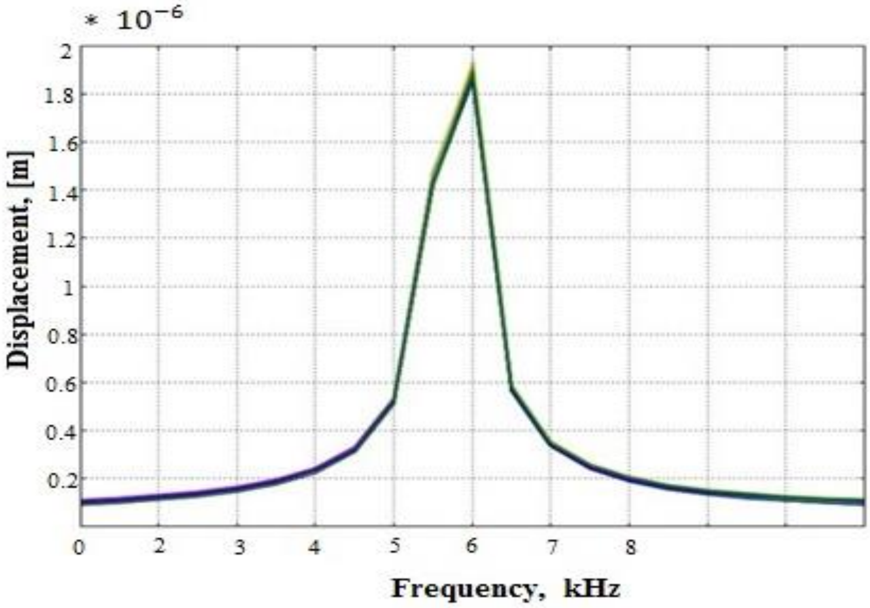


Figure 26. The frequency analysis using solid work.

The frequency analysis of unstressed Vibropad device is done using solid works software. The assembled parts of Vibropad has used to analysis the frequency by a simulation study. In the study, the frequency is selected. The materials for parts were applied respectively. The meshing is done for the device. The meshing is done finer using standard mesh. The total number of nodes in meshing applied were 77377 and the total number of elements were 45205. After the meshing for the device is achieved, the simulation study will be done. The simulation study shows various amplitudes and frequency ranges of Vibropad device. The frequency range gradually increases from the lower to higher.



Graph 2. Numerical frequency curves analysis of the unstressed Vibropad device.

The frequency response in above graph shows that the vibropad device vibrates with uniform amplitude throughout the operating surface at the excitation frequency of 6kHz. The peak of the frequency occurs at 6000 $\mathrm{H}z$. The peak of frequency occurs at a displacement of $2 * 10^{-6}\,m$. The peak of frequency response curves coincides at this displacement and frequency. At this place, Due to high excitation of force, the uniform vibratory displacement at every point of the surface occurs. It gives a better quality of replication of master microstructure.

Theoretically, to know the uniform vibratory displacement at every point of the top operating surface. The uniform vibratory makes the better replica according to the studies. The graph represents the “Numerically simulated frequency response curves”. The graph is drawn frequency in x-axis vs y-axis displacement.

The focus of the graph is to detect the frequency to know at which the peaks of the frequency response curves coincide. The mutual peaks of the Operation Deflection Shape (ODS) in the graph shows the uniform displacement throughout the analysis.

By seeing the results of the graph, the device gives uniform vibratory displacement at every point of the top operating surface, which satisfies the result. The quality of the replica is increased due to it and high-frequency excitation occurs at in graph makes the uniform displacement vibrations. The high frequency excitation occurs at 6Khz of frequency a $2*10^{-6}$m of displcaement of frequency. This is achieved through using the comsol multiphysics software 4.4. The exsising vibropad device use to have high frequency exciation a 7Khz. Therefore, the frequency remains to be equal in both process so newly designed vibropad device will be a better alternative to the exsisting vibroactivepad.

