POLITECNICO DI MILANO

School of Industrial and Information Engineering
Master of Science in Mechanical Engineering

Design and development of an innovative auto-adaptable Gripper in automated rework process

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Abstract

The aim of this thesis is to design an innovative auto-adaptable gripper for the rework of electronic boards in order to simplify the process and make it more flexible and more efficient. The idea was to create an air-vacuum gripper with the ability of gripping rectangular components by a vacuum mechanism and the ability of covering the component perimeter perfectly for the refinishing operation or repair of an electronic printed circuit board assembly, usually involving desoldering and re-soldering of surface-mounted electronic components. The main feature of this design is its reliability and efficiency while maintaining simplicity.

Glossary

As is characteristic of any upwardly mobile technology, its practitioners are continuously coining new technical terms and abbreviations, which are given a more or less agreed meaning. It will be useful to provide a necessarily limited list of them at this point.

ASIC	Application-specific integrated circuit.
ASTM	American Society for Testing and Materials.
BGA	Ball Grid Array: a plastic or ceramic body containing an IC, with its IOs, in the form of solders bumps, located on its underside.
CC	Chip-Carrier: a square-bodied, plastic or ceramic SMD, with an IC inside.
Chip	The term 'chip' has acquired several meanings, among them the following: an IC on a ceramic substrate; an SMD which contains an IC; a resistor or ceramic capacitor, encased in a rectangular ceramic body. Unless expressly stated, the term 'Chip' will always have this last meaning in this book.
COB	Chip-on-board; a bare chip, glued to a board and connected to its circuitry by wire bonding.
CSP	Chip-Size package: an SMD with a plastic or ceramic body which is not much larger than the chip which it contains.
DIL	'Dual-In-Line': a through-mounted device (TMD) containing an integrated circuit with two parallel lines of legs.

FC	Flip chip: a bare chip with solder-bumps on its underside. Like a BGA, it can be reflow soldered directly to a circuit Board.
Flux	A chemically and physically active compound that, when heated, promotes the wetting of a base metal surface by molten solder by removing minor surface oxidation and other surface films and by protecting the surfaces from re-oxidation during a soldering operation.
IC	Integrated Circuit: an electronic circuit carried on the surface of a silicon wafer.
I/O, IO	In/Out: the solderable connectors or leads of an SMD
MCM	Multi-Chip Module: an array of interconnected ICs, Mounted on a common substrate, such as a multilayer PCB, or a silicon or ceramic or glass wafer, to be soldered to a circuit board.
Melf	A ‘metal electrode face-bonded’ component: a resistor or a diode, encased in a cylindrical ceramic body with metallized solderable ends.
PCB	Printed Circuit Board.
PLCC	Plastic Leaded Chip Carrier: a CC with a body made of plastic, with J-shaped legs on all four sides.
QFP	Quad Flat Pack: a plastic body containing an IC, with gull- wing legs on all four sides.
SMD	A Surface-Mounted Device.
SO	‘Small Outline’: an SMD, with a plastic body, carrying gull wing legs on opposite sides.
SOIC	An SO, with an IC (usually with a 1.25mm/50 mil pitch).
SOT	An SO transistor.
TMD	Through-Mounted Device: a component with connecting wires or legs, which are inserted into the through-plated holes of a circuit board.
TH	Through Hole.
THT	Through-Hole Technology.
VSOIC	‘Very small outline’: a fine-pitch SOIC.

Contents

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of figures

List of tables

Chapter 1

Rework process

1.1 Introduction

In electronic manufacturing, rework is defined as an activity which replaces defective components with those which are acceptable such that the populated board performs to specification. Some of the fabricated products in manufacturing processes can be defective due to an unstable production environment, non-perfect technology or human mistakes [1]. Rework of PCBAs is not only required to eliminate general process errors but also to produce upgrades or revisions, and engineering change orders. Since the advent of printed circuit board assembly (PCBA) that began with the assembly of through-hole (TH) components, rework of PCBAs has been necessary. Increasing product complexity has made rework and repair more difficult and the low-cost reworking of PCBAs is one of the main issue of PCB manufacturers.

Printed circuit board assembly (PCBA) rework is an acceptable process step in PCBA manufacturing and widely performed using manual and semi-automated tools. Although PCBA has been substantially improved with fully automated, accurate assembly machines and the use of robots, unfortunately, there has not been a significant improvement in rework equipment because the forecasted cost of this equipment has made it impossible to justify a fully automated rework cell. Manufacturers of rework machines, equipment suppliers and researchers have tended to put most of their efforts into designing more efficient and effective manual rework equipment; others have carried out research to improve manual rework efficiency by using advanced techniques and methods (Camurati et al. 1989, Carrol 1991, Driels and Klegka, 1991, Strong 1992). Consequently, rework tasks are being carried out mainly by skilled operators, with the help of various disassembly and assembly tools.

Manual rework often introduces problems such as, good joints are repaired because of inadequate inspecting, good components are damaged while repair of the other components takes place, long rework cycle times and talented rework personnel cannot always be recruited. Most important, however, is that as the component size on boards becomes smaller, the lack of process control and the operator dependency of the tools. The use of an automated rework cell provides advantage of lower rework cost, less scarp rate and consistent rework quality. Robot applications in PCBA are increasing rapidly due to the need for small batches and quick change over. Consequently, the increasing use of robots and vision systems resulting from high accuracy and flexibility requirements have made them more acceptable, and the gradual reduction in their cost makes their use more feasible. With the robot’s multi-functional ability, it is suggested that a well-designed cell could be economically deployed for the assembly, inspection and rework of defective components.

At present, robotic assembly cells are not often utilized continuously, and it would be possible to use the cell for rework as well. Even if a cell were being fully utilized, reducing production to carry out rework would be cost-effective because of the high cost of rework.

Furthermore, since the PCBAs being repaired would probably have been assembled by the same cell, cost and technical problems associated with component and PCBA feeding, jigs, sensory requirements, grippers, etc., would not usually occur and information about the layout of the board already stored by the cell controller could also be available to the rework system [2], [3].

1.2 Electronic component technology

There are two type of methodology of attaching the components onto the PCBs: Through-hole and Surface-mount technology.

1.2.1 Through-hole technology

Also called "**thru-hole**", refers to the mounting the electronic components which have leads are inserted into holes drilled in printed circuit boards (PCB). In this technology, components are placed on one side of the PCB and soldered on the opposite side either by manual assembly or by the use of automated grid insertion mount machines. Through-hole components are into the categories of axial, radial and multiple lead components such as dual in-line (DIL), pin gray array (PGA) and sockets. There are also other types of components (Fig. 1.1) such as electrolytic capacitors or transformers, connectors and various passive devices as well as high power semiconductors in larger packages such as the TO220 and O201 SESD devices [4].

Despite the development of surface mount devices, the TH components are still being widely used in printed circuit board assembly whenever miniaturization is not essential [5], [6].

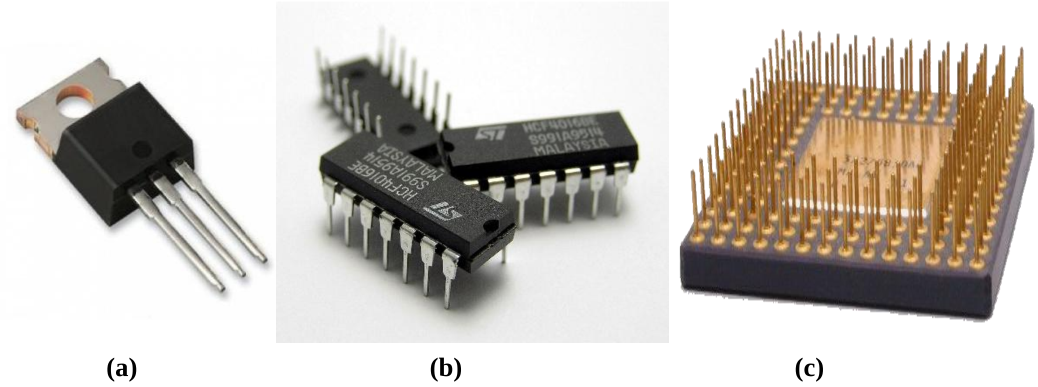


Figure 1.1. Some types of TH component: (a) TO220, (b) DIL, (c) PGA

1.2.2 Surface-mount technology

SMT is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit boards (PCBs). Surface mounting has become widely used in industry in the 1980s. The most obvious benefits of Surface Mount Technology (SMT) compared to older through-hole (TH) technology is increased circuit density and improved electrical performance and space saving due to being able to mount components on both sides of the printed board. Space savings depend on the type of product and the ratio of SMT to through-hole components. With SMT more complex circuit design are possible. Less obvious benefits include reduced process costs, higher product quality, reduced handling costs, and higher reliability, eliminates the needs for drilling, reduced component size [7].

The surface mount technology is unsuitable for large, high-power, or high-voltage parts, for example in power circuitry, also is unsuitable for components that are subject to frequent mechanical stress such as sockets. SMDs cannot be used directly with plug-in breadboards so requiring either a custom PCB for every prototype. Manual assembly or repair of SMD's is difficult.

1.3 Rework process

In our imperfect world, zero-fault soldering does not exist. Soldering faults will occur, and because even one single fault makes a board unusable, each of them must be corrected by rework or corrective soldering. Rework is the term for the refinishing operation or repair of an electronic printed circuit board (PCB) assembly, usually including desoldering and re-soldering of surface-mounted or through-hole electronic components. The function of the rework cell is to remove and replace individual defective components from PCB without damaging the board, the surrounding components, or the solder joints of the other components.

Regarding this fact that the piece cost of PCB increases and production quantities decrease, repair of defective boards through rework has become an important part of the production process. Rework has been traditionally carried out by a group of skilled operators, with the help of various disassembly and assembly aids.

Rework of electronics is due to:

- Poor solder joints due to faulty assembly or thermal cycling.
- Unwanted connection of bridges due to unfavorable solidifying of solder droplets that connect points that should be isolated from each other.
- Faulty components.
- Engineering parts changes, upgrades, etc.
- Expensive cost of total board replacement.

Depending on the type of product and its sale value, it may sometimes be cheaper to scrap a faulty circuit than to rework it.

To automatic rework, the detailed analysis of manual rework procedures, methods and tooling are necessary. Table 1 summarizes the general electronic component removal and replacement procedure for both types of electronic component technology [8], [9].

Table 1. General steps of component rework

SMD rework	TH rework
-Prepare assembly for rework -Identify faults - Flux the target area -Preheat the local target area below -Heat and remove the component -Clean pads to remove excessive solder -Dispense solder cream to the pads -Pick and Place the new component -Reflow solder paste	-Cut protruding legs of target component -Flux defective area -Preheat target area -Reflow by solder fountain -Remove defective item -Flux defective area -Resolder holes -Place new component

1.4 Equipment of rework

1.4.1 Heat sources

Almost every heat source which is applied in production soldering finds its use in rework: soldering irons in various forms, heated tweezers and thermodes, solderwaves in miniature form, infrared radiation, hot air or gas. With all of them, efficiency of the heat transfer (conduction, convection, or radiation) from source to joint is of the essence, together with precise temperature control [10]. Primary heating methods are those principally responsible for achieving solder reflow (as will be shown in section 1.5) during a component installation or removal process. These are to be distinguished from methods used for pre-heating and auxiliary heating.

In rework process, for both technologies, preheating is necessary to protect the PCB from heat shock. Pre-heating is required when there is a risk of localized heat shock in the substrate, components or both in order to help reduce delamination and to activate the flux.

The goal of preheating is to first ramp up the assembly and/or component at an acceptably safe rate until it reaches a target temperature at which the assembly (or component) is thermally soaked or evenly heated thereby eliminating dangerous temperature gradients which could produce immediate damage, degradation over time or reduction of reliability.

Pre-heating is typically accomplished from the bottom side of PCB assembly by either a temperature controlled conductive heating plate, a controlled convective heating device, or a system which combines both conductive and convective heating.

1.4.1.1 Primary heating methods in manual rework

Conductive Heating Methods

Handheld conductive heating devices generally place into one of the two following categories [11]: Continuously Heated Devices and Pulse Heated Devices, each with their own potential advantages.

Continuously Heated Device

Continuously heated devices such as soldering irons, thermal tweezers and thermal pick devices may be held at selected idle tip temperatures prior to use. Using a soldering iron for rework must have a well tinned tip, preferably with a drop of molten solder on it, to establish instant and good thermal contact with the joint. The size and the shape of the tip must suit the type and the configuration of the joint.

Pulse Heated Device

There exist different kind of devices for surface mount installation such as resistance tweezers which can be categorized as pulse heated devices. These type of tools would produce heat in their tips and work with low voltage and high current. They can be used also in removal, cup terminal soldering and auxiliary heating of connector pins during removal.

Some of the offered advantages by using pulsed heated devices:
- Effective at transferring a large amount of heat to a targeted area rapidly
- Low mass tips heat up and cool down rapidly
- Can control amount of heat delivery with power setting and dwell time

Convective heating methods

The other type of heating method is convective heating which is used in nozzle-focused hot air jet hand pieces, semi-automated bench top workstations and also high powered devices.

These devices are primarily used for SM component installation and removal and introduce the following advantages:
- The need of external flux or tinning can be avoided for thermal transfer.
- Can be used to effectively install and remove components whose solder joints are not directly accessible by conductive heating methods, e.g., BGAs (Ball Grid Arrays) and chip components with bottom only terminations.
- Non-contact process which, if used correctly, will not disturb joints or obstruct view.
- Slightly misaligned surface can be fixed and re-align with this method without necessity to remove it.
- In comparison with conductive heating method, leaves less solder and residue for surface mount component removal.
- It is possible to control the heat delivery amount by:

✓ Gas/Air temperature
✓ Gas/air flow rate
✓ Distance of nozzle from work
✓ Nozzle design-Dwell time

1.4.1.2 Reflow methods in automated rework

Studying of manual rework techniques and current developments in industrial assembly robots have indicated that the development of a successful fully automatic robotic network is very much dependent on the reflow techniques chosen for both SM and TH components. It was found that no existing reflow technique is completely suitable. Iris-focused, laser and hot gas are suitable for SMT, while, solder fountain is suitable for THT.

Iris-focused IR

This uses a halogen light bulb to develop short-wave IR light. The light is focused through lenses and the spot size of the heat source is adjusted through an iris ring for supplying the heat for desoldering and resoldering. The system requires four lenses where each of these cover a group of different-sized SM components, and there is continuous linear adjustment of the spot size for each lens. Lens changing could be carried out by a manipulator. The temperature of the heat source is much higher than the target temperature of the joint. For this reason, such systems demand precise dosage of the radiation input, and ideally a feedback from the joint temperature to the heatsource.

Blowing or disturbing nearby components is eliminated when using an IR heat source [12].

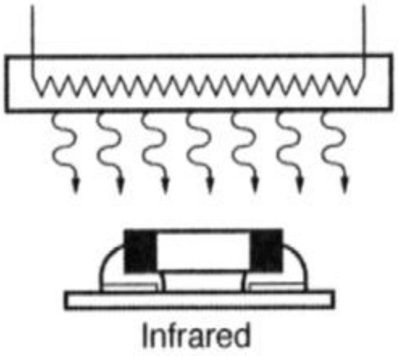


Figure 1.2. Conductive heating of an IR [13]

Laser

Laser beams focused on the joint of a multilead device, are another option for supplying the heat for desoldering and resoldering. By controlling laser variables such as beam power, focusing and plus rate, soldering or desoldering process can be done quickly with eliminate bridging and diffusion problem from pad to pad. Focusing system applies a tightly focused beam of energy to one joint at a time, stepping rapidly from joint to joint [14].

