Olli Koski

AUTOMATICALLY ROTATING JIG FOR PRINTED WIRED BOARDS

AUTOMATICALLY ROTATING JIG FOR PRINTED WIRED BOARDS

Olli Koski
Bachelor's Thesis
Spring 2020
Mechanical engineering
Oulu University of Applied Sciences

TIIVISTELMÄ

Oulun ammattikorkeakoulu
Konetekniikka, Koneautomaatio

Tekijä(t): Olli Koski
Automaattisesti kääntyvä jigi piirilevyille
Automatically Rotating Jig for Printed Wired Boards
Työn ohjaaja(t): Kai Jokinen
Työn valmistumislukukausi ja -vuosi: Kevät 2020
Sivumäärä: 50 + 49 liitettä

5G- teknologiaa kehitetään vauhdilla eteenpäin ja tarkistettavien piirilevyjen määrä kasvaa jatkuvasti. Piirilevyjä mitataan manuaalisesti, mikä on hidas prosessi ja sitä halutaan nopeuttaa automatisoimalla prosessi. Tämän opinnäytetyön tarkoituksena oli kehittää automaattisesti kääntyvä jigi piirilevyille, jotta automaattinen mittausprosessi voidaan suorittaa piirilevyn molemmilta puolilta kääntämättä piirilevyä manuaalisesti.

Projekti suoritettiin tuotekehitys projektina systemaattisesti vaiheittain edeten esisuunnittelusta detaljisuunniteluun. Työ aloitettiin ongelman määrittämisellä ja vaatimuslistan laatimisella, minkä jälkeen päätoiminto jaettiin osatoimintoihin ja niille etsittiin ratkaisuja. Ratkaisu vaihtoehdot pisteytetiin ja niiden perusteella valittiin yksi ratkaisu jatkokehitykseen. Valitusta ratkaisusta tehtiin Solidworks ohjelmalla 3D- malli ja valmistuspiirustukset. Tarvittavat laskelmat tehtiin PTC Mathcad Prime ohjelmalla.

Projektin tuloksena syntyi valmistuskuvat piirilevyn jigistä ja sen kääntölaitteesta prototyypin valmistamista varten. Jatkokehityksessä kiinnitysmekanismeja voitaisiin yksinkertaistaa, jolloin mitattavien piirilevyjen kiinnittäminen jigiin olisi tehokkaampaa ja nopeampaa parantaen kokonaisprosessia.

Asiasanat: piirilevy, kokoonpano, tuotekehitys, jigi, automaatio

ABSTRACT

Oulu University of Applied Sciences
Mechanical Engineering, Machine Automation Engineering

Author(s): Olli Koski
Automatically Rotating Jig for Printed Wired Boards
Supervisor(s): Kai Jokinen
Term and year when the thesis was submitted: Spring 2020
Pages: 50 + 49 appendices

5G technology is rapidly being developed and the amount of the printed circuit boards to be measured is constantly growing. Printed wired boards are manually measured which is a slow process and, therefore, to speed up the process through automatization is desired. The purpose of this thesis work was to develop an automatically rotating jig for printed circuit boards so that necessary measurements can be performed on both sides of the board without manually rotating it.

The project was carried out as a product development project by systematically moving forward step by step from the preliminary design to the detailed design. The project was launched by defining the problem and drafting a criteria list after which the main function was divided into subfunctions and studied solutions for them. Each solution was scored and according to the results, one solution was selected for further development. In the further development phase, a comprehensive model was created by using SolidWorks and necessary calculations to support chosen machine parts by using the Mathcad.

Detailed drawings of the jig and rotating mechanism was produced as a result so that the prototype can be manufactured. The unit could further be developed by simplifying the attachment mechanisms which would result in reduced installation time of the device under test to the jig and, therefore, speed up and enhance the entire process.

Keywords: printed circuit board, assembly, product development, jig, automation

TABLE OF CONTENTS

1 INTRODUCTION

Printed wired boards (PWB) or printed circuit boards (PCB) are often used in several different industrial and domestic applications such as computers, radios and televisions. Due to the wide scope of applications, Layout designers are challenged to continually develop more advanced structures while passing the mandatory standards and ensuring that the customers' needs are met.

Before the PWB is delivered to the customer, several various tests are run through it to ensure its proper functionality. Testing is a very time-consuming phase in PWB's developing cycle as it takes a few weeks depending on the product and if any flaws in signals or errors in software are discovered, additional weeks are required to fix all the necessary issues. (1.)

Currently, the testing procedure is executed manually by engineers. However, completely automated testing unit is currently being developed and of which this automatically rotating jig for printed wired boards is part of. Main purpose of this jig is to automatically rotate 180- degrees to enable the unit to complete complex signal measurements from the top and bottom faces of the PWB. The goal is to design an automated jig for a wide range of products with different dimensions and shapes.

This thesis work is commissioned by Nokia.

2 TEST AUTOMATION PROJECT

When a prototype of the product is developed, a comprehensive range of digital signals are measured to detect electromagnetic interferences, signal integrity, rise and fall times etc. Presently, the complete testing procedure is executed manually by digital engineers and a single PWB may contain more than ten thousand signals which is very time consuming and results in increased costs. (1.) Test Automation Project is a project where variety of the testing procedures are being automated.

2.1 Measuring digital signals

“Digital signal is discretely timed signal in which information is represented by a number of well-defined discrete values that one of its characteristic quantities may take in time”. (2, NOKIA SharePoint -> Terminology -> MOT_List ->digital signal). Typical instruments that are used to measure digital and analog signals are an oscilloscope and a passive or active probe.

Measuring digital signals in the 5G- development requires more expensive and sophisticated measuring instruments compared to domestic and educational use. In order to measure the latest DDR4- memory for instance, is recommended to possess an oscilloscope with 16GHz bandwidth (3, p. 42).

Signal quality is determined as a pass or a fail within certain standards and specifications set by component manufacturers. Each test has certain signals to be measured and a report must be written.

Several issues must be considered and acknowledged before signal measurements can reliably be taken such as selecting the correct differential or single-ended probe, oscilloscope with required applications and several physical phenomena for instance, if the length of the ground lead in single-ended probing is increased, the inductance and measured signal excites ringing at a lower frequency (Figure 1) (4, pp. 2-4).

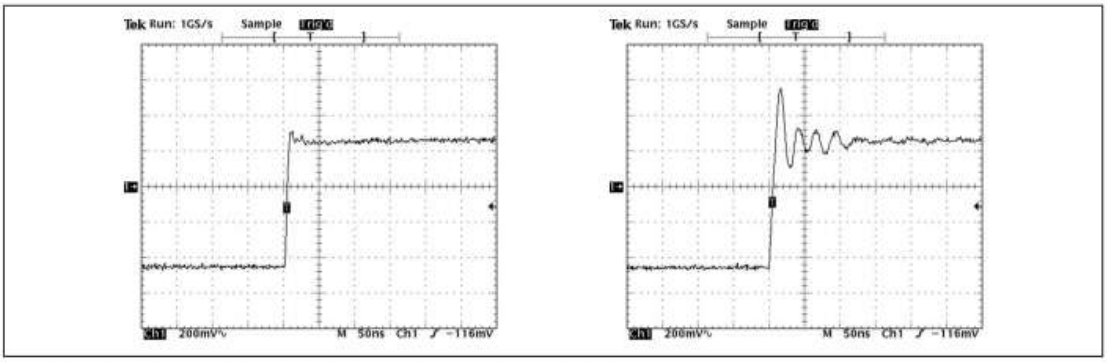

Figure 4a and 4b. The figure on the right shows the effects of inductance caused by a long ground lead.