5.2 Experimental frequency response analysis of device

With self- made setup, experimental frequency response analysis of pre-stressed device is analysed. It contains a dynamometer, Vibropad device, Laser doppler vibrometer and a clamp. The clam is pre-stressed the device according to the conditions of thermal imprint technique. The universal dynamometer with attached tension sensor which is used to measure pressure. The pre-stressed devices of vibration response are registered with laser doppler vibrometer. The experiment of pre-stressed is done after the analysis using simulation software’s and Finite element analysis to check the outputs are same. They also mean to check the output are positive that the device can produce the replication of master microstructure. The experimental frequency response analysis is done to achieve the output experimentally to know whether the theoretical results is same in experimental too.

The figure 27 shows the experimental setup of pre-stressed device as follows,

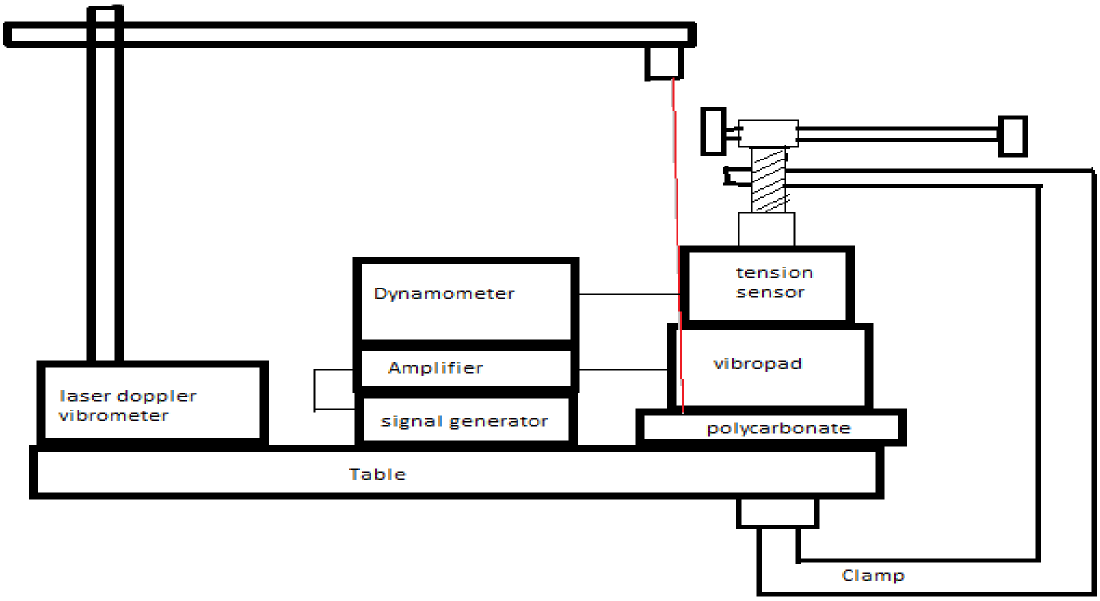


Figure 27. The setup for frequency response analysis of pre-stressed vibropad.

The frequency response of pre-stressed device was analysed. At 0.5 and 1 cm from the midpoint. The clamp, the polycarbonate, dynamometer was covered with midpoints.

6 Fabricated Vibropad

The fabrication of Vibropad device is done according to the dimensions. The vibropad device each part has respective material. The fabrication is according to the design drawn in Solidworks 2017 software. The ceramic rings and other parts are slightly varying in measurement but they are round. The last part heating plate part is complicated in design, it must be fabricated carefully. The heating part is fabricated according to design into two parts. Hence, they were assembled using four screws. The fabricated heating parts and the prototype of vibropad device is shown in figure 28, 29 and 30 below,