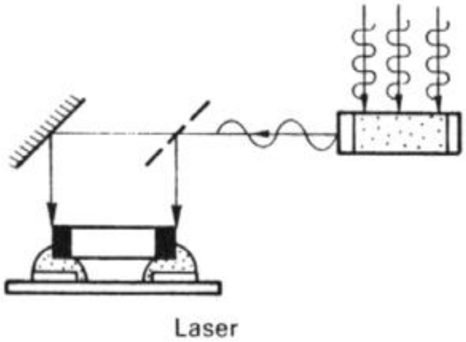


Figure 1.3. Laser reflow [13]

Hot air or gas

Being a convection method of heating, widely used for desoldering or resoldering SMDs with a hot air or gas jet of a controlled temperature. This method may take more time than other reflow technique because they transfer their heat to the joints by convection, which is much less efficient than conduction through molten solder or contact with beam so this must be taken into account when deciding on the reworking procedure. With hot air or gas soldering, a small spot of solder paste is preplaced into or near the joint. Hot air or gas device has equipment with interchangeable arrays of jet nozzles, which direct the hot air or gas towards the joints on all four sides of the SMD at the same time. With most hot-air desoldering machines, the board is preheated locally from underneath, for reasons mentioned in section 1.4.

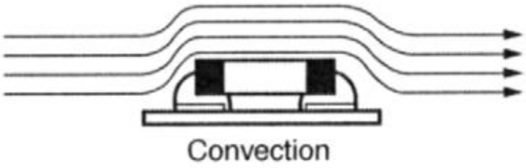


Figure 1.4. Reflow by hot gas [13]

Solder fountain

The machine is based on the wave soldering principle and incorporates a set of nozzles through which molten solder is pumped. The wave generated by this is in the shape of a fountain and is controlled by the pump speed and nozzle height and shape. The solder fountain operates for a period of determined dwell time and is the switch off by the cell controller. The design of nozzle arrangement provides constant solder. There are two different techniques generally used to generate a solder fountain. These are adjustable segmental nozzle [15] and replaced nozzle adjustable methods [16].

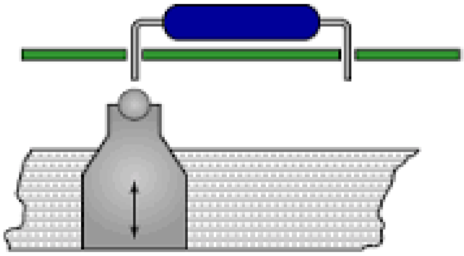


Figure 1.5. A solder fountain [17]

1.4.2 Rework cell

The workplace or work station is where the desoldering and resoldering of PCB components are carry out by necessary equipment and essential rework tools such as reflow tooling, underside heating, exchangeable devices, control devices, etc. Figure 1.6 illustrates the included hardware of the robotic rework cell.

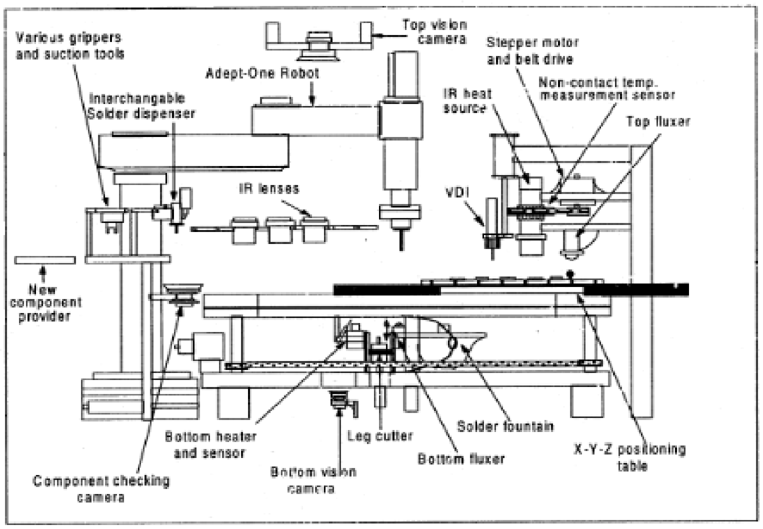


Figure 1.6. Illustration of the equipment in the automated rework cell [18]

1.5 Reflow soldering

The making of a good soldered joint needs the right amount of solder, flux and heat, in the right place, and at the right time. Reflow soldering of solder paste is the primary interconnection method used in SMT assembly process. Reflow soldering is a process in which a solder paste is used to temporarily attach one or several components to their pads. To begin with, solder and flux are placed on one or both joint surfaces, after which the entire assembly is subjected to controlled heat, which melts the solder, permanently connecting the joint.

The purpose of the reflow soldering is to melt the solder and heat the adjacent surfaces, without overheating and damaging the board and electrical components. The conventional reflow profiling [19] can be broken down into several phases, each having a distinct thermal profile: preheat, thermal soak, reflow, and cooling.

The reflow profile is determined by the type of solder paste in use, and is also influenced by the PCB thickness and component sizes being mounted.

Preheat phase preconditions the PCB assembly prior to actual reflow stage and reduces thermal shock of PCB assembly. This stage is used to bring the entire assembly (PCB, components solder paste/flux) up to temperature.

A temperature rise rate lower than 6 ºC/second should be used because higher rates may cause damage to the components being mounted on the board. This phase is often the longest of phases the ramp rate.

Thermal soak stage starts at the end of the preheat stage and allows the temperature across the surface of the board to achieve equilibrium at a level near the melting point of solder. In this phase the solder paste volatiles are removed. Thermal soak involves flux activation to remove surface oxides.

Reflow stage is where the mechanical/electrical connection is made through the formation of intermetallic and the solder changes from a solid to a liquid, and will flow in the areas where solder paste has been applied and solder mask is not present.

The temperature control in this stage is critical. If it is too low cold solder joints may form with a dull or grainy appearance, while if it is too high might damage the component, PCB charring.

Cool down is the final stage where the solder cools from the peak temperature to solidus. Fans are usually used to circulate cooler ambient air around the PCB. This phase determines the grain structure when solidified therefore a fast cooling rate is desired to create a fine grain structure.

Figure1.7 shows a standard reflow profile for Lead-free and eutectic Tin/Lead alloy solder. The preferred profile is prepared by the solder paste manufacturer and is variations in chemistry and viscosity of the flux matrix may require small adjustments to the profile for an optimized process.

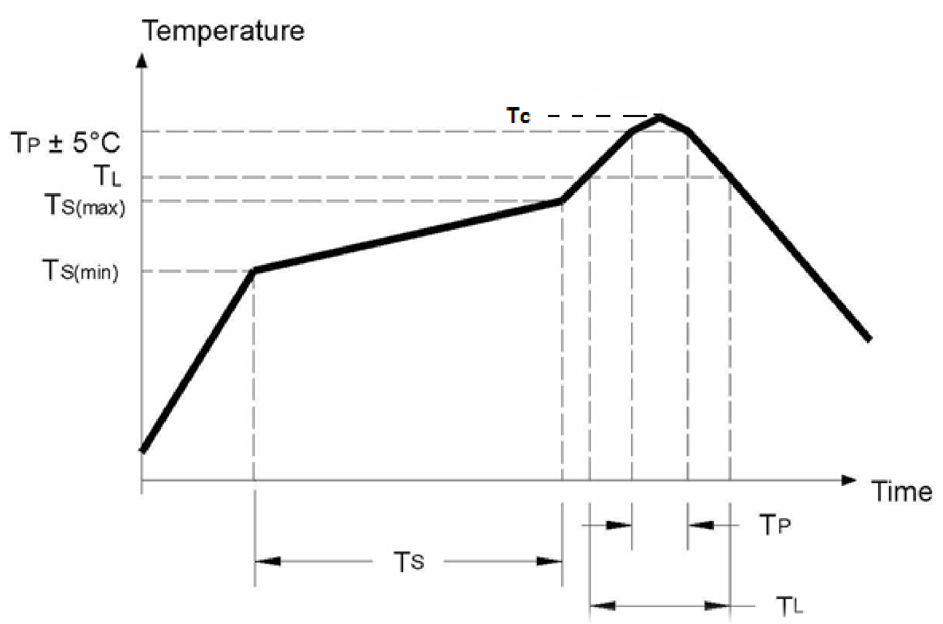


Figure 1.7. Max Reflow Recommendations [19]

Table 2. REFLOW PROFILES [20]

PROFILE FEATURE	SN-PB EUTECTIC ASSEMBLY	PB-FREE ASSEMBLY
Preheat/Soak		
Temperature Min (T_{SMIN})	100°C	150°C
Temperature Max (T_{SMAX})	150°C	200°C
Time (t_S) from (T_{SMIN} to T_{SMAX})	60-120 seconds	60-120 seconds
Ramp-up rate (T_L to T_P)	3 °C/second max.	3 °C/second max.
Liquidous Temperature (T_L)	183°C	217°C
Time (t_L) maintained above T_L	60-150 seconds	60-150 seconds
Peak package body temperature (T_P)	For users, T_P must not exceed the Classification temp in Table 2. For suppliers, T_P must equal or exceed the Classification temp in Table 3.	For users, T_P must not exceed the Classification temp in Table 3. For suppliers, T_P must equal or exceed the Classification temp in Table 4.
Time (t_P) within 5°C of the specified classification temperature (T_C); see Figure 1	20 seconds	30 seconds
Ramp-down rate (T_P to T_L)	6°C/second max.	6°C/second max.
Time 25°C to peak temperature	6 minutes max.	8 minutes max.

Table 3. SN-PB EUTECTIC PROCESS - REFLOW PEAK TEMPERATURES(TC)

PACKAGE THICKNESS	VOLUME mm^3 < 350	VOLUME mm^3 ≥ 350
< 2.5 mm	235°C	220°C
≥ 2.5 mm	220°C	220°C

Table 4. PB-FREE PROCESS - REFLOW PEAK TEMPERATURES (TC)

PACKAGE THICKNESS	VOLUME mm^3 < 350	VOLUME mm^3 350 -2000	VOLUME mm^3 > 2000
< 1.6mm	260°C	260°C	260°C
1.6mm-2.5 mm	260°C	250°C	245°C
> 2.5mm	250°C	245°C	245°C

1.6 Automated rework

Description

Since robots are used in PCBA manufacturing, PCBA robots are equipped and have been developed with multi-functional capabilities to assemble and inspect PCBAs. If the same equipment is used for rework, the high cost of the robot, on account of vision and other sensory needs can be eliminated and this can justify the investment. If both processes are using the same equipment, integrating rework and manufacturing processes leads to challenging planning and control problems. An automated rework system thus becomes an alternative technology to manual or semi-automated rework to increase the quality, reliability and elimination of most of the operator errors [21]. Automation of manual rework activity has drawn academic attention, but development of fully automated rework equipment has been hindered until early 1990s due to high cost predictions and complex process requirements. In one hand, in the last few years, although the number of rework stations available on the market has grown considerably and increasing product complexity of PCB, the piece cost of PCB increases and production quantities decrease, which has been increasing the required training and skill level of the rework operations and leads the rework and repair more difficult. And in other hand, manual rework often introduces problems such as, introducing any additional faults, placing the wrong component, damage to other components, long rework cycle times[22] make process expensive and the ability of humans to carry out rework cannot always be sufficient regarding to this fact that the component pitch size on boards becomes smaller. Therefore, the automated rework provides a solution to these problems.

The automation of rework firstly comes the SM components due to the use of a lot fine-pitch components. The automated robotic rework has been designed for both SM and TH technologies which each require completely different tools and rework method to deal with. By development of an automated rework workcell, direct operator involvement has been nearly eliminated. When the operation is finished, the board is removed and the entire cycle repeated, therefore, the cycle time and the quality of rework are improved. An automated robotic rework cell consists an adept-one robot manipulator, mechanical transfer devices, programmable logic controllers, some cameras, exchangeable devices such as grippers and suction tools, lower and upper rework tooling and other tooling necessary for rework.

Once decisions had been made on the reflow methods (which described in section 1.4.1.2) for TH and SM components, analysis and decision making was carried out to specify the other rework tooling necessary for automation. To achieve fully automated rework, it was thought that the following aspects need to be considered:

- Preparation of PCBA for rework:
  - Cleaning of PCBA from dust and contamination, etc.
  - Removal of conformal coating.
  - Removal of obstructions.
- Underside heating in order to protect the PCB from localized heat shock.
- Cleaning excess solder from pads without damaging the board.
- Solder cream dispensing, is essential for SM component attachment.
- TH and SM defective component fluxing, to improve heat transfer, and to dissolve the oxide on the joints.
- Cutting clinched legs of TH component and removal of TH and SM components, using an end milling cutter for outstanding legs of defective TH components.
- Post desoldering and resoldering cleaning.
- Heat control during reflow solder.
- Sensor control tools.
- Sensory and supervisory control requirements for components verification, placement, force sensing, etc. [23], [24].

Common automated rework devices

The PCBRM systems from Air-Vacuum engineering company and Zevac's SSM system provide precision selective rework of THT components.

Figure 1.8. PCBRM100 [25]

The ONYX and DRS systems provide an unparalleled level of automation and process control for SMT rework and assembly. The Tool Changer automatically selects and changes nozzles based on program instructions. The Pick & Preparation station provides automatic component pick up and preparation including flux dipping, paste on device and solder paste dipping. These include fully automated non-contact site cleaning, force-controlled auto placement and motorized vision/zoom. (Fig. 1.9 and 1.10).

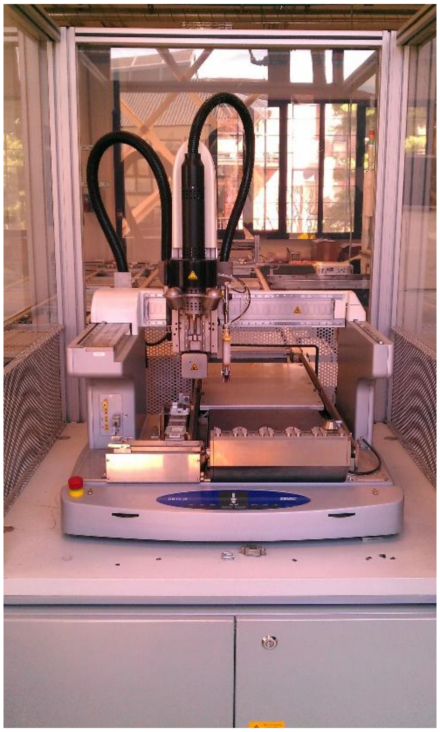


Figure 1.9. ONYX29 (Zevac Company). PHOTO.

Figure 1.10. DRS27T.6Z (Air-Vac Engineering Company) [26]

1.7 Air-Vacuum nozzles

Description

Since its founding in 1960, Air-Vac Engineering Company has been an innovator in the development of technical products designed. When surface mount technology emerged, Air-Vac again led the industry with the introduction of the Hot Gas Reflow Module in 1986.

Air-Vac Engineering has developed innovative solutions for almost every type of SMT rework, repair, micro assembly, dispensing and selective soldering challenge [27].

Mechanical Structure

An Air-Vac nozzle mainly consists of two Parts: a vacuum suction tube in center of the nozzle in order to pick & place the component and an external nozzle to direct the hot gas onto surface of targeted component. (Fig. 1.11). The Air-Vac use a combination of controlled heat and continuous vacuum in the same device which is hollow and heated.

Air-Vacuum Nozzle is suitable for: PBGA, TBGA, CBGA, CCGA, SBGA, CSP, QFP packages.