FIGURE 1. Example phenomenon that must be considered. Effect of inductance caused by a long ground lead (4, p. 4)

The measuring process, however, is relatively simple: The probe is attached to the oscilloscope with an appropriate cable and the tip of the probe is placed on the physical test point on the device under test (DUT) the signal is desired to be measured from. The signal appears on the screen of the oscilloscope where it is analyzed by the engineers.

2.2 Semi-automatic testing unit

The first step in the process of launching towards the automated unit was to create the Feasibility Study. The Purpose of the Feasibility Study is to assist project managers to take all the relevant factors into account in terms of technical, economic and legal aspects to see if the project is valuable enough and, eventually to decide if it can successfully be completed (5, Investopedia -> terms -> feasibility study.) Based on the studies the project was approved and automation process were divided into two major milestones: the semi-automatic and fully automatic (6).

The semi-automatic phase was focused on master application development which will control the whole test unit: to set up instrument settings correctly for each test, create connection to the DUT, run all the programs automatically without the need for manually open them and, responsible for each actuator in the unit.

2.3 Fully automatic

Where semi- automatic milestone focused on application development, the fully automatic phase introduces all the automated mechanical movements inside the unit and removes the need of constant manual movements between the test points.

The test points are in both sides of the DUT which requires the jig to be able to rotate 180- degrees automatically without the need of an operator. In the early phase of automatization development, the jig must be rotated frequently to avoid the testing process being interrupted. The goal, however, is that all the test points on the top side of the jig are prioritized jig is rotated only once after the top side is successfully tested. This can be achieved through software optimization and developing an algorithm that will recognize which side the test point is on.

3 PRELIMINARY DESIGN

A preliminary design is a phase in machine and product development of which primary goal is to create a preliminary detailed design. A preliminary detailed design generally describes a few concepts that would solve the specified problem. In this phase the definition of the product architecture, subfunctions are introduced and preliminary design of key components can be modelled without specifying the complete geometry, materials and tolerances. (7, pp. 11-16, 24.)

Preliminary design was implemented to achieve concept of solutions that would suffice. This section consists of clarifying the problem, creating a list of requirements, dividing the main function into subfunctions, introducing solutions to the subfunctions, creating a morphological box, scoring the solutions and choosing the solution for detailed design.

3.1 Clarifying the problem

The automatically rotating jig had a few areas that caused challenges and demanded solutions in order to be capable of rotating accurately and yet holding the PWB at fixed location. The problems were categorized as follows: mechanics for rotating the jig, ability to hold the PWB at fixed location the entire time, supports for the PWB to avoid bending caused by gravity and a cooling unit to avoid components from overheating.

3.2 Requirement analysis

Requirement analysis can be represented as a list of demands and hopes which should be considered in a design project. It creates the demands for the geometry of the product, standards and protocols to be used and defines the basis for what is needed. It also assists on evaluating each decision made and to be made. The demands are classified in three groups. Fixed demands which must be considered in every case. Minimum demands which should be accomplished to a specific point, exceeding that may be beneficial but not harmful. Hopes are customer's wishes of specific functions or abilities that are fulfilled if it is feasible (Figure 2). (8, pp. 93-94.)

Change date	FD MD H	DEMAND	Importance
		1. GEOMETRY	
	FD	The jack is used in a garage (there is free space on both sides of the car,	
		approx. 1,5 m on both sides).	
	FD	The capacity must be capable of handling cars defined in fig. 6.4.	
	FD	Storing of the jack must be easy without an excessive use of space.	
		2. KINEMATICS	
		One of the lifting modes in fig. 6.2 must be possible.	
	MD	**3. FORCES**	
		Lifting capacity is 1300 kg.	
	MD	Necessary muscle force $\leq$ 150 N.	
	T	**4. ENERGY**	
	FD	Muscle energy of operator is used.	
		5. MATERIAL	
	FD	Steel in form of plate or profile.	
		6. SAFETY	
	FD	Working below the lifted car must be safe:	
		- securely lifted	
		- safe connection with the car	
		- wide contact area with the ground	
		- access to the lifted car possible (fire guarding during welding	
	FD	**7. MANUFACTURING**	
	H	No grinding	
	FD	Presses can be used	
	H	Plate thickness $\leq$ 8 mm.	
		Simple structure.	
	FD	**8. CHECKING**	
		Testing with car of weight 2000 kg.	
	H	**9. TRANSPORT**	
		Transport inside the car.	
	MD	**10. USE**	
	MD	Weight of jack $\leq$ 50 kg.	
	MD	Weight of individual parts $\leq$ 20 kg.	
		Time for preparation and lifting $\leq$ 5 min.	
	FD	**11. MAINTENANCE**	
		No maintenance needed.	
	MD	**12. COSTS**	
	H	Manufacturing costs < á 250 Fmk	
		(assumed annual production 2000 pcs/a)	
	KV	No investments in machines or buildings.	
		13. DELIVERY TIME	
		Structure ready for manufacturing until ....)	
		FD = Fixed demand MD = minimum demand H = hope	

FIGURE 2. Example list of demands for car jack (8, p. 94)

The list of demands was declared as requirement analysis and it was classified at the beginning of the project. Figure 3 shows what functions and properties were considered. In this analysis the fixed demand, minimum demand and hope were expressed as mandatory (MR), optional requirement (OR) and wish (W).

MR, OR, W	Requirement	Date	Note
	1. Geometry		
MR	500 x 609 mm PCB has to fit		
MR	Rotating 180 degrees around the horizontal axis		
OR	1000mm Max. total length		
MR	Height at least 350mm		
MR	Width at least 550mm		
MR	PCB fixed to frame/jig only from two sides		
MR	DUT supports (to avoid bending when force is applied)		
MR	5mm is maximum space between side and component		
OR	180-degree rotation locks		
	2. Calculations		
MR	Precision tolerance max. +-0.1mm		
MR	Force, moment of inertia, angular momentum		
MR	Required power		
OR	Bearings		
OR	Transimission		
	3. Source of energy		
OR	Electricity (step motor/servo motor etc.)		
	4. Material		
W	Aluminium, S235, Plastic, rubber		
	5. Safety		
MR	ESD - protected		
MR	Parts that have a risk of coming in contact with PCB's components must be grounded or resistant enough to electricity (NOKIA environmental Level 2), IEC 61340-2-3 for assembly supports and jigs 10^5 < Rg< 10^9 Ω		
MR	Cooling unit for DUTs		
	6. Software/logic		
W	PLC, arduino/Raspberry pi etc.		
	7. Manufacturing		
W	Standard components		
W	Machining		
MR, OR, W	**Requirement**	**Date**	**Note**
	8. Equipment		
OR	Sensors		
MR	Motor		
MR	Fans		
OR	Pneumatic accesories		

FIGURE 3. The list of requirements

3.2.1 Mandatory requirements

In the list of requirements several functions and properties were classifies as a mandatory requirement because of strict demands set for the jig to operate purposefully as a part of the complete and complex test cell unit. Generally, every geometrical function must be fulfilled due to the limited dimensions of the test cell as well as rotational movement of exactly 180 degrees to meet the expectation of the total deviation of 0.1mm in precision accuracy.

Certain calculations such as applied force, moment of inertia and required power from the motor were mandatory calculations to optimize smooth rotational movement, sizing proper motor and designing supports that can withstand the applied force of the probe and gravitational force of the PCB.

Safety related functions and properties must be considered in every relation and, therefore, they were labeled as mandatory requirements. The two most crucial issues to be considered were the protection from the electrostatic discharge (ESD) and component overheat. ESD is a flow of electricity between two electrically charged objects (9, p. 8). In printed circuit boards, ESD may cause severe damage in sensitive components which is extremely cost increasing factor. The same risk exists with the factor of overheating for which the cooling unit is necessary. In addition, every component that might encounter components, must be covered with material that is electrically resistant enough according to the IEC 61340-5-1:2016 (9, p. 17.)