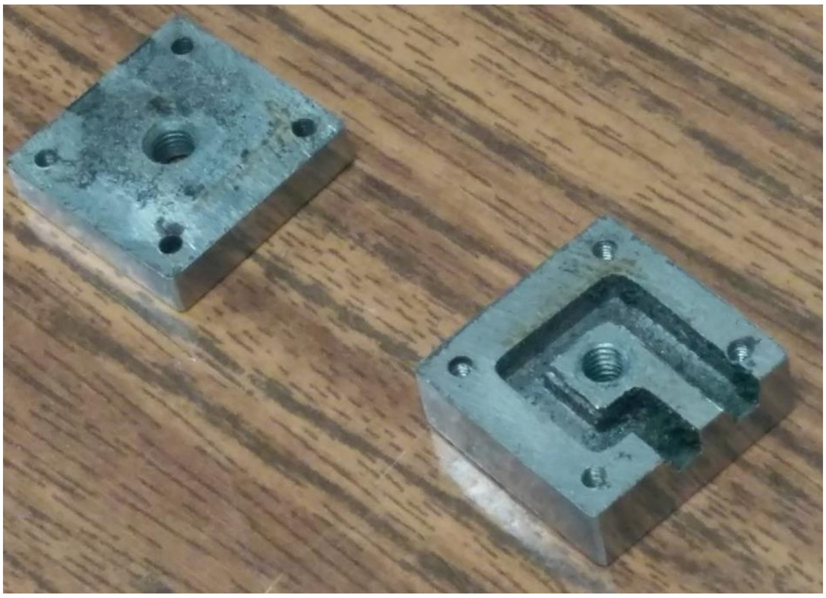


Figure 28. The heating plate fabricated parts of Vibropad device.

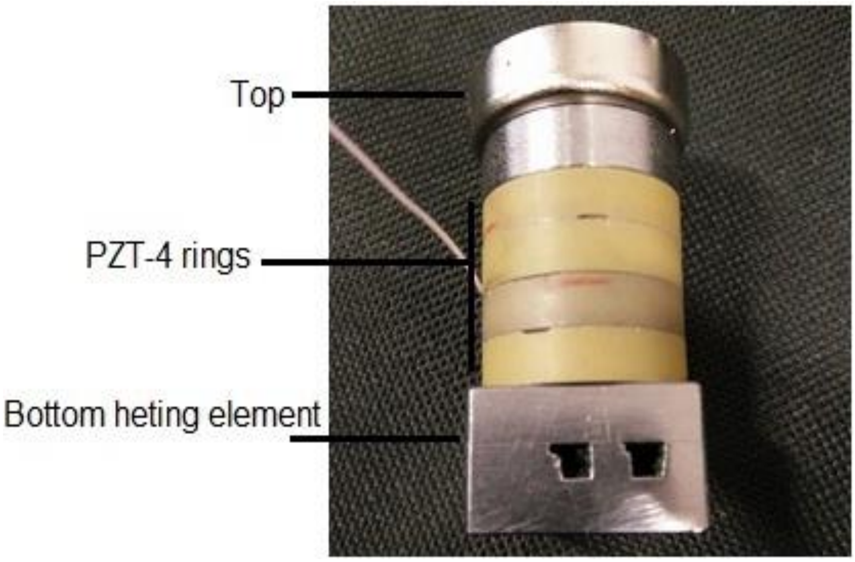


Figure 29. The Vibropad device fabricated prototype.

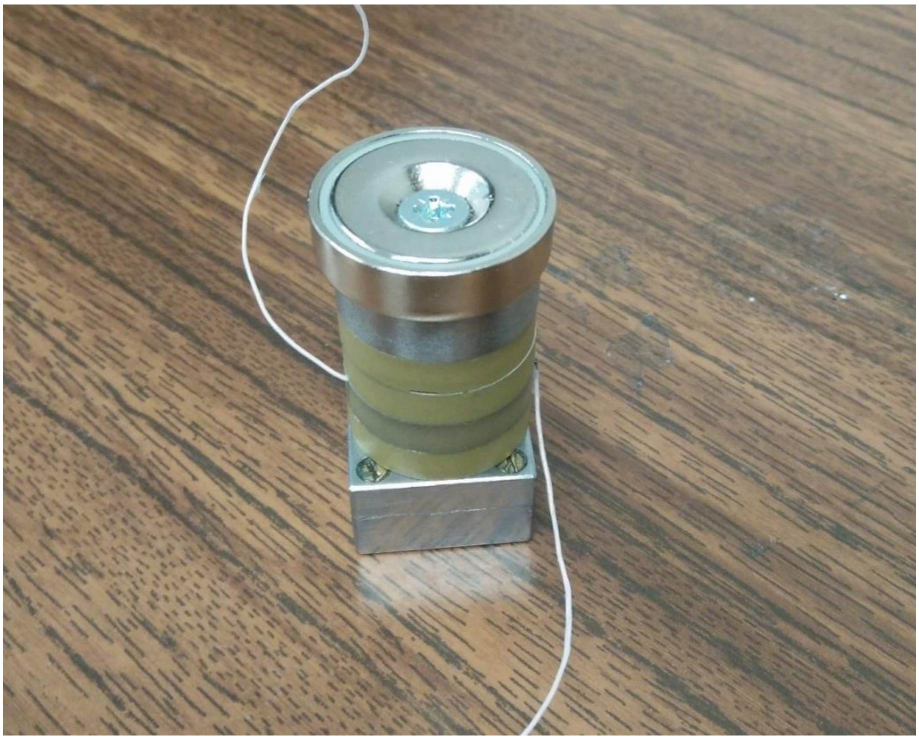


Figure 30. Another view of fabricated Vibropad device prototype.