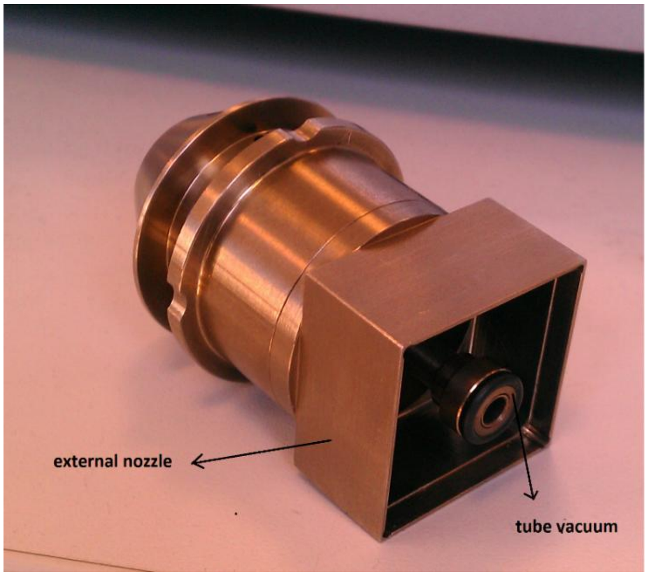
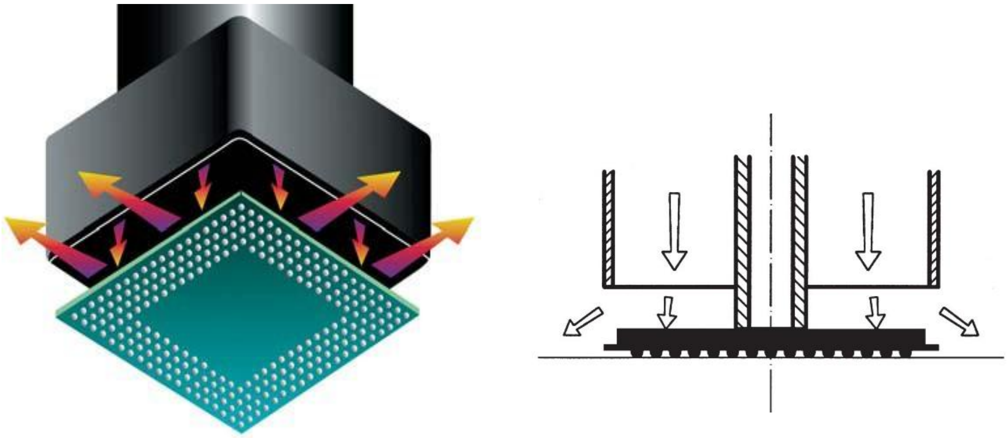


Figure 1.11. A typically Air-Vac nozzle. PHOTO.

Type of air-vacuum nozzle*

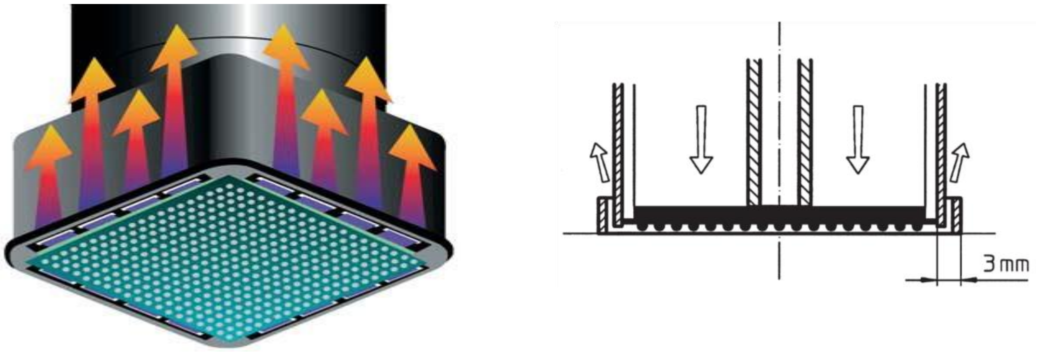
1) **EZ / EZL** gas nozzles: it is required zero adjacent clearance. EZ nozzles do not include a component insertion tool as they are not package specific.



(a) (b)

Figure 1.12. (a) Schematic of the EZ gas nozzle; (b) section view of the model

2) **X** gas nozzles: it is required minimum 3.0 mm adjacent clearance. X nozzles include a component insertion tool to reduce handling and simplify insertion of the component into the nozzle.



(a) (b)

Figure 1.13. (a) Schematic design of the X gas nozzle; (b) section view of the model

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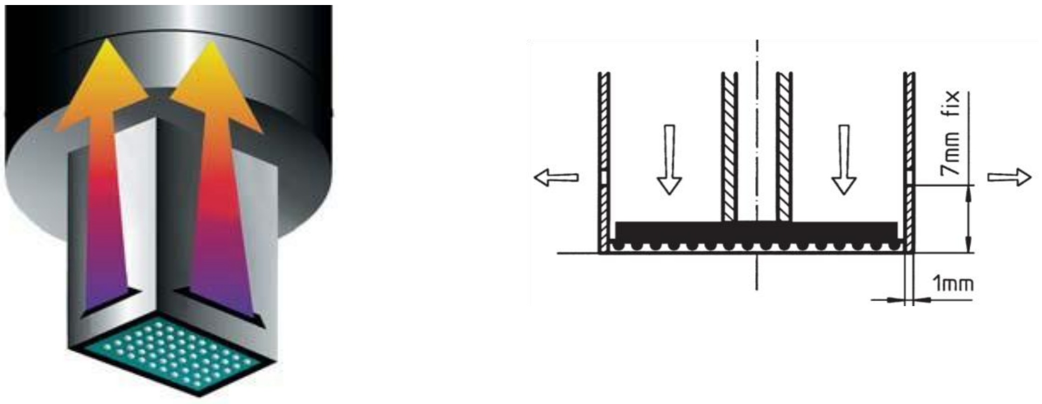
*These classification of gas nozzle are defined by Air-Vacuum Engineering Company. INTERNET: http://www.air-vac-eng.com

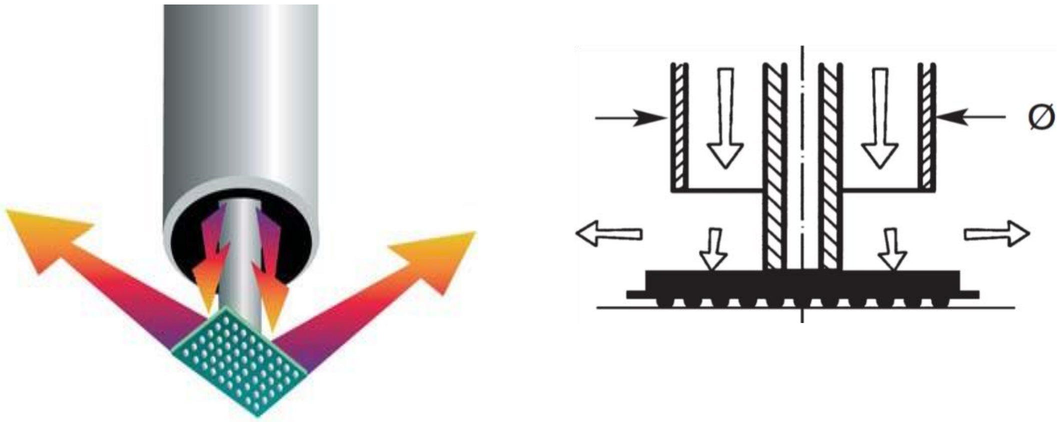
3) **Y** gas nozzles: Distance to next component minimum equal to 1.0 mm.



(a) (b)

Figure 1.14. (a) Schematic design of the Y gas nozzle; (b) section view of the model

4) **DVG** gas nozzles: Distance to next component is 0.0mm.
For µBGA, CSP, Chip 01005, 0201, 0402...



(a) (b)

Figure 1.15. (a) Schematic design of the DVG gas nozzle; (b) section view of the model

Note: The component's dimensions are necessary for the definition of the gas nozzles.

1.8 Summary

During the phases of re-work of circuit boards there are various stages where it is necessary to manipulate, warm, clean, desoldering, resoldering, etc. different types of components.

During the rework of a PCB is being used many different specific tools for each type of components to be processed, so is required:

- Supply of many tools.
- introducing several and time consuming tool changer phases due to various configuration of components onto a PCB.
- A large station of tool holder

Therefore it is necessary to create a novel gripper with the ability to adapt to various packaging that would lead to simplification of the rework process, making it more flexible, more efficient, and not very expensive.

This gripper can be a good replacement for a range of tools in rework process to manipulate the surface mounted devices.

Chapter 2

Preliminary Designs

This chapter will deal with primarily designs for the development of a new type of tool which will be used for full automatic rework system (e.g. ONYX 29 hot gas of Zevac Company) in order to manipulate SM components.

2.1 Considerations

- The gripper can be divided in tree main sections (Fig. 2.1):
  1-“Gripping system” to pick and place the component with a standard tolerance of +/- 0.05 mm (0.002in) or better is recommended. A suction mechanism is considered as gripping system for the design of the gripper which have the advantage of being able to grip on one surface only. The vacuum suction nozzle is placed in the center of the gripper.
  2-"External nozzle" involves a set of moving-parts that can be adapted to the configuration of the component onto PCB assembly. In addition, the external nozzle direct the hot gas onto the surface of the desired component for desoldering or resoldering, in order to not damage the joints of surrounding components.
  3- "Holder" of gripper which from one side is installed to robot end-effector and on the other side the external nozzle and grapping system are mounted.

-To avoid generation of a complex model, we can take advantage of the common type of Air-Vacuum nozzle in industry in order to design "holder” and "gripping system" of gripper, in this way no significant changes would be applied on these sections, so the main focus would be applied on design of "external nozzle".

This is due to the fact that by changing the ending part of the gripper (holder), it will be necessary to use additional elements or techniques to attach the gripper to the robot interface. In case it would be necessary to install the innovative gripper to a different robot's end-effector, just the holder has to be replaced.

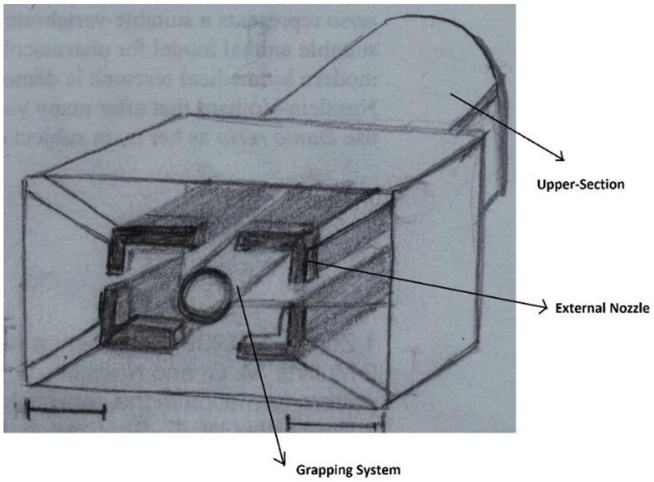


Figure 2.1. Gripper parts based on an air-vacuum nozzle

2.2 Specifications of the project

Before introducing the preliminary designs, it is necessary to create a list of all the significant problems concerning the application**.** The following guidelines such as mechanical structure and energy, were set for the gripper at the beginning of the design:

- Temperature operation is up to 573.15 Kelvin degrees (300 °C).
- Covering closure property, maintains a closed configuration, completely cover the component's perimeter. In fact the components in a PCB are close to each other, so if a gripper configuration isn't completely closed, leads to have a heat loss and unwanted heated surrounding components. Surrounding components create a tight working area.
- An important aspects of this efficient robotic gripper is its "shape-switching" feature, the ability to adapt and switch on different rectangular shapes without limitation in size ratio.

- Handling components of different size (a product family must be handled without a gripper exchange). The gripper must be capable of supporting a wide range of component sizes from 0.79 mm to 30 mm.
  In general the packaging size of the common SM components in rework process varies from 0.05 mm on a side to 40 mm, but this project is focused mainly on the size range of 0.79 mm to 30 mm. (Fig. 2.2).

- Realizable with the minimum number of actuators. The main features of the gripper are its reliability and efficiency and its simple and auto-adaptable features which help to have minimum number of actuators. At the same time it must be a law-cost alternative to common nozzles in the industry.

Observing the majority of component's dimension is placed in a range from 3 to 10 millimeters.

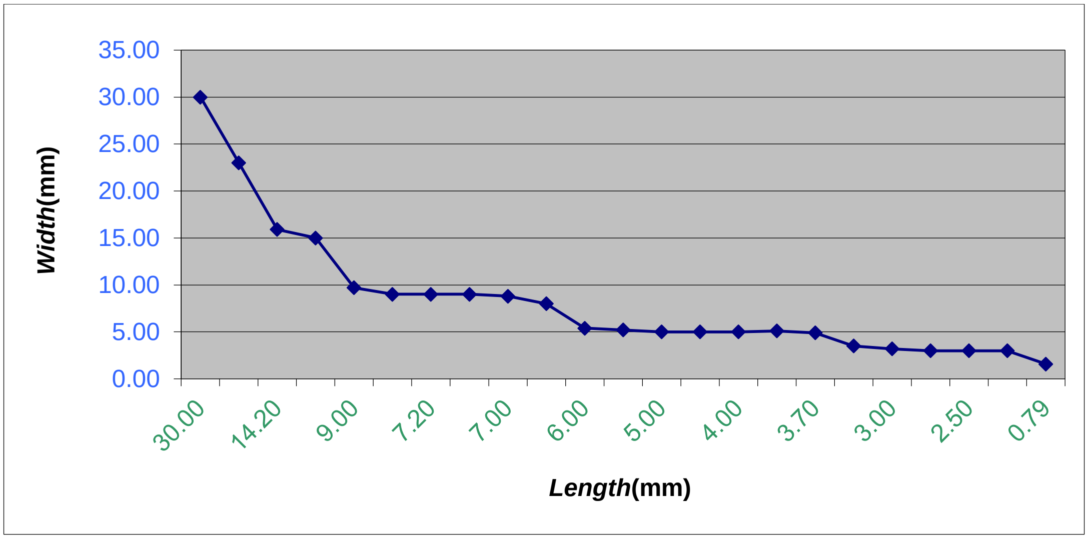


Figure 2.2. SM component's dimensions in two common PCB.

2.3 Development of ideas

After the specifications introduction it is time to show primary ideas that have been developed until the achievement of the final solution. During the project's analysis Solidworks® mechanical design software had been used in order to facilitate the procedure of designing and controlling the implementations and modification of the system.

2.3.1 Four-Finger gripper

This idea, inspired by Servo Motor Electric Gripper (Fig. 2.3), consists in a gripper with four translating fingers in the corners for covering the component's corners. (Fig. 2.4). The gripper could have 1 degree of freedom for linear motion, so only one electric motor or a pneumatic actuator could be used.

Figure 2.3. A typically servo motor electric gripper [28]

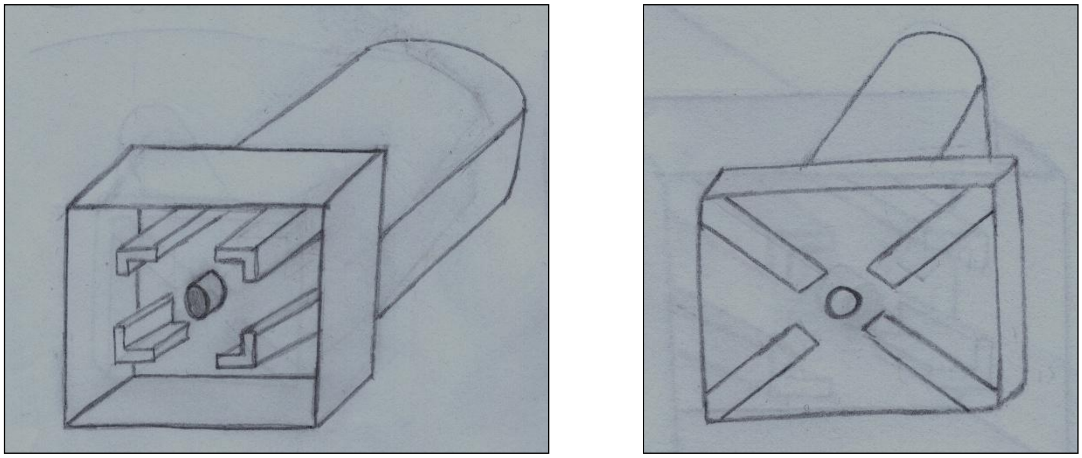


Figure 2.4. (a) Schematic design of four-fingers gripper; (b) Design of the planar base of the suggested model

Drawbacks and Features

- Movement only in diagonal direction, therefore, length to width ratio remains constant. For example if we consider the ratio equal to 1.33, the gripper can cover only rectangular components with ratio 1.33.
- There is a gap between the corners so the hot gas can transfer to outside blowing nearby components.