3.2.2 Optional requirements

A few functions were declared as optional requirement since there were not occurred any specific demands for using a certain exact product or material but rather general product or material of a certain family for example, the source of energy was to be electricity but whether the motor was a servo motor, stepper motor or equivalent electrically operated, was not emphasized.

The total length was planned to be less than 1000mm however, exceeding that slightly would not cause any issues. The matter of bearings and transmission were discussed as a possible part-solution of the jig and they were left undetermined at this point of the design process and return to it in case they are defined later in the chosen solution.

Most of the accessories and equipment were also defined as optional requirement because at that moment, it was uncertain of what sensors or controllers will be used.

3.2.3 Wishes

The final group the list of demands is divided into is the wishes. In this project the wishes included the use of standard components, basic materials such as aluminum and steel, manufacturing by machining and embedded control system that has or is easy to create compatible interfaces with the logic of the whole test cell.

3.3 Main function and subfunctions

In the systematic designing process, to find applicable solutions, the main function must be split into subfunctions. Figure 3 shows an example of dividing the main function into subfunctions.

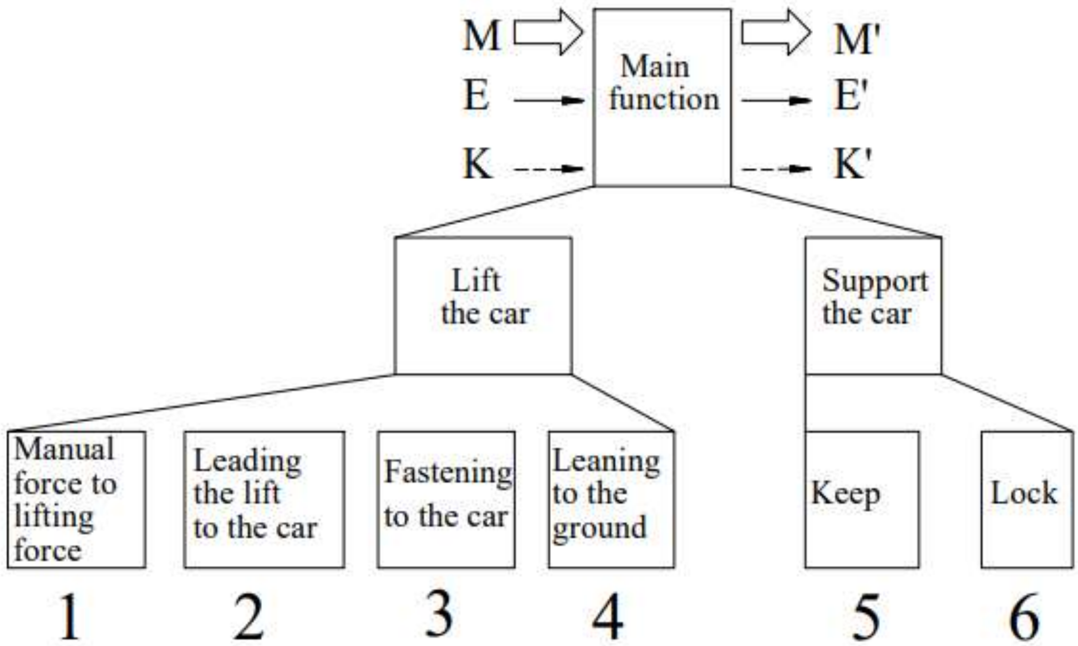

FIGURE 3. An example of dividing the main function into subfunctions (8, p. 97)

The main function was divided into five subfunctions: logic/controlling unit, attaching PWB to the jig, rotating and locking mechanism, supports for PWB and the cooling unit (Figure 4) based on the conclusion that by finding a solution for those would effectively resolve the main function.

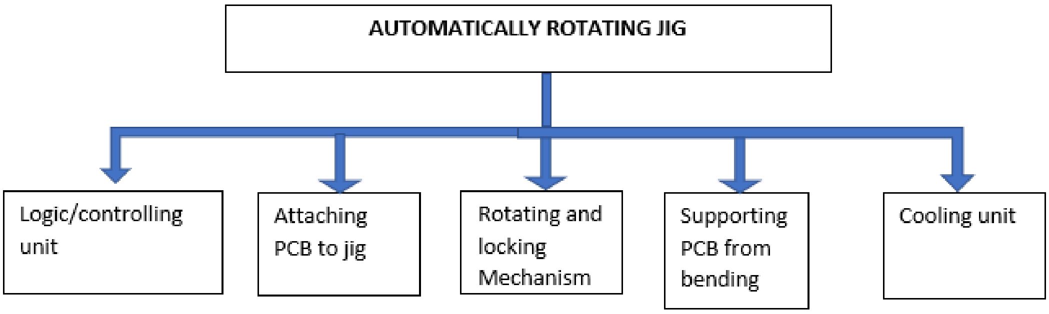

FIGURE 4. The main function divided into subfunctions

3.3.1 Logic/controlling unit

Almost inevitably, a logic or a controlling unit is required in every automated system. A control system often consists of five basic components (figure 5.): input, process being controlled, output, sensing elements, and controller and actuating devices.

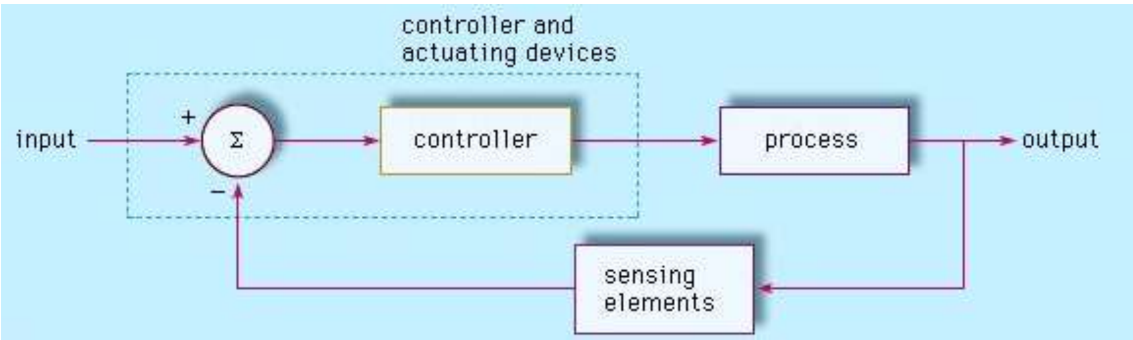

FIGURE 5. The components of a feedback control system and their relationships (10.)

The input represents the reference value of the system which is desired operating value of the output. The sensing elements are sensors or other measuring devices that monitor the variable of the output. If the value of the output differs from the reference value, the controller and actuators will behave accordingly to influence on the output variable. (10.)

The feedback control system is needed in this automated jig as well. However, in the preliminary design phase, more detailed specification of which system is selected was left undefined. At this point the purpose was to map the need for it.

3.3.2 Attaching PCB to the jig

It was enormously important to consider that the PCB remains at the fixed location the entire time to meet the accuracy of 0.1 mm that was specified in the requirement analysis. Consequently, if that goal is failed to accomplish, the entire test cell unit is unable to execute any measurements reliably. Moreover, additional challenge was brought up by the fact that the distance from the nearest component to the side of the PCB might only be 5mm and the PCB can only be hold at place from two opposite sides.

3.3.3 Rotating and locking mechanism

Measurements must be taken from both top and bottom sides of the PCB which creates the need for automated rotating mechanism. Due to the strict accuracy tolerances and cabling, it must mechanically be ensured that rotation is not allowed to pass beyond 180 degrees (11).