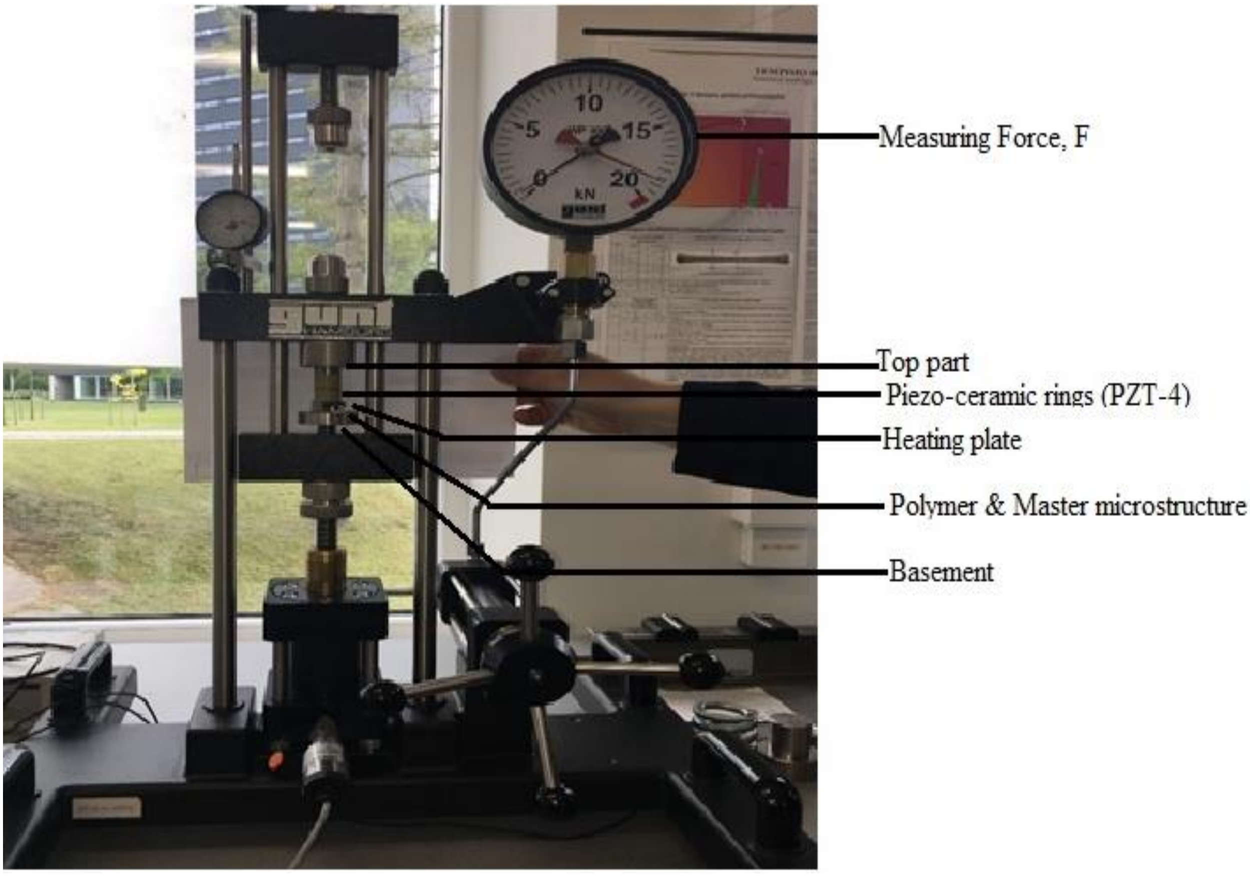


Figure 31. The replication of master microstructure experiment using vibropad.