To obtain allowable size range, first we should define length and thickness of the corners and minimum and maximum of gap's length between corners. (Extreme of the range)

In order to resolve the first disadvantage (movement in diagonal direction), the fingers can move in two directions x and y (Fig. 2.5), so it's suitable for any rectangular component with any size ratio. Moreover, it is necessary to have two actuators to move the fingers, but the problem related to the gap between the corners is still present.
In order to cover the gap we can utilize flexible joints such as metal bellows, silicone rubbers, flexible plates, etc.

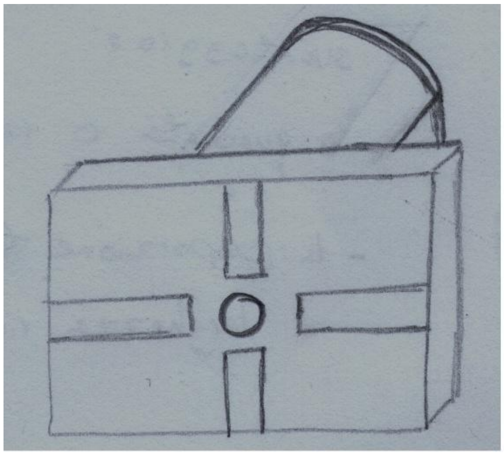


Figure 2.5. Alternative design of the base of the suggested model

1. Metal Bellows

Description:

Metal bellows (Fig. 2.6) are elastic vessels that can be compressed when pressure is applied to the outside of the vessel, or extended under vacuum. When the pressure or vacuum is released, the bellows will return to its original shape.

Some features of metal bellows are:

- Can work at high temperature.
- Can cover a wide dimension range.
- To move the metal bellows, an air-vacuum system can be used.

Range achievable with this model depends on min and max possible length of flexible joints.

Range equation is $[(2(D-S)+L_{min}), (2(D-S)+L_{max})]$*

For example: if we consider D=5 mm, S=2 mm, L_{min}=4 mm, L_{max}=10 mm. The range is equal to [10, 16]. We could see that the magnitude of the range depends only on the elongation capacity of the metal bellow.

Figure 2.7 shows the designed external nozzle with metal bellows in open position.

Figure 2. 6. A common metal bellow [29]

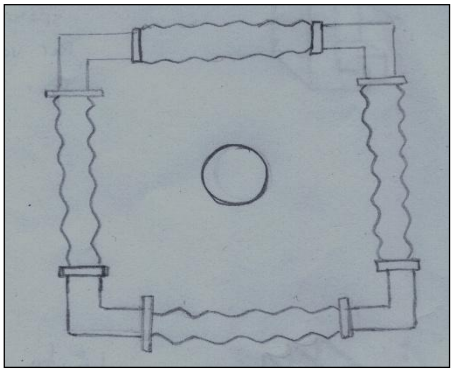


Figure 2.7. Designed gripper with metall bellow

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* The parameters: thickness of the fingers (D), length of the fingers (L), and maximum elongation of the metal bellows (L_{max}) and minimum compression of the metal bellows (L_{min})

2. Silicone rubbers

Description

Silicone rubber components have characteristics of both inorganic and organic materials, and offer a number of advantages not found in other organic rubbers. Silicon rubber is generally non-reactive, stable, and resistant to extreme environments and temperatures from -55 °C to +300 °C while still maintaining its useful properties.

Some properties of silicone rubber are good elongation, creep, cyclic flexing, tear strength, compression set, dielectric strength (at high voltage), thermal conductivity, resistance to oils, solvents and other chemicals, moisture and steam resistance, weather ability, compression set, flex fatigue resistance, vibration observation[30]. Some of the mechanical property of silicon rubbers are shown in Table 5.

The permitted range of the gripper is the same as the one brought before, this range depends on the min and max possible length of flexible joints.

Table 5. Mechanical features of silicon rubbers

Mechanical properties	
Hardness, shore A	10-90
Tensile stress	11 N/mm^2
Elongation at break in high-temperature conditions	½ that of the initial value
Max temperature	+300 ^{o}C
Min temperature	-120 ^{o}C
Elongation fatigue(×10,000 times)	30-500

2.3.2 Sliding Arms

The suggested gripper consists of four-metal arms and works through a slide mechanism for self-adapting. According to the shape of the arm (Fig. 2.8), each arm's final part slides through the chamber until reaches its final boundary. This mechanism has 4 degrees of freedom, with using a proper mechanism can be reduced from 4 DOF down to 2 DOF, so it requires two actuators to run successfully.

Features:

- Suitable for both square and rectangular shape.
- No fatigue problem for reason of bending.
- We have a closed configuration.
- The size range of gripper is limited.
- Allowable size range is obtained from equation: [(X-S) , (2X-S)]*

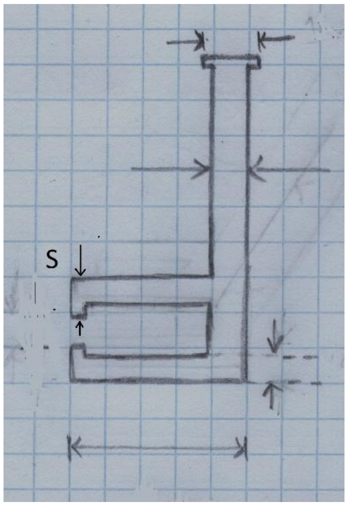

Figure 2.8. Arm shape

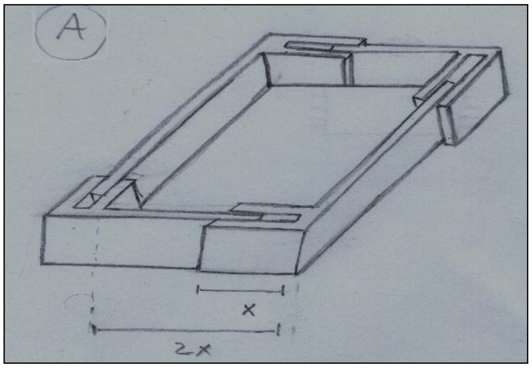

Figure 2.9. The biggest configuration

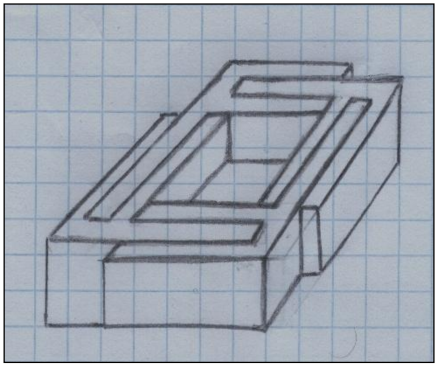

Figure 2.10. The smallest configuration

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*The parameters are shown in Fig. 2.8 and 2.9

2.3.3 Third solution

This idea is suggested to improve previous solution to eliminate its disadvantages creating a suitable notch on the end of each arm in order to address the excessive parts in to the notch, when the gripper moves from the largest configuration to adapt to smaller configuration. (Fig. 2.11).

Features

According to ability of the arms to coming out of the original configuration, the tool is capable of covering a wider size range. This model is suitable for components with both rectangular and square shape. To move the tool, it is necessary to use two actuators (the model has 2 D.O.F). The excessive parts coming out of the original configuration (protrusion problem) might disturb nearly components and damage them.

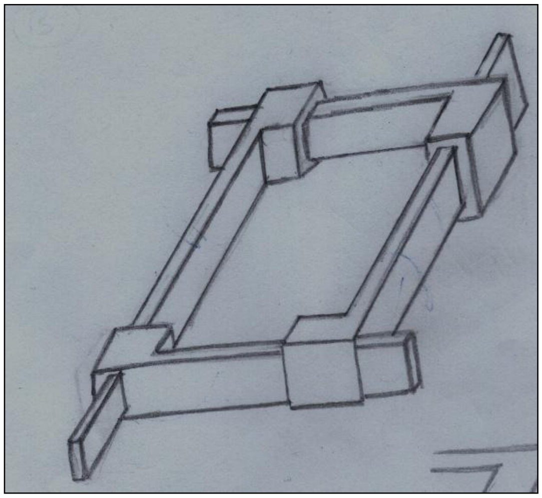
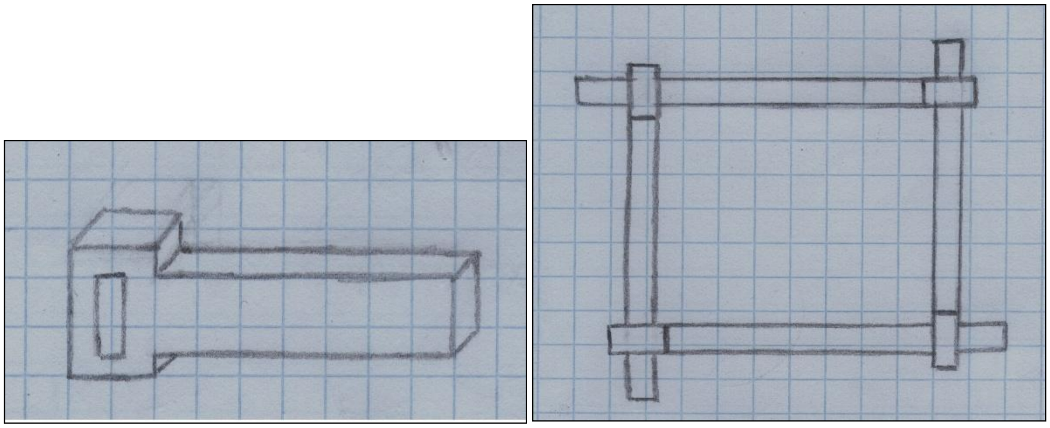


Figure 2.11. Schematic design of suggested model

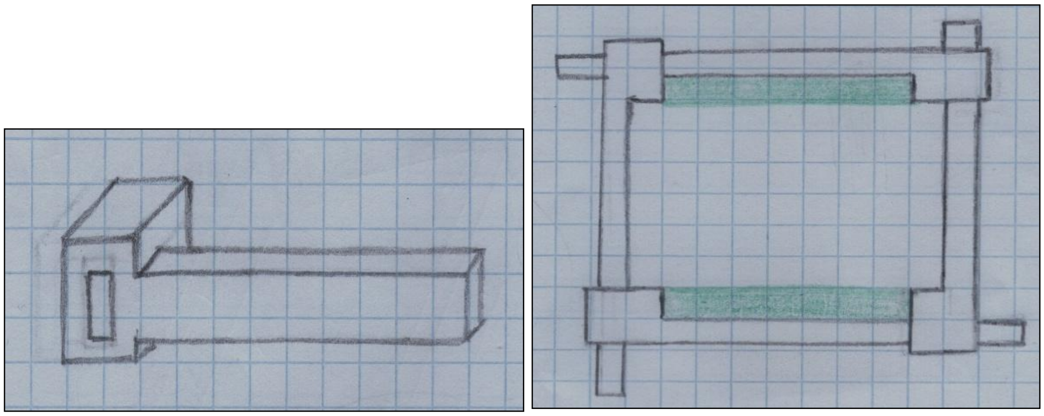
Shape of arms

Two type of gripper’s arm shape are suggested for the third solution. Fig. 2.12 illustrates the first type which with this shape there isn’t any gap around the targeted component to rework process, while Fig. 2.13 shows another type of gripper’s arm shape which, there is a gap around the component utilizing this model.



(a) **(b)**

Figure 2.12. (a) First type of arm shape; (b) Schematic design of the model

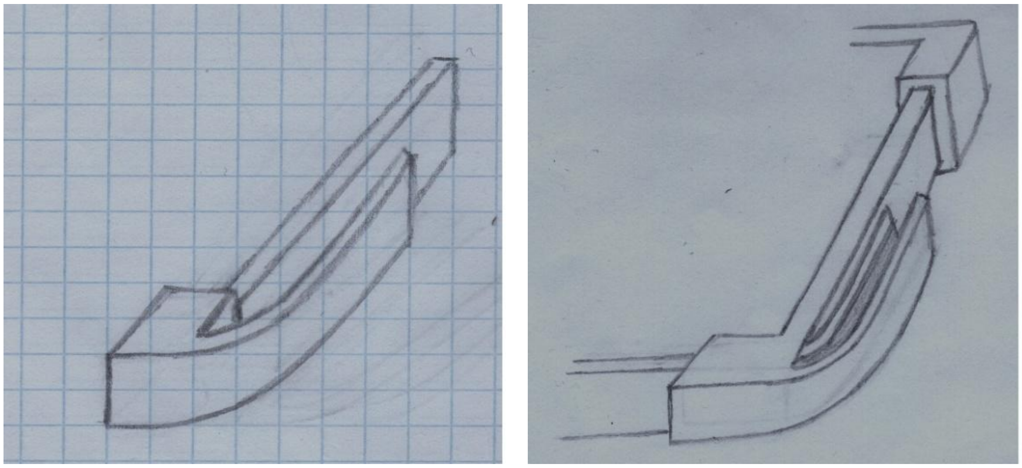


(a) **(b)**

Figure 2.13. **(a)** Second type of arm shape; (b) Schematic design of the model

To resolve the problem of disturbance caused by excessive parts, the arm shape below (Fig. 2.14) can be used.

Regarding this arm shape, when the gripper moves from the biggest configuration to the smallest one, the bent guide conducts the excessive parts to the devised chamber. The most important issue regarding this model is the fatigue effect due to cyclic bending of the moving part. In addition, the friction effect in bended zone of the bent part would be enormous in comparison to the other models. Moreover, plastic deformation resulting from continuous mechanical deformation and high temperature would be probable.



(a) **(b)**

Figure 2.14. **(a)** Arm shape with a bent parte; (b) placement of the excessive part inside a bent part

2.3.4 Telescopic arm

Description

This idea is extracted from the Telescoping Robot Arm. (Fig 2.15). According to the specification of the project we used the model (b) of Fig. 2.15.

The gripper is made up by four telescopic arms (Fig 2.16), that each one consists two moving sections.

Figure 2.17 illustrates when the gripper is completely open (biggest component that the gripper is able to cover). In this case, the two parts of the arm are at their final limits. Figure2.18 shows the smallest configuration of the gripper. In this case the two parts are well placed in each other creating the finest and tiniest configuration.