3.3.4 Supports for PCB

The largest printed circuit board around 500mm x 600mm and the mass is approximately 3kg. Those two properties combined is enough for gravitational force to slightly bend the PCB without additional supports and increase the risk of failures in the measuring process. As mentioned earlier, the dimensions and shapes vary between products and therefore, the support must be designed universally so that it is feasible for every product.

3.3.5 The cooling unit

During the testing process, components tend to overheat due to the constant flow of current without separate cooling unit to transfer the thermal energy to elsewhere. Cooling must simultaneously be produced to both top and bottoms faces of the DUT. In addition, the cooling unit must be able to concentrate the cooling to a specific area on the DUT or generally cool down the entire area of the board.

3.4 Solutions for subfunctions

When subfunctions were defined, alternative solutions for subfunction were being studied. At this phase of preliminary design in fact, the emphasis was in studying several different alternatives without worrying about the quality or functionality of the solution. Table 1 shows variety of solutions for each subfunction that could potentially solve desired functions.

TABLE 1. Drafts of alternative solutions for subfunctions

Subfunction number	Sub function	solutions for subfunctions				Note
1	LOGIC/CONTROLLING UNIT	Arduino	Raspberry pi	PLC		
2	ROTATING AND LOCKING MECHANISM	Electric motor, cogwheel transmission and shaft	Pneumatic cylinder and connecting rod/ crankshaft based	Hydraulic cylinder and joints	Two connected pneumatic cylinders with joint	Locking mechanism is torque of motor and/or mechanical lock in rotating shaft.
3	ATTACHING PCB TO JIG	Tightening to holding parts with screws	guide profiles	quick fastens	pressure/friction based. High friction coefficient (material) with compressive force	
4	PCB SUPPORTS	Air bag	support screws	middle support (vacant space designed specifically for supports)	electric motor with cylinder shaped support plate	
5	COOLING UNIT	Existing design	liquid cooling	low surrounding temperature	Thermal conduction through material design	

3.4.1 Evaluating alternative subfunction solutions

3.4.1.1 Logic

In the perspective of the Test Automation Project, it is suggested that a programmable logic controller (PLC) is the most effective controlling unit in this project because the interfaces between this PLC and the one with responsible for the entire unit would have already been created (12). Even though, an Arduino and a Raspberry Pi are generally applied in relatively small and simple applications with one or a few functions, they would probably be able to handle the level of automated functions required in this jig with lower cost compared to a PLC. The unit’s controller or a master was also considered as a possible solution for this subfunction. However, if each automated accessory requires an input and output slots for cabling, it may not be advised to connect them all to the master controller of the unit and reserving all the slots but instead, creating a controller unit that is responsible for the automated jig and inserting it between the master controller of the unit and the accessories in the automatically rotating jig, would be more beneficial because then the test cell unit has several controllers or PLCs all commanded and controlled by the master controller.

3.4.1.2 Rotating and locking

The basic rotating mechanisms that were considered were a shaft with cogwheel transmission (Figure 6) powered by an electric motor, pneumatic or hydraulic cylinders attached by a single joint with a custom crankshaft-based rotation (Figure 7). The benefits of an electric motor with a cogwheel transmission are for instance, motor's enhanced torque through cogwheels to the shaft is equivalent to the gear ratio and diminished moment of inertia of the shaft and other rotating parts (13, p. 3). Hydraulic cylinders can produce a lot of force enabling an ease rotational movement. However, it was noticed that they can also leak which may not be wanted when handling sensitive components. Pneumatic function in matter of rotating the jig would solve the possible leakage of the hydraulic application in the loss of power though. Both, hydraulic and pneumatic solutions require space which may not be available in a compact test cell unit in a laboratory condition.

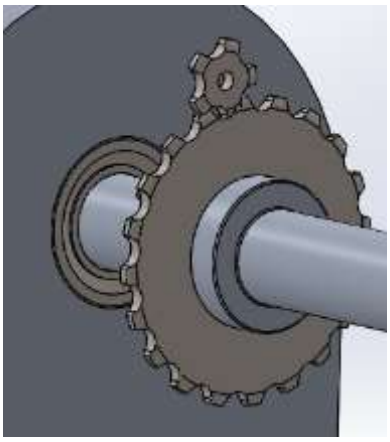

FIGURE 6. A sketch of the shaft with the cogwheel transmission

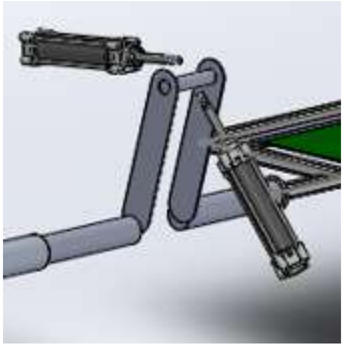

FIGURE 7. A draft of the pneumatic or hydraulic cylinders attached to a single joint

3.4.1.3 Attaching the PCB to the jig

Being able to attach the PCB to the jig accurately, easily and reliably is probably the most vital function in this jig because the automation unit may be unable to locate the test points if the PCB moves after it is fastened to the jig or during the rotational movements. Tightening the PCB to the holding parts with screws is efficient but time consuming. Guide profiles allow a simple and rapid attachment, though, there might not be enough force to keep the PCB fixed to a specific location. Quick fasteners enable fastening the PCB quickly and effortlessly but may demand customization if standard quick fasteners for the mechanical holes of the PCB do not exist. It was experimented that using a relatively weak compressive force to the opposite sides of the PCB is enough to hold it still if material with a high friction coefficient is considered. Figures 8-10 show sketches of attaching PCB to jig.

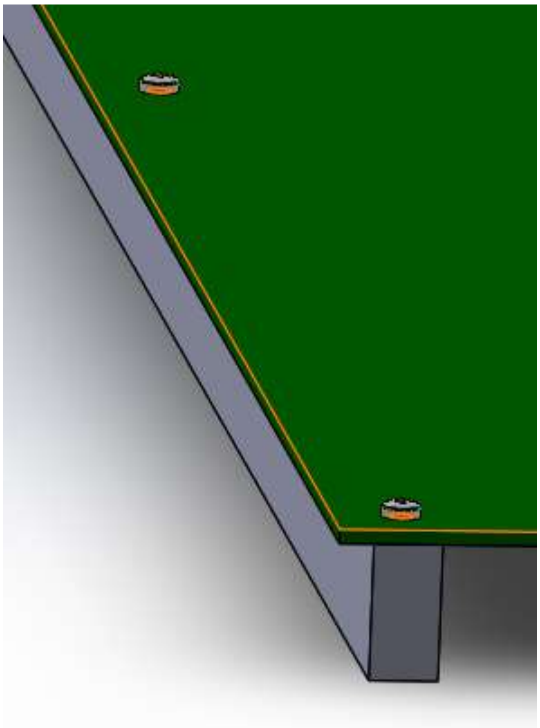

FIGURE 8. Tightening the PCB with screws

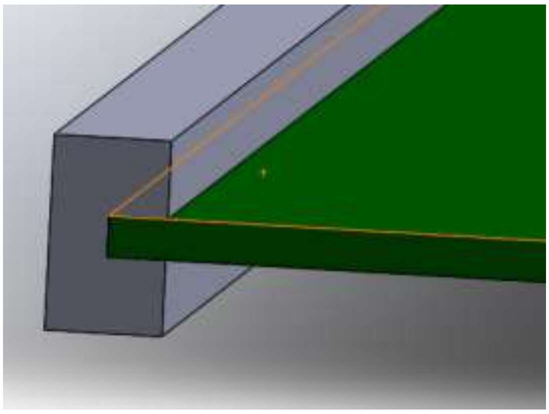

FIGURE 9. Attaching PCB to jig with guide profiles

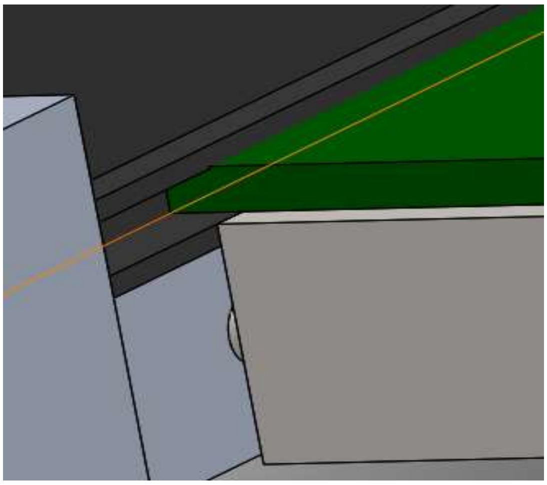

FIGURE 10. Holding the PCB at fixed location through material design and friction