The replication of periodical microstructures is experimented using vibropad. The vibropad is placed in the middle of the equipment which will compression to the device since it is tightened strongly. The compression is given by rotating the steering. The pressure given is indicated above. The process of vibropad is done as said before. The compression on the device delivers tension, frequency due to vibrations of high excitation of piezo ceramics and heating temperature of heating plate in device together gives the replication. The heating plates makes the polycarbonate to melt slightly to make the replica of master microstructure. The wire at heating plate is for delivering the heat to the device. The polycarbonate will be a plastic material. The experiment gives the replication of maser microstructure. The polymer and master microstructure is placed below the vibropad device. The figure 31 shows above the equipment of replication process and the figure 32 shows the vibropad device placed in replication equipment as follows,

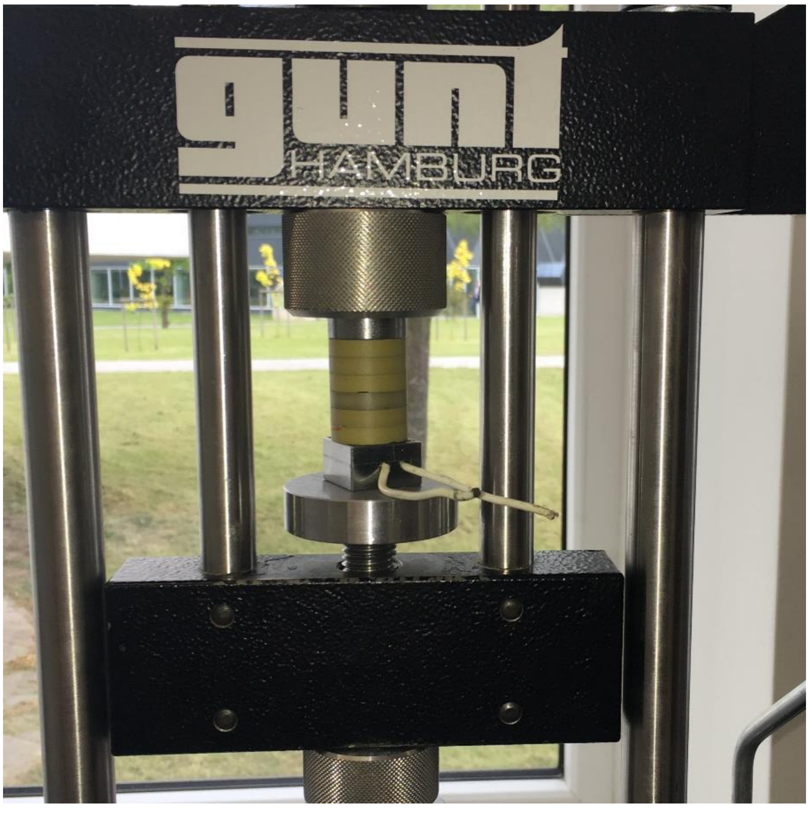


Figure 32. Vibropad device in replication equipment.

7 Conclusion

The vibropad device is developed from the existing Vibroactive pad. The results were analysed for the Vibropad device. The developments were done in design mostly. The frequency of the device is analysed using software. The results are concluded as follows,

1. The design of Vibropad is achieved using the 3D Cad Solidworks software. The dimensions were done according to the design and the dimensions were drawn in mm. The Vibropad device design; it contains two steel parts diameters- 26mm and 24 mm), four PZT-4 rings (outer diameter – 22 mm, inner diameter – 10 mm, and height – 20 mm) and heating plate. The device is tightened with a bolt.
2. Using Comsol Multiphysics software and Finite Element Analysis the frequency and displacement were determined theoretically and using software by using the simulation process. The frequency peak occurred at 6000 Hz and the frequency at displacement is $2*10^{-6}$m. The results show that Vibropad device is an alternative to the existing Vibroactive device. Even the design provides strength to its shape since there is no deflection of shape during the vibrations
3. The fabrication of newly designed Vibropad device is achieved. The Vibropad device is ready for replication of master microstructure process experimentally in KTU material science laboratory, KTU Mechanical Engineering & Design Faculty.

Therefore, the Vibropad device is an alternative model to the existing Vibroactive device. It will make the replication process easier than existing.

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