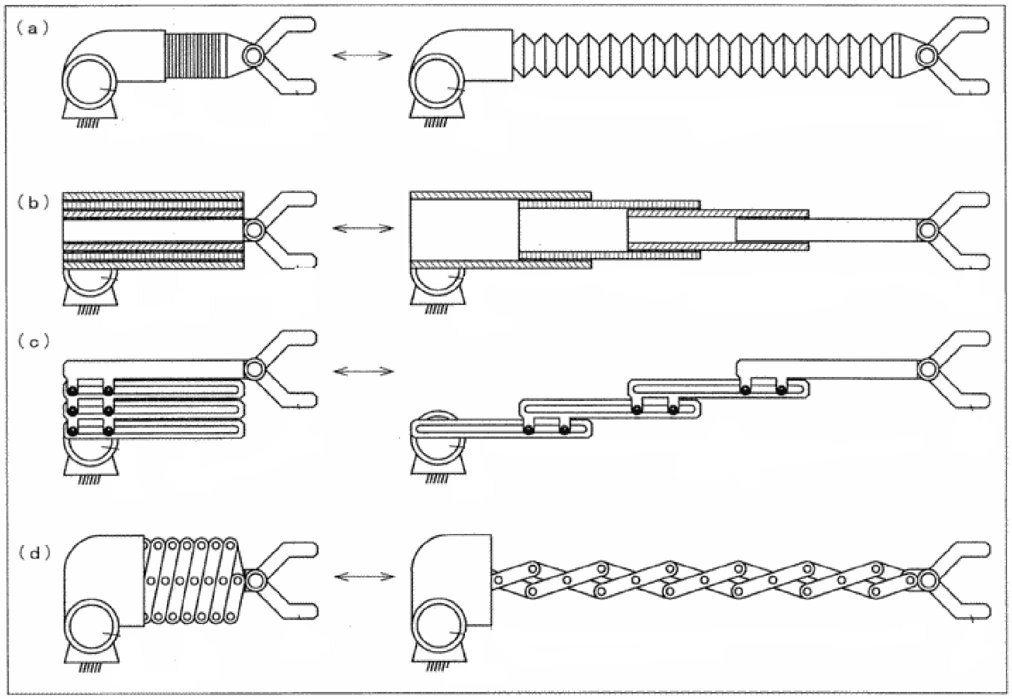


Figure 2.15. Telescoping robot arm [31]

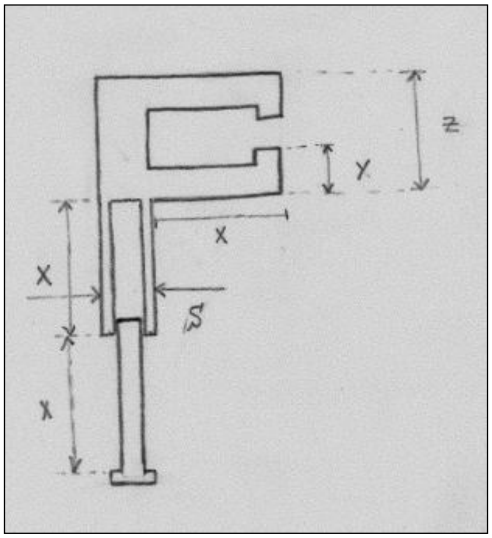


Figure 2.16. Shape of the arm

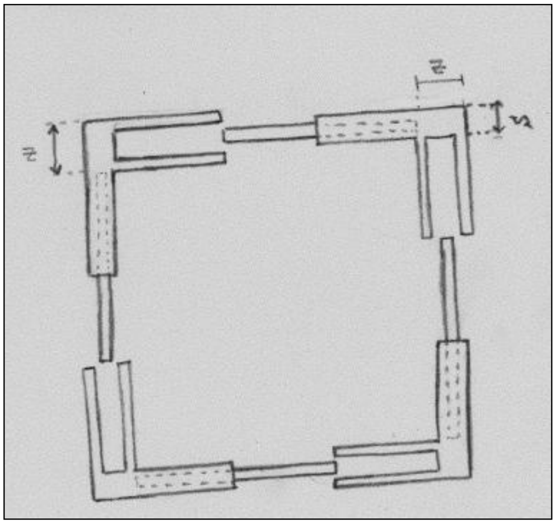


Figure 2.17. Biggest configuration

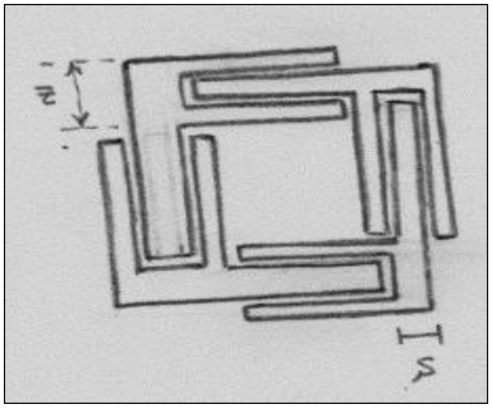


Figure 2.18. Smallest configuration

When the gripper is in the wide-open position (Fig. 2.17), the unoccupied space around the component (Grey zone) is maximum (Fig. 2.19). By adding more moving parts the amount of this useless space enlarges and due to the poor temperature isolation, the total efficiency reduces therefore it must be avoided or be minimized. Moreover, since individual component in PCB are placed closely to each other, this kind of gripper expansion would conflict with geometrical properties of other component on PCB.

The size range to adapt is equal to:

[(X-Y), (3X-Y)]

For example if we define X=10 and Y=2, the gripper is able to handle component with size from 8×8 mm to 28×28 mm.

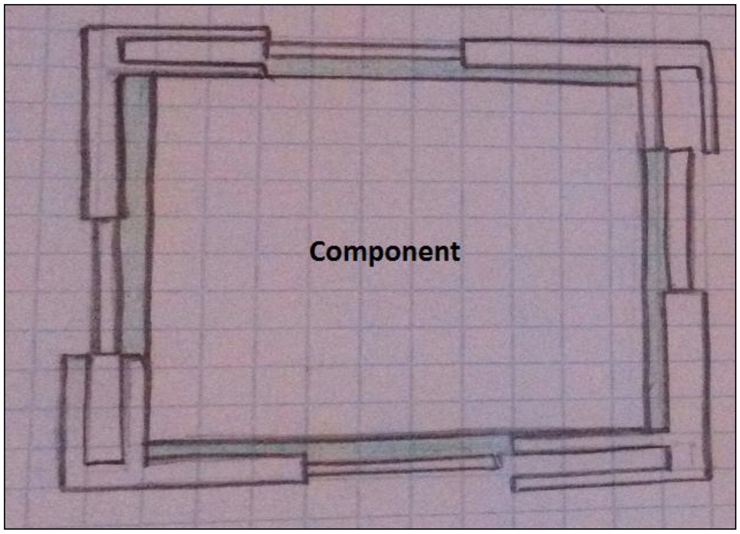


Figure 2.19. Covering of a component by the proposed model

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*The parameters are shown in Fig. 2.16

2.4 Comparison of proposed models

In this section, I will briefly compare different aspects in construction of the proposed models of a gripper. Then after selection of the favorable design, the section will deepen some structural properties of this device.

● in first proposed model, as the gripper could handle only rectangular shape with fixed ratio due to diagonal movement of fingers, this idea can't be a proper model.

● In the second model, separation distance between different parts of the gripper increases, which leads to increase in thermal loss and finally decreases total efficiency. Besides, we have to keep in mind the fact that, the components dimension are small (millimetric size) and devices such as silicon rubber, metal bellow in this size range are not commercially easy to find and production of these tools needs extra costs to be manufactured.

Moreover, the effect of fatigue and plastic deformation due to its cyclic application in high temperature (300 °C) in long term must be considered.

By first review of suggested model we find out that although this recent model solves some problems in comparison to previous model, but the gripper cannot adapt to very wide configuration range. The main goal of the project is to design an auto-adaptable gripper which can be a good alternative for a set of nozzles. Because at the moment in the industry for each component's size, there is a unique nozzle, by introducing a gripper with the higher ability to cover a wider range, it is possible to eliminate the usage of several nozzles and reduces the total cost of operation.

● In the third proposed model, the most fundamental issue that is faced, is the moving parts of the gripper that are coming out of the original platform. Whenever the biggest configuration is not requested, these excessive parts can damage surrounding components.

Moreover, in the case of using guiding tunnel in order to drive the coming out part to other side, we might face with other kind of challenges such as fatigue and permanent plastic deformation. (described in section 2.3.3)

● In the telescopic arm model, the problems in previous suggested models have been solved but the only problem still existing is the unoccupied space around the components that have to be eliminated (Fig. 2.19). Its minimization is achievable by modifying the design.

Table 6. Summery of allowable size range of suggested models

Four-Finger	[(2(D-S) +L_{min}) , (2(D-S) +L_{max})]	If: L_{min}=5 mm L_{max}=8 mm D=5 mm S=2 mm Range=[11 , 14]
Sliding arms	[(X-S) , (2X-S)]	If: X=10 mm S=2 mm Range=[8 , 18]
Third solution	[0 , L+2S]	If : L=10 mm S=2 mm Range=[0 , 14]
Telescopic arm	[(X-Y) , (3X-Y)]	If: X=10 mm Y=2 mm Range=[8 , 28]

Since by the use of different models the applicability varies, the advantages and limitations of each design changes. According to table number 6, we find out that the telescopic arm is able to cover the wider size rang, satisfying the specifications of the project.

Choosing the primary model of the telescopic arm, now we can design it more in details and analyze it.

Chapter 3

Reconfigurable Gripper Design

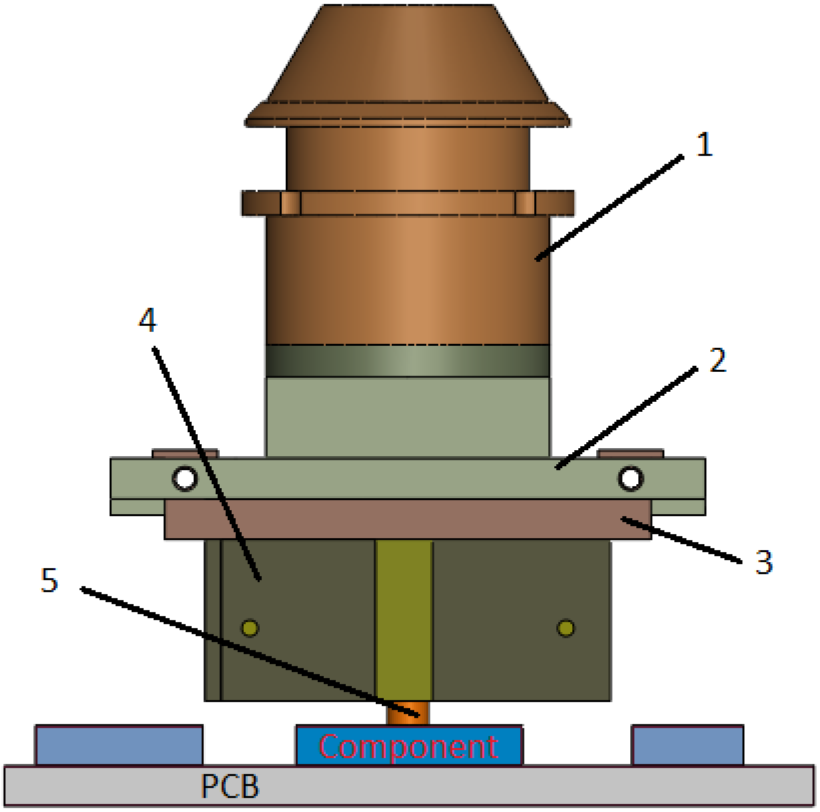

Figure 3.1. Components of the gripper: 1-Holder. 2-Planar_base. 3-Guide. 4- Carriage. 5-Vacuum tube.

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3.1 Problem hierarchy of the designed gripper

One way to systematically search for the specification is to create a hierarchical list of all the significant problems concerning the application [32]. The problem hierarchy [33] method can be used as an efficient tool in a systematic process and workpiece analysis. In addition to the process and workpiece, it can be extended to internal gripper analysis and economic factors.

The basic problem is divided into four subproblems, which are the most crucial in the gripper application. The four subdivisions are workpiece, process, old grippers and economic aspects.

The workpiece plays an important role in the gripper design. The particular size rang, shape, mass of the workpiece (to pick and place) and available space around of the targeted component onto PCB determines the final design.

The process where the gripper is operating dictates the design parameters and materials.

We can select useful parts of the actual grippers (Air-Vacuum nozzles) and its characteristics for rework process. Actual grippers' components which have the same task as holder and gripping system, can be used in new gripper's design. The detailed parameters work as a checklist, and support directly the completion of the design specifications.

Economic aspects should not be forgotten in the design. The simple design of the gripper ensures the ease of manufacturability and reliability of operation. The cost of the development, the numbers of exploited actuators and price of the components set real limitations to the design.

The result of the hierarchical problem analysis allowed to obtain the final design of the gripper.

3.2 Design of the primary gripper

The interaction between a robot and workpiece is generally executed by a robot gripper. The problem in robotic systems is how to design, sufficiently fast, reliable, flexible, and efficient industrial grippers within the given project schedule.

This chapter is explains the design and modeling fundamentals for a reconfigurable multi-degree-of-freedom gripper, designed to automate the rework process of SM components.

The preliminary design in the beginning the gripper needs to be conceptualized. In figure 3.2 the model of primary version of gripper (as described in section 2.2.4), is represented. However there would be some changes to meet all necessary requirements for designing the overall structural layout of the gripper. The analysis in term of thermal leakage, fixturing problem, slidable features and etc.

The model has four DOF, and consists a pair of parallel-guides (1), where the supporting leg (2) of the carriages (5) are held. The guides can move only longitudinally through the devised linear guides (3) in the planar-base (4), along with mounted leg of the carriage, while the carriage, can move only transversally by sliding inside the linear guide.

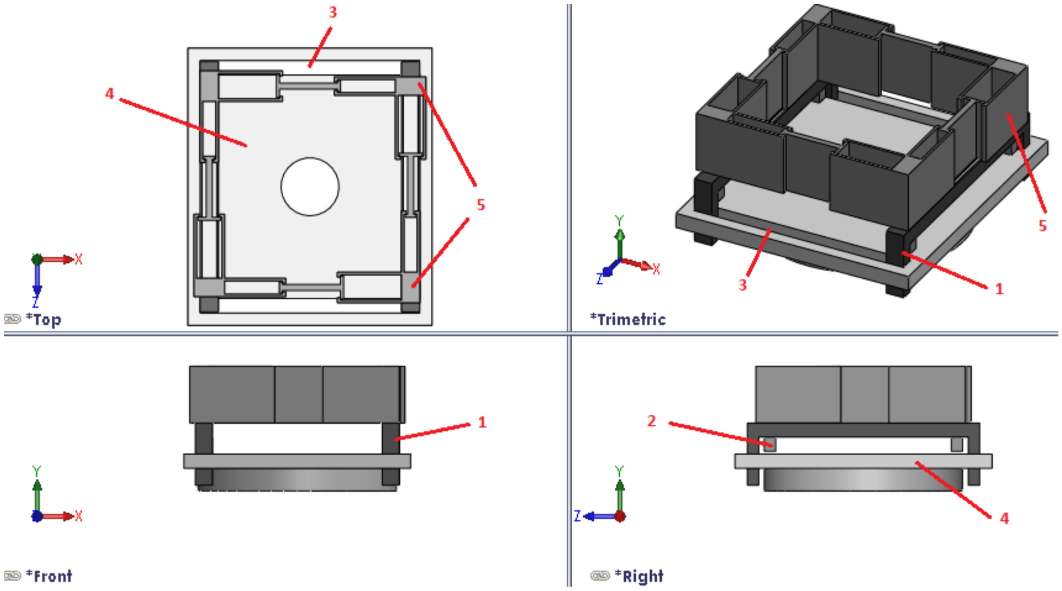


Figure 3.2. Solid primary model of the gripper

3.3 Mechanical Design

Figure 3.3 shows the gripper’s final design after evaluating all considered guidelines for the gripper design (mentioned in section 2.2).

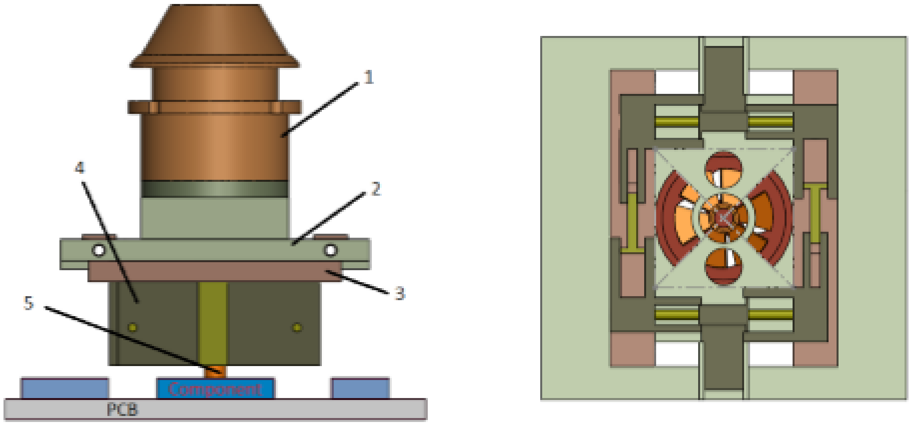
Before showing the technical drawing of the gripper, it is useful to remember some notes about the final design of the tool.

1-The robot gripper adapts at the packaging with size from 10×10 mm to 28×28 mm, without limitations in aspect ratio.

2-The gripper includes a vacuum tube (no. 5 in Fig. 3.3) to pick and place the components. On one hand, the vacuum tube’s diameter is adequate to that of the smallest component’s configuration, whereas the vacuum generator can create sufficient picking force, with this tube size, to pick-up and place the largest component the cell is designed to rework. On the other hand, it is necessary to have constant air flow which requires suitable space around the suction unit. So, in overall by consideration of above mentioned term, the outer diameter has been sized to half of the smallest component.

3-The height of the moving parts and the shapes of the positioned holes on the planar base has been chosen after fluid simulation which will be discussed in section 3.5.