3.4.1.4 Supports to avoid bending

The most challenging section in designing of the jig is likely to be the supports for the PCB due to components' altered locations through different versions of prototypes. A pressurized "air bag" covers the complete area of the DUT and supports it evenly. It would be in contact with components which will not cause any issues if material is electrically resistant and physically elastic to allowing components being sunk into and, thus, supported effectively. If the air bag is applied, the ability to cool down the components may bring additional challenges in the designing of the cooling unit. Figure 11 shows a rough draft of the pressurized air bag as a middle support.

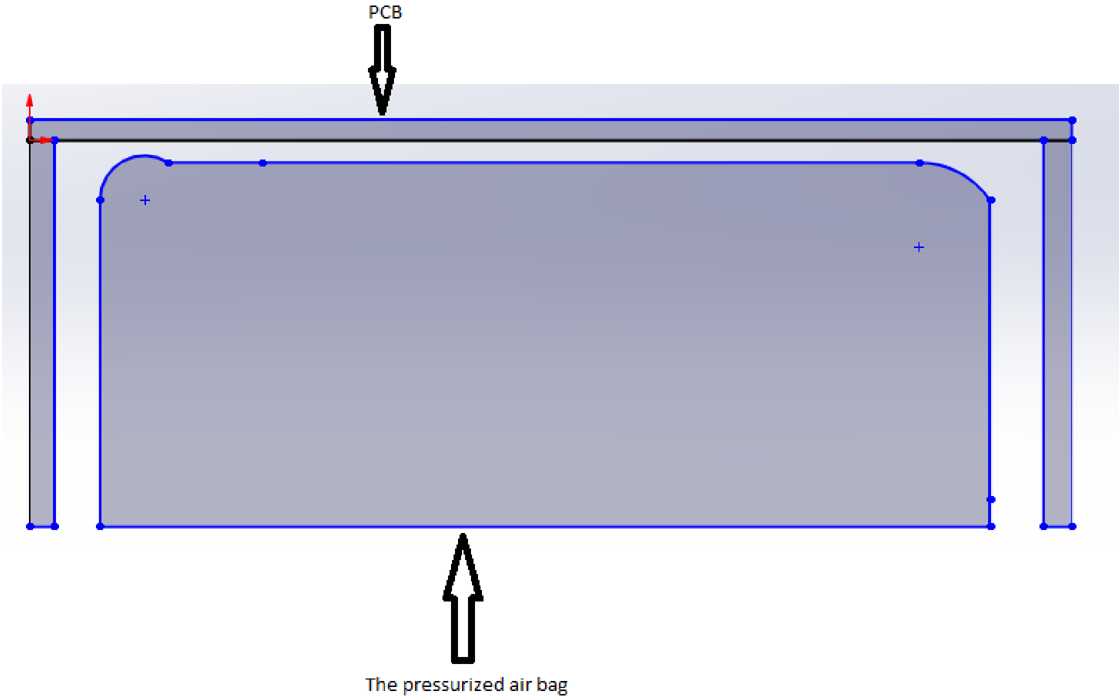

FIGURE 11. A rough draft of the pressurized air bag as a middle support

The support screws through the mechanical holes of the PCB, however, is a more viable option as the holes already exist and there can be found a broad list of standard screws which decreases the need of designing and manufacturing custom components. Moreover, it is a simple yet effective solution that is theoretically going to meet the demands. On the other hand, as the DUT is rotated, the coordinates of the holes are changed as well. This brings up a mathematic and algorithmic problem of figuring out the new coordinates automatically when the PCB is rotated. Figure 12 shows a draft of support screws through the mechanical holes of the PCB.

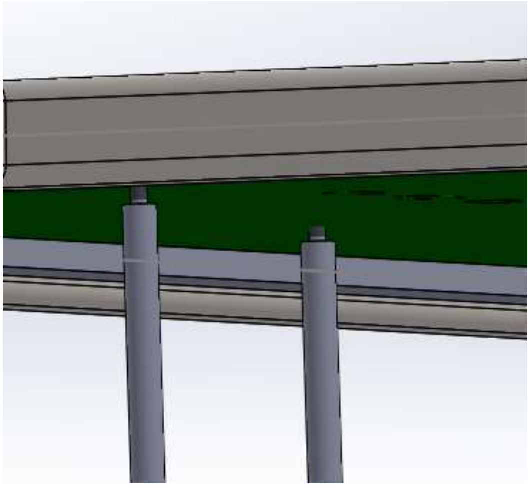

FIGURE 12. Supporting the PCB with support screws through the mechanical holes of the PCB

If the dimensions of the PCB exceed certain limits, there will be a vacant space designed in the layout specifically for the middle support (Figure 13) that is needed in the production line. Therefore, it might effectively be applied when designing proper supports for the PCB. In addition, certain products require a test adapter for which supports are also needed. The test adapter must be connected to the prototype in order to be able to measure each signal. (1.)

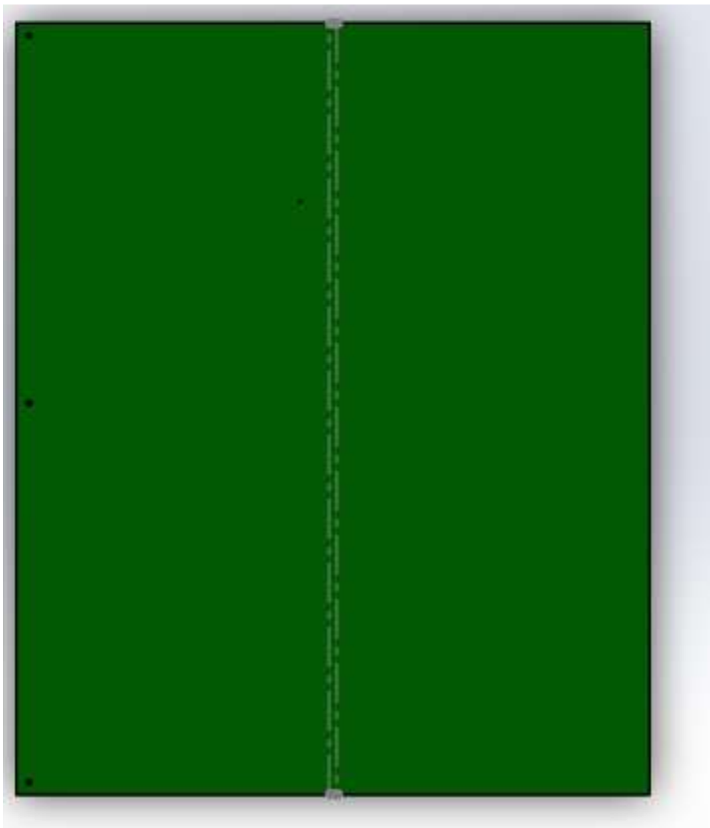

FIGURE 13. Space occupied for the middle support

3.4.1.5 Cooling down the PCB

Currently, there are fans blowing (Figure 14) air through the heat sinks in which the thermal energy is transferred from the heating components. The existing design is effective if the fans are aimed towards the heat sinks. Moreover, fans can quite effortlessly be automated.

FIGURE 14. Currently used fan for cooling

Liquid cooling has an excellent thermal performance and effective heat removal ability. However, it is recommended to note that liquid cooling requires hosing or piping and it along with cabling can cause major challenges in the unit's already limited space.

Low surrounding temperature with air flow would assist in terms of enhancing thermal convection. This option, though, was ruled out as of the fact that the PCB must be tested in several different temperatures ranging between -40°C to +65°C. Thermal conduction through material design may not suffice as the same context has already been applied to heat sinks and, yet, external fans are required because the total amount of thermal energy produced during an intense testing phase can raise up to 1 kW. (6.)

3.5 Solution combinations for the main function

Table 2 shows the chosen total of three best combinations for the solution of the main function.

TABLE 2. Three different solutions for the main function

Solution #	LOGIC/CONTROLLING UNIT	ROTATING AND LOCKING MECHANISM	ATTACHING PCB TO JIG	PCB SUPPORTS	COOLING UNIT	NOTE
1	PLC	Electric motor, cogwheel transmission and shaft	pressure/friction based. High friction coefficient with compressive force	middle support (vacant space designed specifically for supports)	Existing design	Modular support head can be designed in case there is no middle support in PCB layout.
2	Arduino	cylinder and connecting rod/ crankshaft based	Tightening holding parts with screws	air bag	Thermal conduction through material design	
3	Raspberry pi	Two connected pneumatic cylinders with joint	pressure/friction based. High friction coefficient with compressive force	middle support (vacant space designed specifically for supports)	Existing design	

The first solution has the PLC as a controlling unit and rotating mechanism is executed with an electric motor connected to the jig by the shaft and transmission. Attaching the PCB to the jig is relied on creating pressure on both faces of the PCB along with material that possess high friction coefficient to avoid horizontal movements. In supports and cooling unit, the existing designs will be applied to a certain point and modified if necessary.

The second solution involves an Arduino as a controlling unit for enabling hydraulic cylinders to rotate the assembly. Screws are used to ensure PCB's fixed location in the jig. Pressurized air bag supports the PCB evenly and tolerances occurring from bending are minimized. In this solution, material design is crucial for thermal performance and cooling down the PCB.

The third option uses a Raspberry pi for controlling same rotating mechanism as in the previous option. Attaching the PCB to the jig, supports and cooling unit follow same properties as in the first solution. Mentioned solutions were found to be the most effective for this application.

3.6 Weighted scoring

Weighted scoring is a method where chosen solutions are evaluated by scoring the most important and essential criteria mentioned in the criteria list and defining how each chosen solution meets these criteria (14). Table 3 shows the weighted scoring of the three chosen solutions.

TABLE 3. The weighted scoring

factor	coefficient	solution #			note
		1	2	3	
Rotating mechanism	0,8	5	3	4	
accuracy	1	5	4	4	accuracy of jig and rotating mechanism
compatability with test cell	1	5	4	3	Ability to implement to the test cell (creating interfaces etc.)
compactability	0,8	4	3	3	The final size of the jig. 5 is small and 1 large
simplicity	0,7	4	2	3	5 is the simplest solution and 1 is the most complex
required force	0,5	3	4	4	amount of force required
cooling ability	0,8	4	2	4	
modularity	0,8	4	4	4	ability to make changes easily
fixing the DUT in position	1	4	2	4	ability to hold DUT in locked position
programmability	0,6	3	4	3	ability to program
DUT supports	0,7	4	3	4	
cost	0,8	4	2	3	1 is most expensive and 5 is cheapest
∑		39,7	29,1	34,1	

In the first column, the most important factors are listed from the criteria list. The coefficient represents the importance of the factor where value 0 is not crucial at all and 1 is the most crucial. The next three columns represent different solutions in the same order as described in section 3.5. In the last column, notes are listed that has additional details about the factors or information about the row in general.

The total points each solution has received is shown in the last row. The first solution received 39.7 points where as the second received 29.1 and the third got

34.1 points. In conclusion, the first solution is expected to be superior compared to the other two. The second solution is more complicated to design, fixing the DUT into the position is more challenging, and the total cost is expected to be higher. The third solution should outperform the second one according to the weighted scoring. Nevertheless, it is evaluated to be slightly less compatible relative to the test cell than the first option. In addition, it physically requires more space and designing consumes more time.

3.7 Choosing the solution

A meeting was set with mechanical engineers to discuss which solution would most effectively operate under specified requirements. The first solution was decided to be taken into further development to the detailed designing. Figure 15 shows the preliminary design of the chosen solution for automatically rotating jig for printed circuit boards.

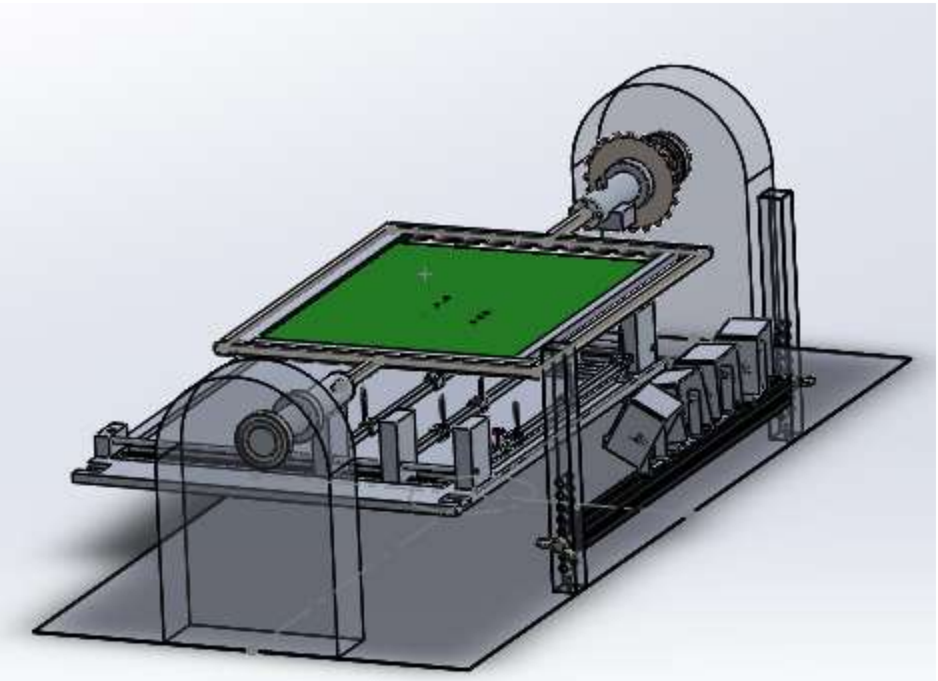

FIGURE 15. Preliminary design draft of the chosen solution (16.)

4 BASIC THEORY OF THE STUDIED MACHINE ELEMENTS

This section covers the basic theory of the machine elements that were needed or considered as a part of the automatically rotating jig.

4.1 Bearings

Bearings are mechanical assemblies that consist of rolling elements. The main purpose of the bearings is to minimize the friction between moving and stationary machine members. There are several different types of bearings, for example, ball and roller bearings and linear bearings. (15.) Figure 16 shows an example of the deep groove ball bearings.

FIGURE 16. Picture of the deep groove ball bearing (16.)