4-an EZ air-vacuum nozzle mechanism (described in section 1.7) has been considered to design the gripper, therefor the external nozzle will be located at a distance of three millimeters from the targeted component’s surface.



(a) (b)

Figure 3.3. (a) Structure of the Robot gripper; (b) The gripper in top view

3.3.1 Holder with Suction tube

Fig. 3.4 illustrates the holder of the gripper which consists of four channels (no. 6). The hot gas enters in the machine through the group of holes which are placed on the bottom of the holder. The suction system is connected to the vacuum tube through the hole no.7. The tube is fasten to the holder by a screw passing the hole no. 8.

The holder is attached on one side to the robot interface and on the other side is connected to the planar base. The connection between holder and planar base could be dismantled.

If it is necessary to install the innovative gripper to a different robot's end-effector, just the holder has to be replaced.

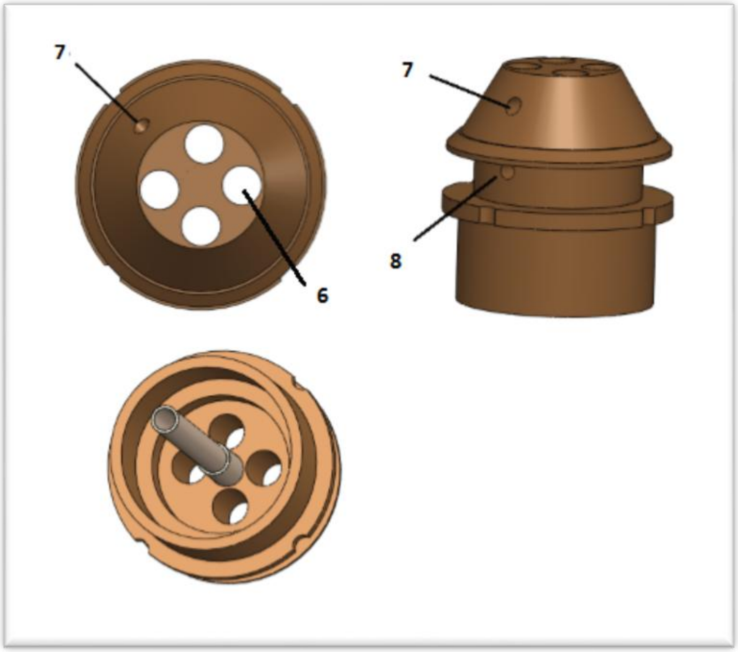


Figure 3.4. Three views of the holder of the gripper

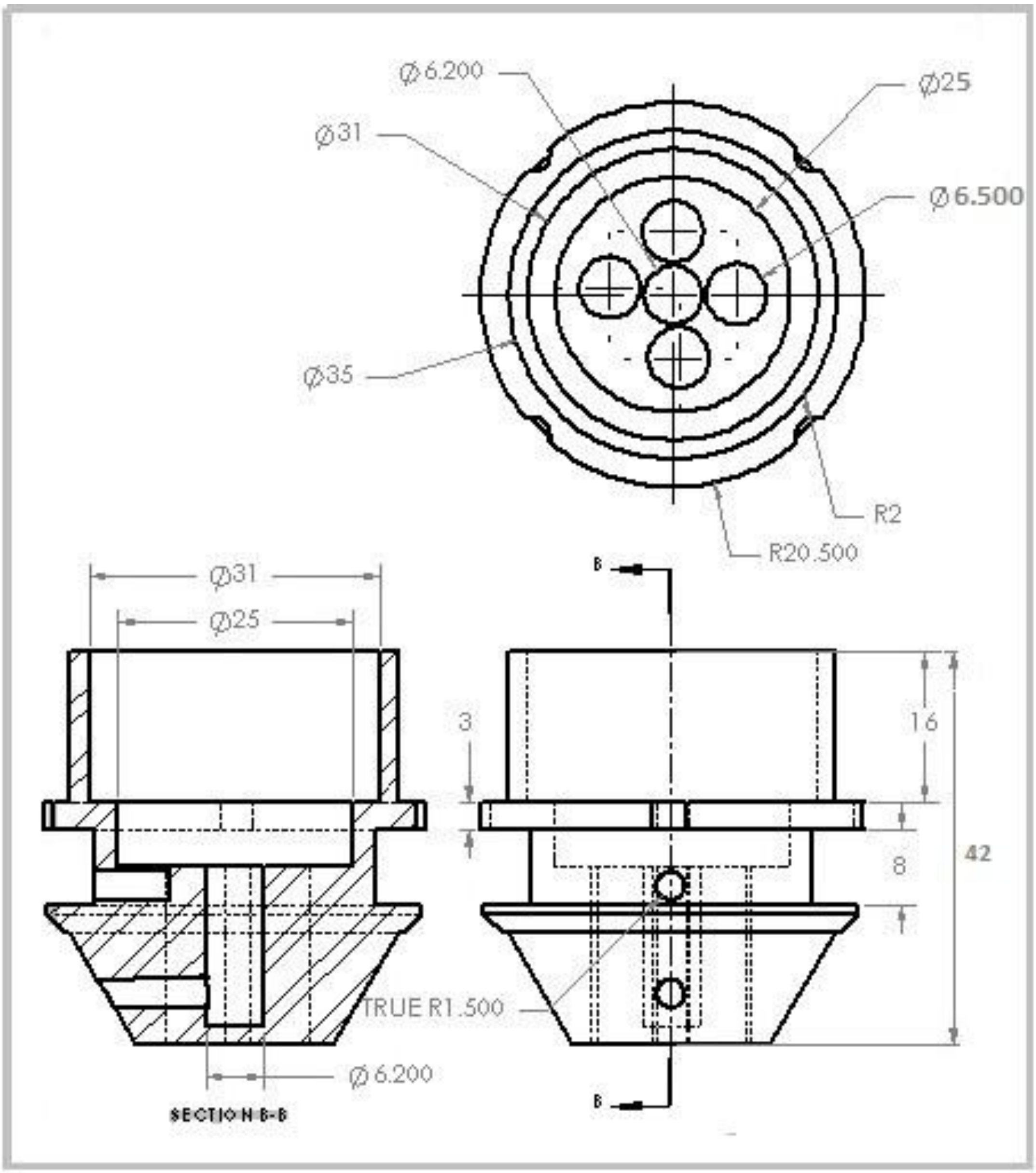


Figure 3.5. Technical drawing of the upper section (all measurements are in mm)

3.3.2 Carriage

Each carriage of the external nozzle consists of two elements: a middle part and an L-part (Fig. 3.6). The middle part is fixed on the guide and connects two L-parts over the guide (Fig. 3.7). The L-part is mobile and slides on the middle part. Its mass will be supported through a supporting leg at the bottom inside of the guide. The movement of the carriages makes the gripper to be adapted to the targeted component configuration.

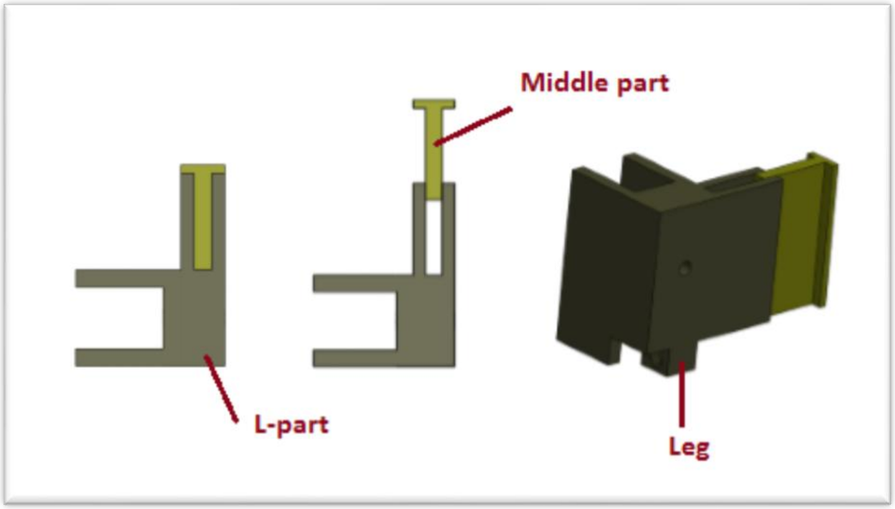


Figure 3.6. Features of a carriage

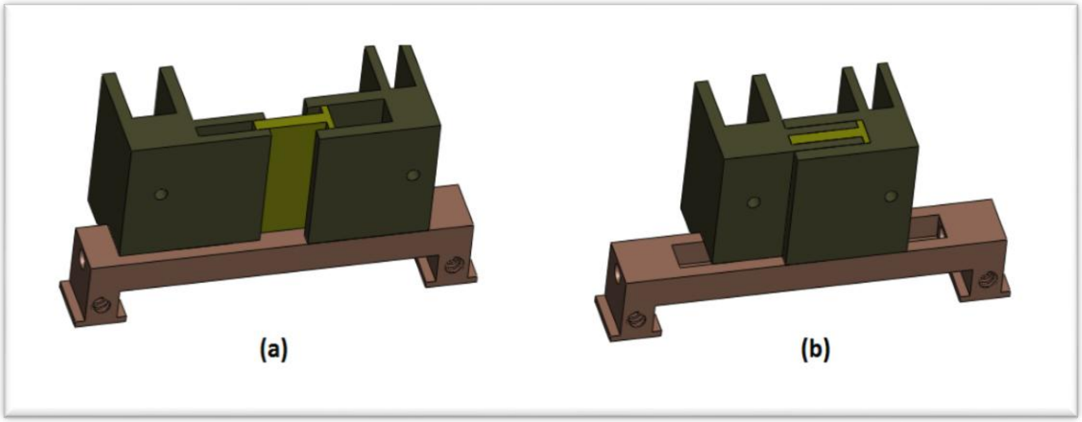


Figure 3.7. (a) The middle part is out of the L-part; (b) the tool is completely closed