In this assembly, the bearings are positioned between the shafts and the support elements of the jig to minimize the friction between the two elements and, thus, diminishing the required torque for rotating the jig.

4.2 Electric motors

An electric motor is a device that converts electrical energy to a mechanical energy. Most of the electric motors operate by developing the mechanical torque through the interaction of conductors carrying current in a direction at right angles to a magnetic field. (17.) There are several different types of electric motors such as servo motors, stepper motors and linear motors that are specifically designed for certain applications requiring for example, high dynamic performance or torque. A servo motor will be used as a source of energy for the rotational movement of the jig. The sizing of the motor is carried out in section 5 detailed design.

4.3 Gear transmission

Gear is a machine component consisting of a toothed wheel attached to a rotating shaft. Gears transmit and modify rotary motion and torque depending on the gear ratio. A gear ratio is the ratio of the rotational velocity of the input shaft relative to the rotational velocity of the output shaft. For example, if the input shaft rotates four revolutions whereas the output shaft rotates once, the gear ratio is then 4. The output torque, in addition, is multiplied by the factor of the gear ratio if the friction is not accounted for. (18.) This creates significant advantages for various application because smaller engines can now be used without the loss of the necessary torque.

Necessity of the gear transmission for the automatically rotating jig will be determined when the total torque needed for rotating the jig is calculated.

4.4 Screws

Screws are, in machine construction, usually, a circular cylindrical member with a continuous helical rib used as a fastener or a force and motion modifier (19). Figure 17 shows the main type of screws and screwheads used nowadays.

FIGURE 17. The main types of screws and screwheads (19.)

There are a few screw connections in the jig of which some may be critical and must be calculated to ensure its functionality.

5 DETAILED DESIGN

The detailed designing includes all the details about the models, dimensions, materials used and necessary calculations. The requirement in the detailed designing was to carry out so specific models and drawings that the jig could be manufactured.

SolidWorks and PTC Mathcad software were used in this thesis work. SolidWorks is an engineering program used for creating models, drawings, finite element method analysis and product data management. PTC Mathcad, on the other hand, is an engineering math software designed for performing and analyzing the most vital calculations (20).

5.1 Defining the required torque

In order to calculate and size machine elements, certain information is needed such as mass, force and dimensions. The most important value to be calculated in this design was the required torque to rotate the jig.

Appendix 1 shows the complete calculations of the required torque. However, figure 18 shows the result of the calculation.

Total moment of inertia	$J := J_m + J_r + J_s = 0.864\ kg \cdot m^2$	
Required torque	$M = J \cdot \alpha$	
revolutions per minute time for 180 degree rotation	$n := 10\ \frac{1}{min}$ $t := 3\ s$	
angular velocity (steadily accelerating movement)	$\omega := \frac{2 \cdot \pi}{t} = 2.094\ \frac{1}{s}$	$\omega_0 := 0 \cdot \frac{1}{s}$
angular acceleration	$\alpha := \frac{\omega - \omega_0}{t} = 0.698\ \frac{1}{s^2}$	
Required min. torque to rotate the assembly	$M := J \cdot \alpha = 0.603\ N \cdot m$	

FIGURE 18. Conclusion of the calculation of the required torque

The total required torque was calculated to be 0.6 Nm. The torque was an important factor because it was used in most of the calculations such as defining stress loads for screws and sizing the proper servo motor.

5.2 Modelling

Modelling was divided into the following sections:

1. Attachment part left and right
2. the frame
3. the jig
4. the shaft coupling
5. the rotational lock of the shaft
6. the main assembly.

The sections1 to 5 represent subassemblies of the main assembly.

5.2.1 The attachment parts

The two most important points with the attachment parts were to hold the PCB at the predefined location and to attach the PCB to the jig. Figure 19 illuminates the designed attachment parts for the PCB

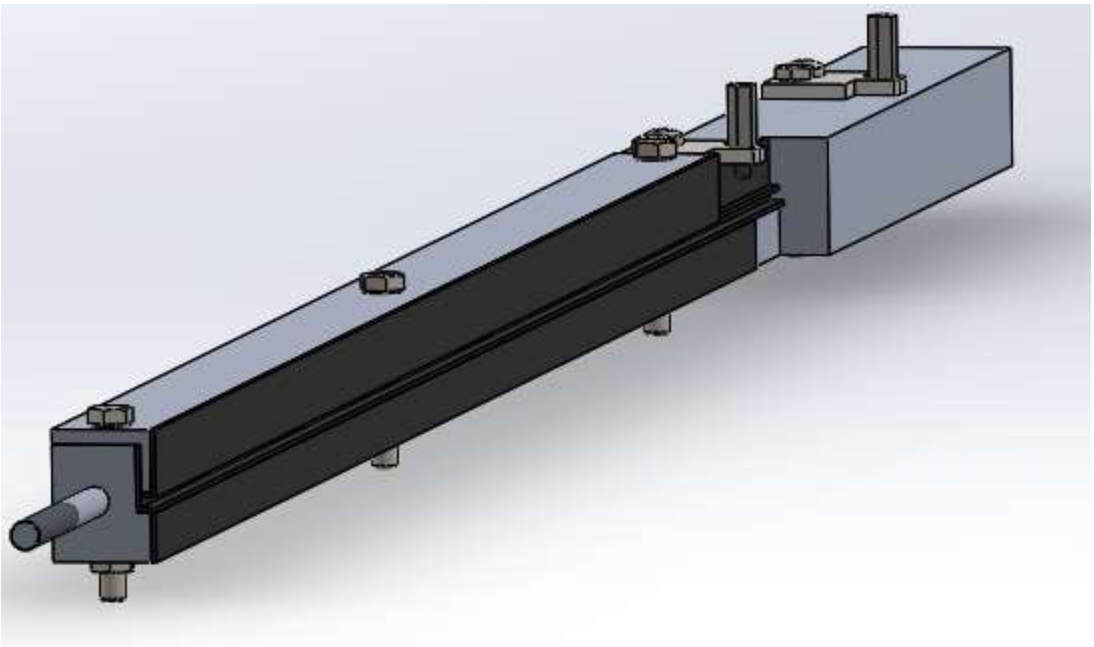

FIGURE 19. The attachment part subassembly for holding the PCB

The subassembly had an upper and lower part between of which there was a 2mm gap where the PCB was attached to. The thickness of the PCB was approximately 2.1mm which created an interference fit between the PCB and the attachment part resulting in holding the PCB tightly at the desired location. However, due to possible alterations in thickness of the PCB, areas that were in contact with the PCB were covered with rubber (shown black in the figure) in order to allow slight variations in thickness. Rubber has, in fact, two other advantages for which it was selected as well: Rubber has a high friction coefficient to further enhance the gripping of the PCB and, it is also an electrically resistant material which was crucial for protecting components from scorching.

The upper part was attached to the lower part with three M5 hex bolts. In addition, there are two support sheets for extension nuts (Figure 20) the purpose of which was to support a test adapter that was mandatory in order to complete necessary measurements.

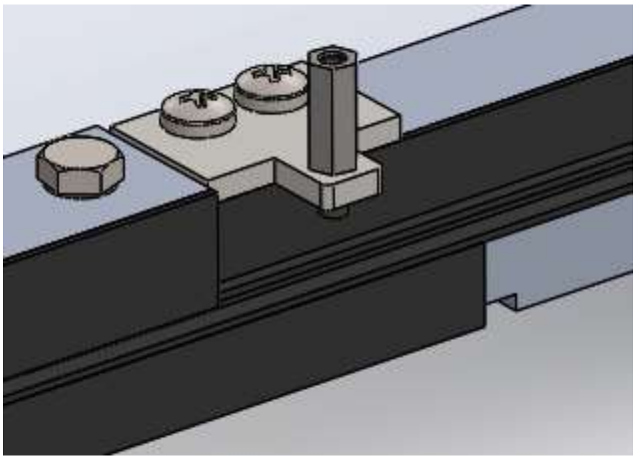

FIGURE 20. The support sheet and an extension nut

The support sheets were attached to the lower part with M4 pan head cross recess screws.