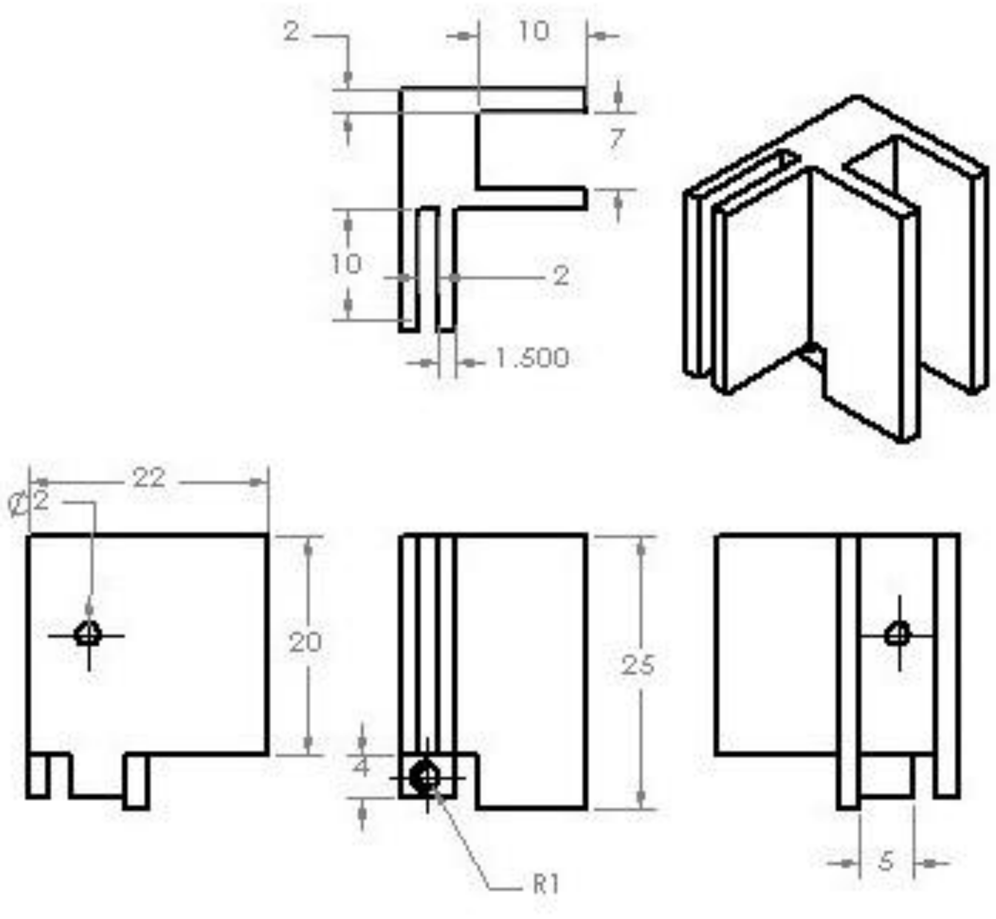


Figure 3.6. Technical drawing of the moving part 01 of the external nozzle

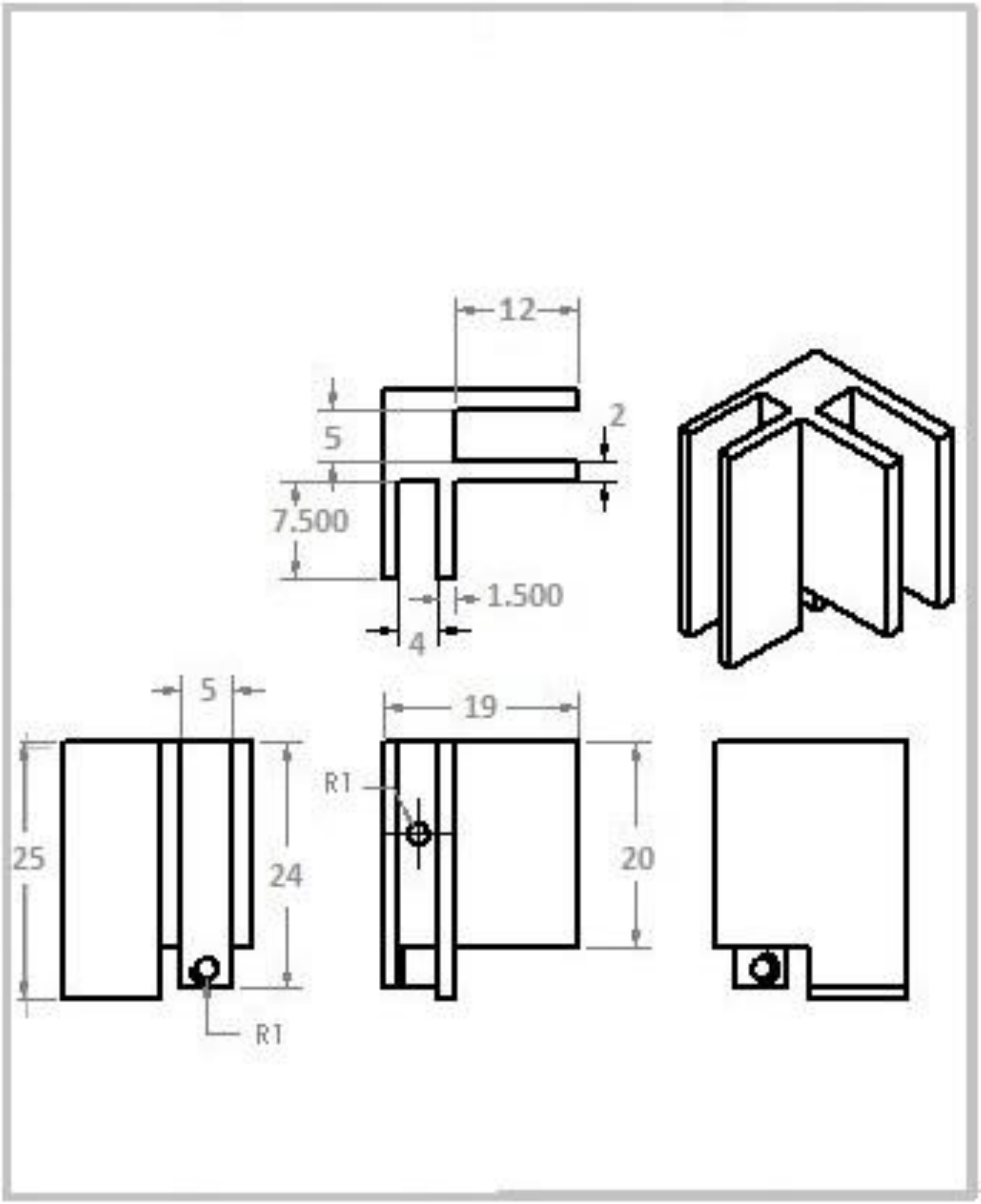


Figure 3.7. Technical drawing of the moving part 02 of the external nozzle

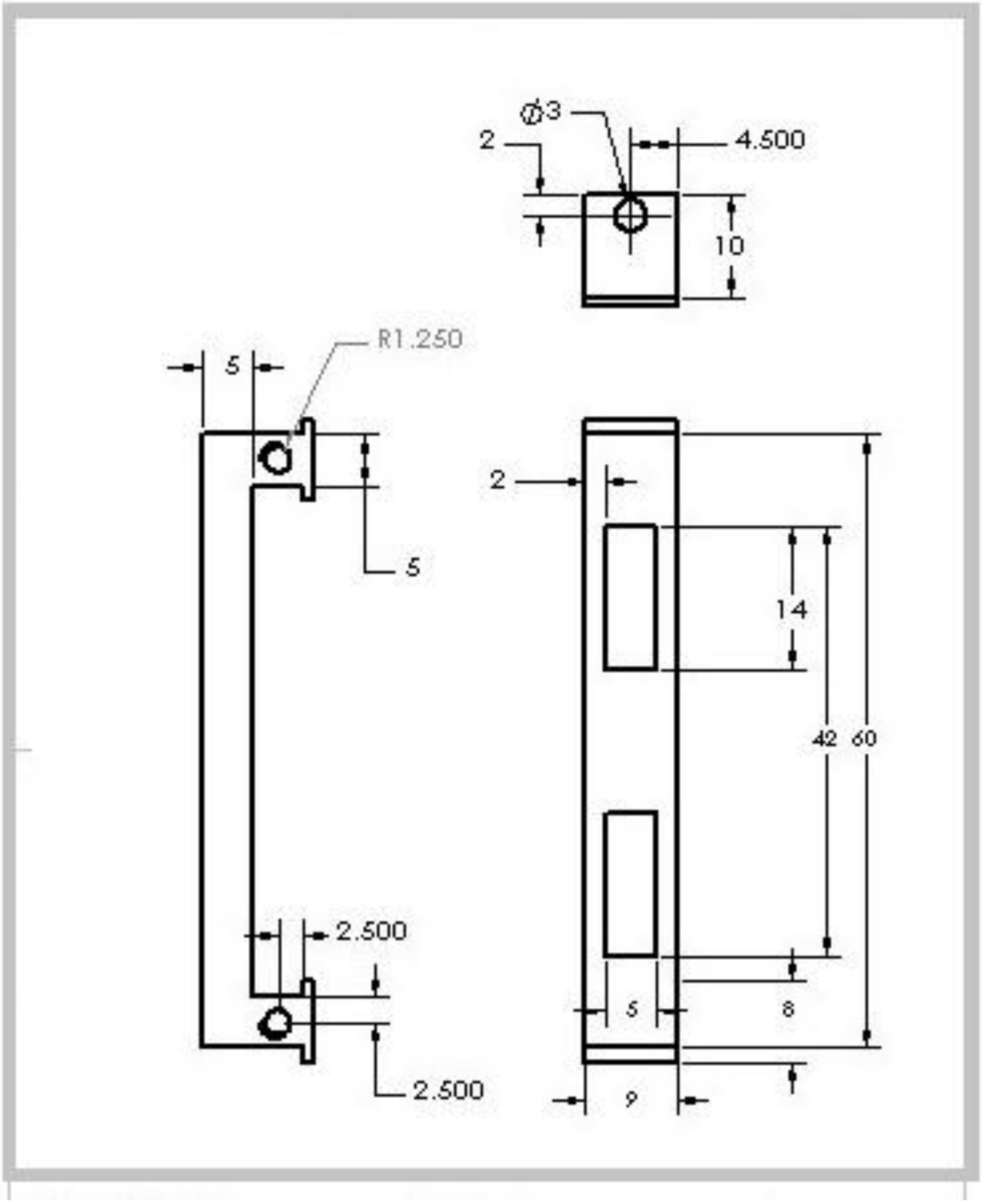


Figure 3.8. Technical drawing of the guide

3.3.3 Planar-base

The holder is connected to the inferior part of the planar base. The two guides are placed in the two parallel linear guide holders on the planar base. In addition a group of holes are compensated in the center to let the hot gas exit from the exhaust holes.

In the following images the technical drawing and a schematic design of the planar base are illustrated.

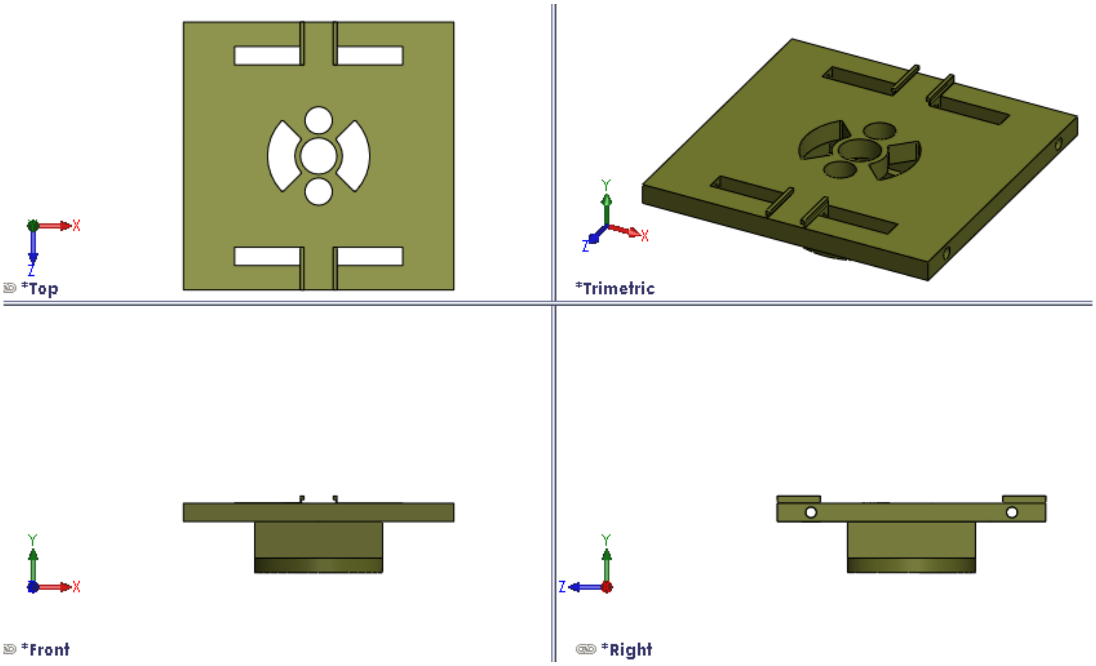


Figure 3.9. Features of the planar base in four views

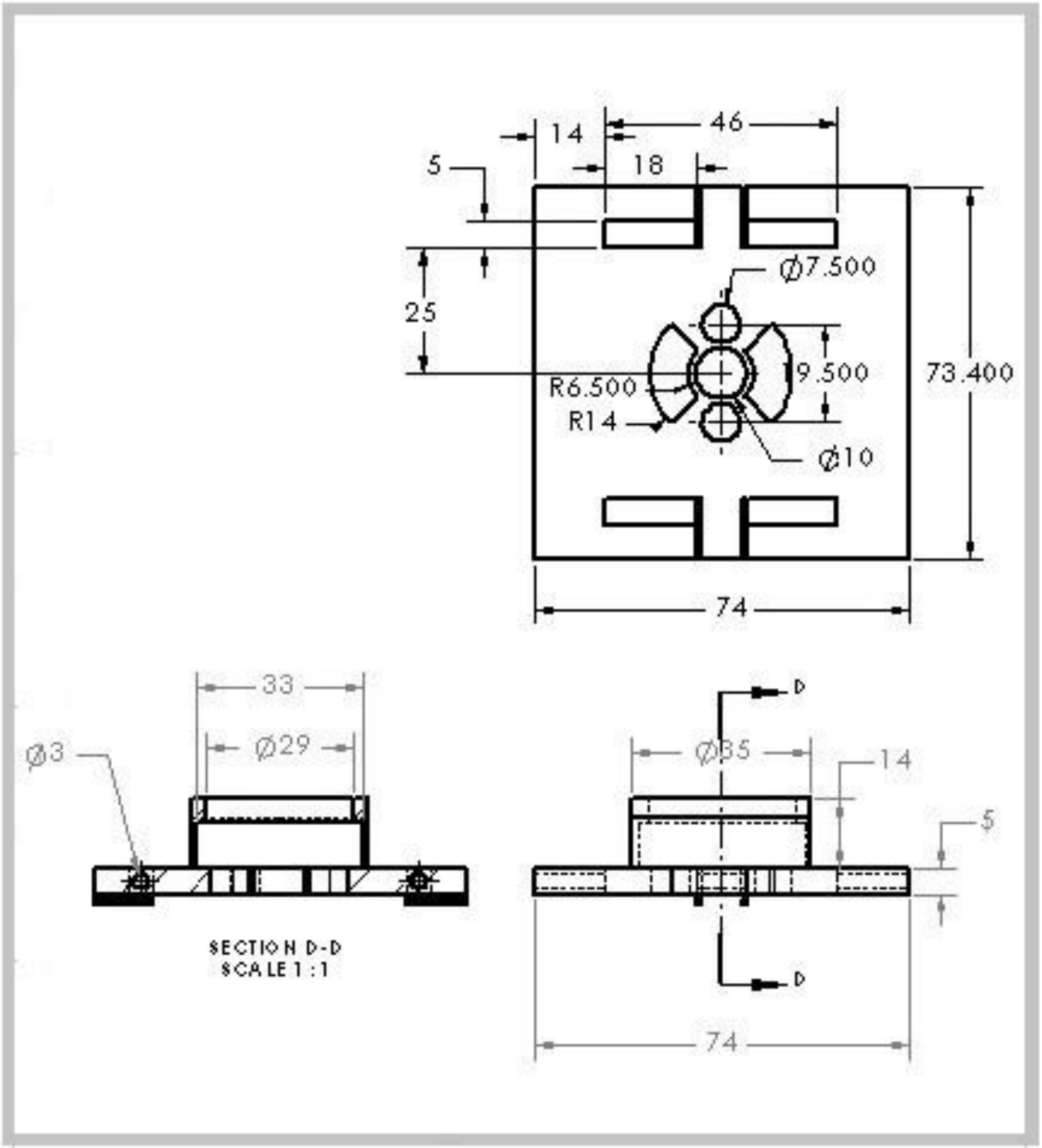


Figure 3.10. Technical drawing of the planar base

3.4 Detail design of the planar base

In automated rework, with utilizing hot gas as reflow method for desoldering and resoldering of the components, gas flow must reach all the component's surface homogeneously. One of the main factors that makes achieving such homogeneous gas flow possible, is the proper configuration of air exhaust holes on the planar base.

The gripper has the ability to adapt to the component size, consequently the dimension of exhaust holes varies with the component size.

Figure 3.13 shows a proposal for the air exhaust holes. Both opposite holes will be covered by the guides when the gripper closes, while circular holes will be covered through the vertical components which move just in parallel of guide's axis. We do not place any hole in blind areas, because we cannot cover them. However, analyzing the flow simulation, could be demonstrated that the hot gas directs onto the component surface homogeneously. (please see next section).

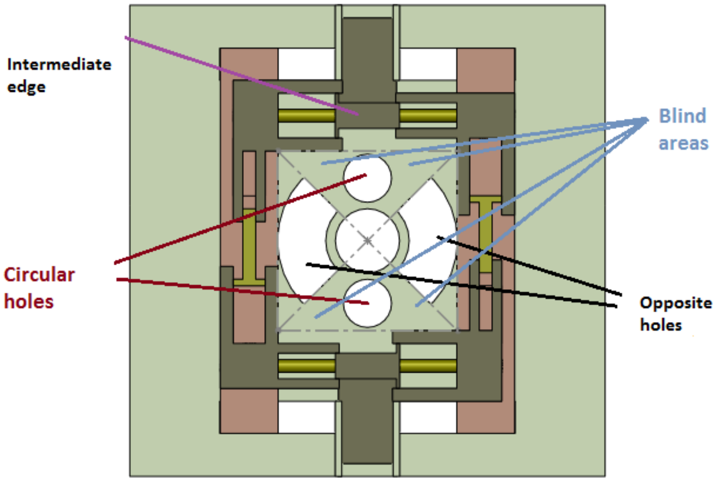


Figure 3.11. Location of the holes onto the planar base

3.5 Configuration design

Figure 3.14 illustrates different configurations of the designed gripper. Figure 3.14 (a) indicates the biggest configuration of gripper, where each mobile part of the carriage is at the end of the guiding line and the holes on the planar base are completely uncovered. Fig. (b) shows a medium configuration and Fig. (c) shows the robot gripper to the minimum size where the holes are closed through the guides and the intermediate edges. The dotted line (work space) shows the component's perimeter. Configuration (a) is critical because the blind areas are maximum, therefore a flow simulation is essential.

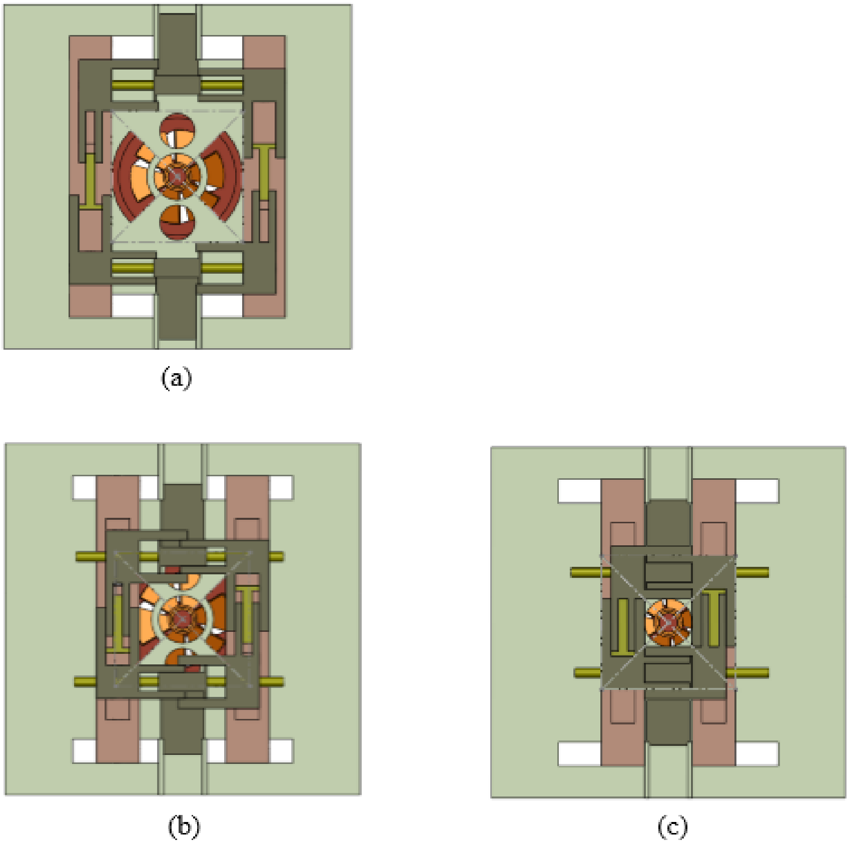


Figure 3.12. Reconfigurable gripper in different configurations. (a) The biggest configuration, (b) A medium configuration, (c) The smallest configuration.

3.6 Evaluating the parts geometry

To evaluate the gas flow within the gripper and the flow distribution onto the component surface, three main configurations of the gripper have been chosen (Figure 3.14). In order to use the flow simulation, the models have been simplified. As expected, in the smallest and medium configuration, the gas flow's distribution is homogenous onto the component surface.

Figure 3.15 illustrates the flow simulation in the biggest configuration of the device. The hot gas directs inside of the external nozzle homogeneously.

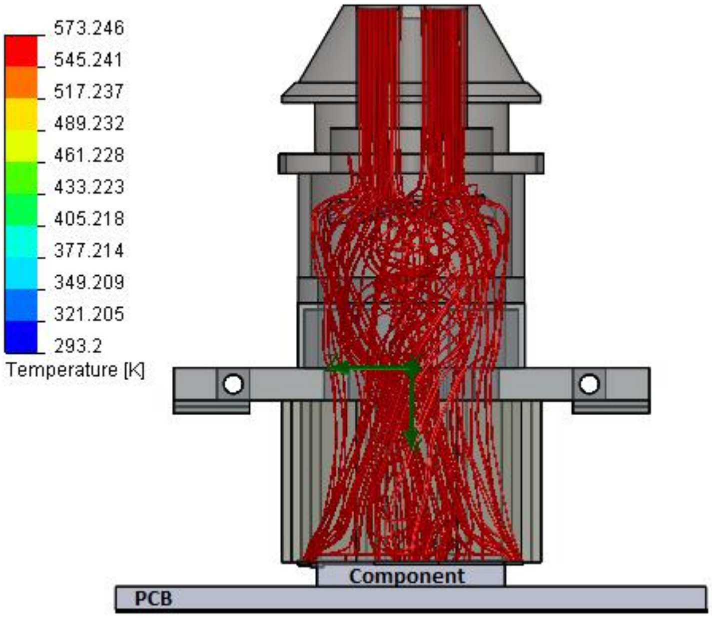


Figure 3.13. Illustration of the gas flow simulation inside of the gripper

Chapter 4

Mechanical structure

4.1 Mechanical Assembly

This chapter intends to explain and to reason on the method of assembly. At the beginning there were numerous problems which have defined new mechanical conditions. These limits will be explained one by one. One of the important problems to manage was the synchronization of the degrees of freedom. As it would be shown in Fig. 4.2 there are 4 independent DOF for 4 sides (left, right, up, down). Using a mechanism illustrated in fig 4.1 it was possible to reduce the DOFs from 4 down to 2. Two horizontal and vertical rails change the area of the planar base by moving the corresponding parallel edges concurrently and symmetrically. Therefore, while the left side closes up to center, the right side does precisely the same movement. This will result in a better movement control and makes the gripper mechanism simpler and more economic by eliminating two DOFs. To reach this target, a double threated bar was used. The first motor applies a torque throw a gearhead to the shaft which has two equal bevel gears. Through these bevel gears, two other threaded bar rotate.

Two ends of the bar are symmetrically threaded up to the middle in opposite direction. It could be made by welding two normal M2 screws on the same end. This mechanism make the two L-parts move simultaneously and synchronously. As the motor rotates a single screw linking the two threaded bars. Here the first problem occurs: it is not possible to utilize a fixed base for other two vertical rails, because the distance between these two sides is going to change. The solution would be exploiting a normal bar instead of a screw and put a motor just for one rail. Therefore, by moving the right side, the left side follows the movement. There is an important point to consider: the second motor has no fix place, hence the first motor have to move the second motor mass as well. It applies a higher inertia to first motor.

But there is a non-negligible problem that if the motor applies forces to the right side, probably the left side's length would not be exactly like the right side because of the elements' bending. Therefor it is useful to exploit two bars passing through all the components of up and down sides. Each bar is stainless steel and has the same diameter as the screw M2. In this way the right side can move the left side easily because the friction in rails is low and at the same time the horizontal rails have not a considerable bending.

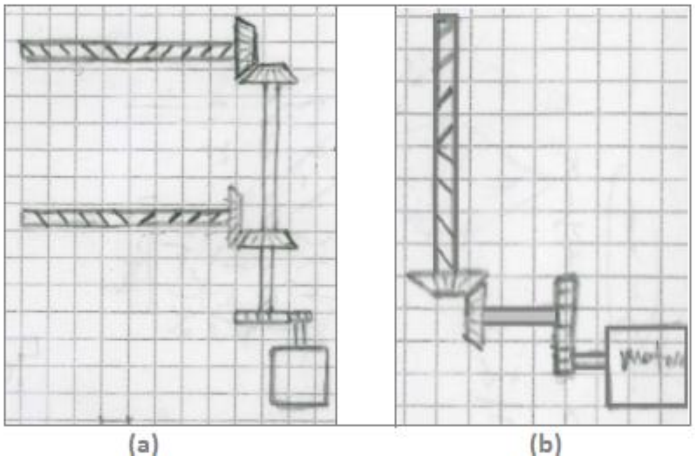


Figure 4.1. Primary concept for the gripper mechanism; (a) adopted for the first DOF; (b) adopted for the second DOF

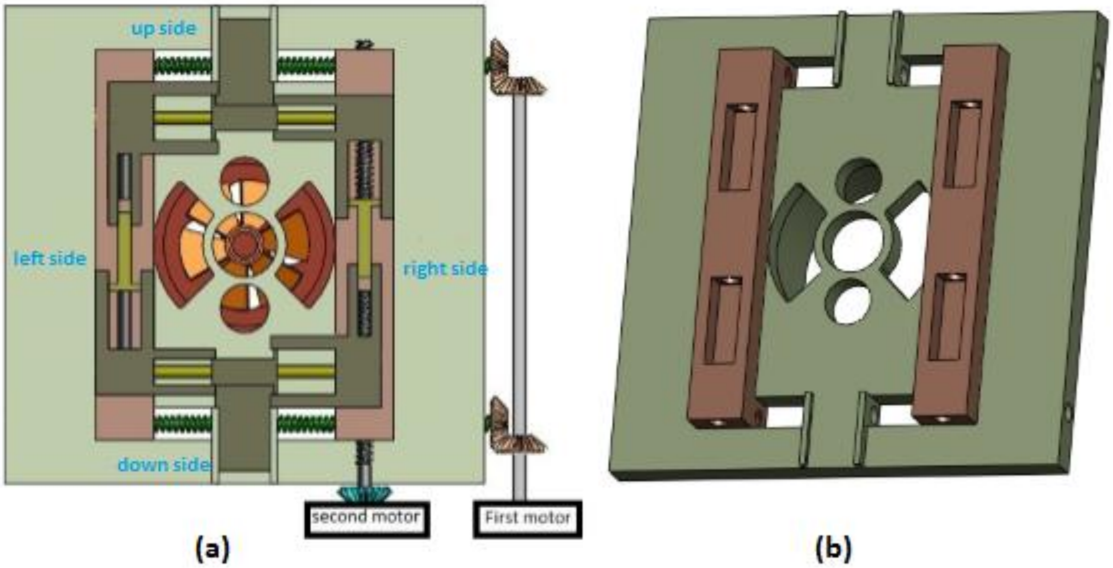
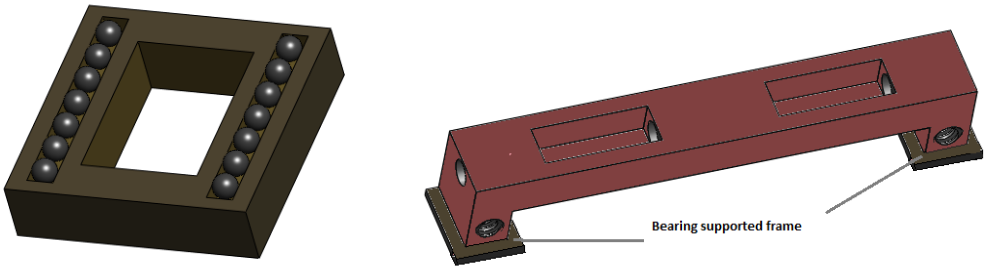


Figure 4.2. (a) Top view of the gripper; (b) schematic of the rails on the planar base and the guides

A fundamental element is a frame supporting all the moving parts (Fig. 4.3). This frame contains two rows of spheres fora friction less contact surface. During the movements all parts should have minimum gap to prevent the leakage of hot air.

The supporting legs of guides is fixed on the frame through a negative tolerance.



(a) **(b)**

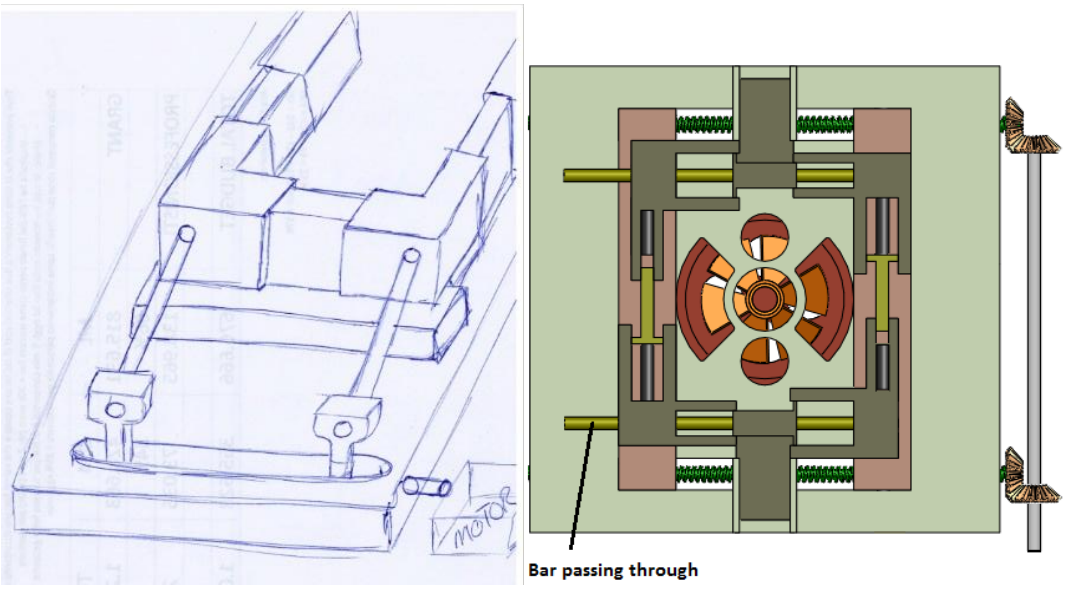
Figure 4.3. A pair of supporting frame (a) at bottom of the guide

Obviously the motor that could be useful in this case is a synchronous motor. There are some different types of synchronous motors and inverters. I suggest a step motor with an acceptable preciseness, because it is appropriate for controlling movement's position and velocity. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller) [34].

To diagnose the external dimensions of the components, there are two ways: in the first way the gripper knows the sizes of the components by data which the operator inputs. The second way would be more complicated because the gripper gets data from a calibrated vision system, which recognizes the dimensions through a camera and then compare them with a component-library.

4.2 Alternative solution

As an alternative solution to reach a fix position for second motor, it is suggested to use the two bars passing through all the components of up and down sides (Fig.4.4.b). As shown in figure 4.4, the bars are connected together through the same mechanism adopted for the first DOF (with using a double threated bar).
Hence the problem of the first solution is resolved and the location of both motors are fixed.



(a) (b)

Figure 4.4. (a) Schematic design of the alternative solution; (b) location of the bar passing through

4.3 Materials

In this section the materials used in different parts of the auto adaptable gripper structure are suggested.

In functionality of the grippers two problems play significant roles in selection of the materials:

First problem is related to thermal expansion coefficient. Since the workplace temperature is high (around 300 ° C), choosing a material with high thermal expansion coefficient can cause blockage in the mechanism or some difficulties in components' movement.

Of course if all the parts are made of the same material, this problem is not anymore that important.

Second problem is friction. Since the gripper is adaptable to different size ratio of components, this task requires frequent sliding of moving parts on the planar base of the gripper. This friction between sliding parts may reduce the useful life of this system, and the total operation efficiency. Therefore all the components should have good sliding features. Since the gripper is attached to the robot interface overturned (upside down) the inertial force due to the gravity can help to reduce the friction.

The proposed materials are reported in the following in case if for different components of the gripper different materials are considered.

The holder, the planar base and the guides of the gripper can be a stainless steels alloy.

For the L and the middle parts of the grippers, which are moving parts, an alloy of tungsten is a proper material regarding to the thermal expansion coefficient, but the selection of a suitable coating would be also essential, this is because of the high probability of tungsten to oxide and its cost.

This anti-wear coating must satisfy basic terms as following:

1-Anti- friction properties
2-Does not delaminate easily during working condition
3-Must withstand working temperature
4-Adequate hardness
5-Reduced cost

Between different types of anti-friction coating in industries we mainly focus on 3 common coating as:

Tungsten Carbide

Sintered tungsten carbide are very abrasion resistant and can also withstand higher temperatures with melting point above 2800 °C. Tungsten carbide is extremely hard with a Vickers number of 1700–2400 and has a Young's modulus of about 550 GPa.

In steel and metals production, tungsten carbide coatings are widely used from ore production through finished product. A multitude of accepted applications show dramatically reduced maintenance costs and improved production quality. It would be applicable by thermal spray coating.

Chrome Oxide Coatings - Cr2O3

Chrome oxide (Cr2O3) coatings provide excellent wear resistance and high chemical resistance. Chrome oxide coatings are commonly applied to rotating and moving equipment, and numerous other parts and components to provide greater wear resistance

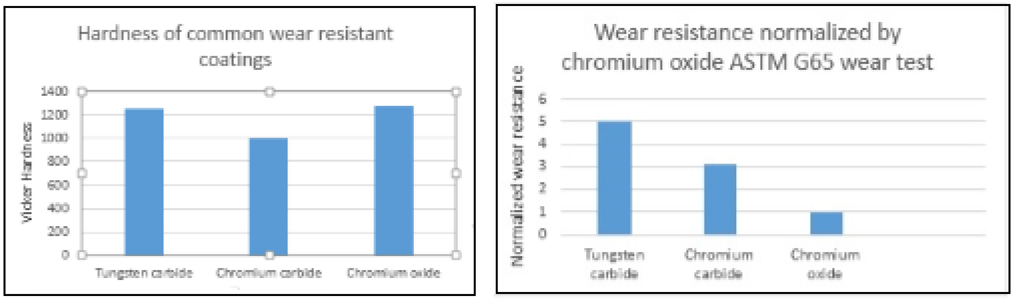
Chromium Carbide Coating

Carbide coatings are a combination of ceramic and metal which is called cermets. Cermets show hardness and wear resistance properties similar to solid sintered carbide components like carbide metal working tools.

By adding chromium carbide crystals into the surface of a metal the wear resistance and corrosion resistance of the metal significantly improves , meanwhile this material maintains these properties at elevated temperatures. The most common composition of this carbide is Cr3C2 with melting point of 1895 °C.

The two following graphs compare the suggested materials from the hardness and wear resistance point of view.

According to the graphs and characteristics of the materials, the best material to use is tungsten carbide which has the maximum hardness and resistance [35]-[39].



(a) (b)

Graph 4.1. (a) Comparison of hardness of wear resistant coating; (b) Comparison of wear resistance normalized

4.4 Conclusions and future works

The activity focused on the conception of an auto adaptable gripper for PCB automated rework.

In particular, this gripper is designed to support the desoldering and resoldering of surface mounted components with hot air or gas jet at a controlled temperature and pick and place them. Indeed, an electronic printed circuit board (PCB) integrates a set of components with different dimensions. Therefore many different specific tools for each type of component to be processed have to be available, introducing several and time consuming tool changer phases.

The proposed gripper can be a good replacement for a range of tools in the rework process to manipulate surface mounted devices. This gripper is a combination of an external nozzle as reflow tool and a suction tube as pick & place tool.

This robotic gripper having the covering closure property and a shape-switching feature can perform the desired task. The proposed design would lead to a simplification of the rework process, making it more flexible, more efficient, and not very expensive.

Future research will focus on the optimization of the design, definition of the materials of the different parts of the gripper, a more detailed analysis of the gas flow inside the gripper, the fabrication of the prototype and a performance evaluation.

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