Machinable aluminum was used as a material for the upper and lower parts to reduce the total mass of the subassembly. However, S355J2G3 steel was selected as a suitable material for the support sheets and every other supporting part to strengthen the assembly and areas where the stresses were occurred.

5.2.2 The frame

Where the attachment parts were designed to a specific product, the frame was designed to be a universal and suitable for several different products. Figure 21 shows the subassembly of the frame.

FIGURE 21. The subassembly of the frame

The frame is a 30 x 30mm solid square aluminum profile attached to each other with M5 hex bolts. The solid profile was selected rather than a tube for the fact that connections and threads may not have been as robust as they are in a solid profile. On top of the frame, there are two standard 35mm DIN rails for cabling purposes.

Figure 22 shows the connection elements to the middle support, shaft and the PCB attachment parts.

FIGURE 22. The main connection elements of the frame

In the middle between the two rails, there are two counterbores for M6 hex bolts which were used to connect the shaft to the frame. Appendix 2 shows the complete calculations of M6 hex bolts where it was checked and confirmed that two M6 hex bolts were robust enough. Figure 22 shows the conclusion of the calculations.

torque at tensile strength limit	$T_m := R_{rm} \cdot W_v = 12.221\ \boldsymbol{N \cdot m}$	
torque at yield strength limit	$T_e := R_{re} \cdot W_v = 9.777\ \boldsymbol{N \cdot m}$	
required torque of the assembly	$T := 0.603\ \boldsymbol{N \cdot m}$	
shear load with 2x bolts	$T = 2 \cdot Q \cdot r$	$Q := \dfrac{T}{2 \cdot r} = 21.536\ \boldsymbol{N}$
shear stress	$\tau := \dfrac{Q}{A_s} = 1.071\ \boldsymbol{MPa}$	
Factor of Safety (FoS)	$n := \dfrac{R_{re}}{\tau} = 358.4$	**OK**

FIGURE 22. Conclusion of M6 hex bolts calculation

The calculation showed that the Factor of Safety (FoS) was 358.4. FoS is a factor that express how much stronger the system or device is than required. In this case, for instance, FoS was 358 which means that the bolts were to withstand 358 times the load or stress that was applied. In conclusion, the two M6 hex bolts confirmed to be suitable.

5.2.3 The jig

The jig is the main subassembly that consists of the left and right attachment parts and the frame subassemblies. Furthermore, in this subassembly, all the supports for the PCB and the test adapter were designed. Figure 23 shows the model of the jig.

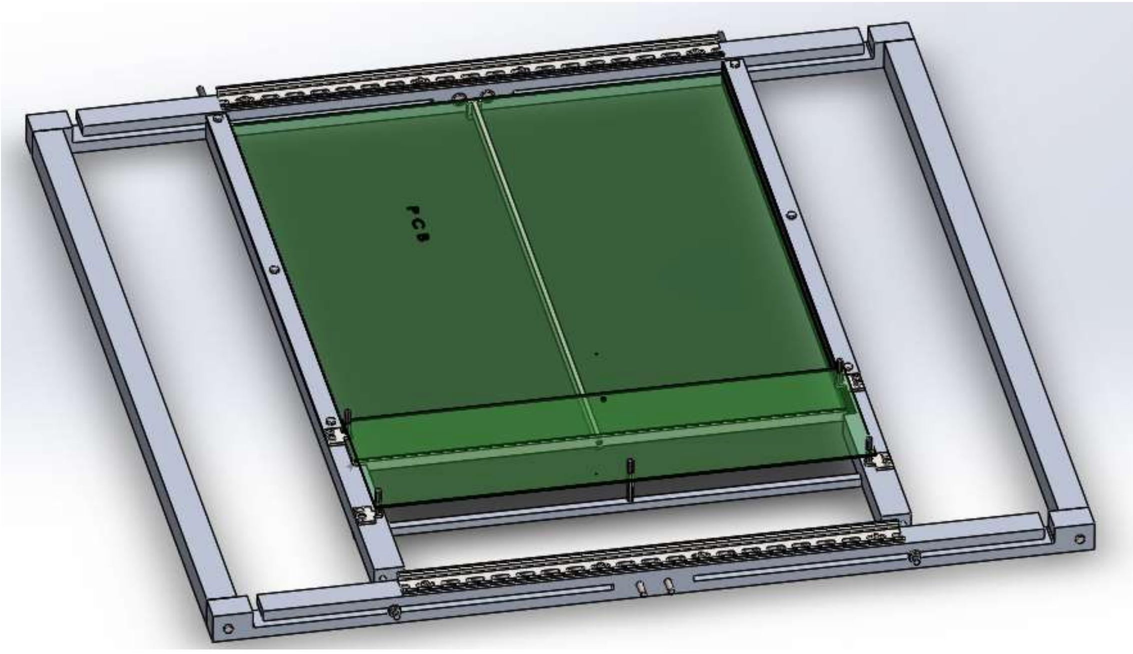

FIGURE 23. The jig

At this point of the detailed designing, the priority was to minimize the bending of the PCB caused by the combination of the elastic material of the PCB and its gravitational force. The bending was effectively reduced by designing the middle support for the PCB and extension nuts for the test adapter. When the PCB is designed, there is a vacant space of a width of five millimeters left for the middle support which had to be considered when designing the middle support since wider than that may cause a short circuit and damage the product.

SolidWorks' simulation tool was used to determine the optimum height of the middle support to diminish the bending while emphasizing compactness and lightness of the part. Figure 24 illuminates the result of the simulation.

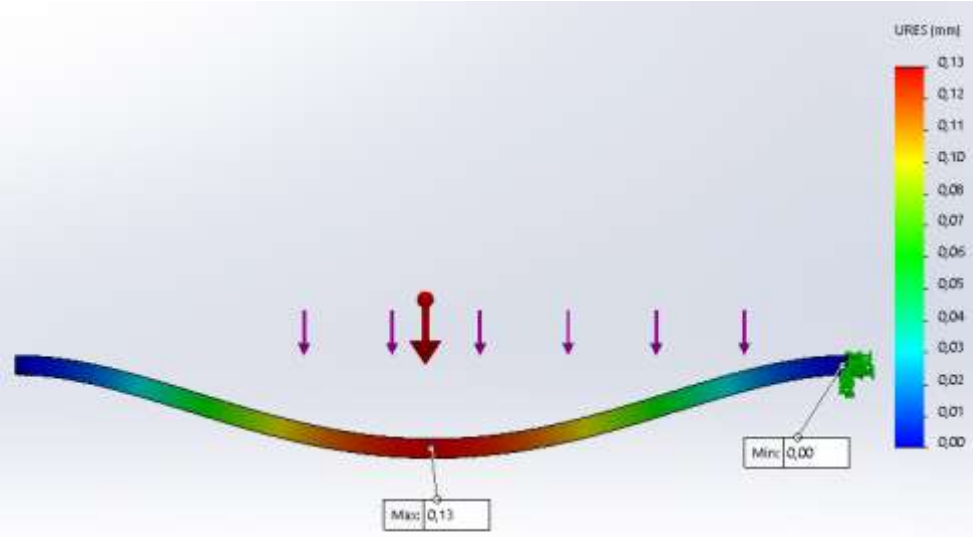

FIGURE 24. The result of the simulation

Using 5mm x 14.1mm middle support (Figure 25), the total bending was 0.13mm which was acceptable.

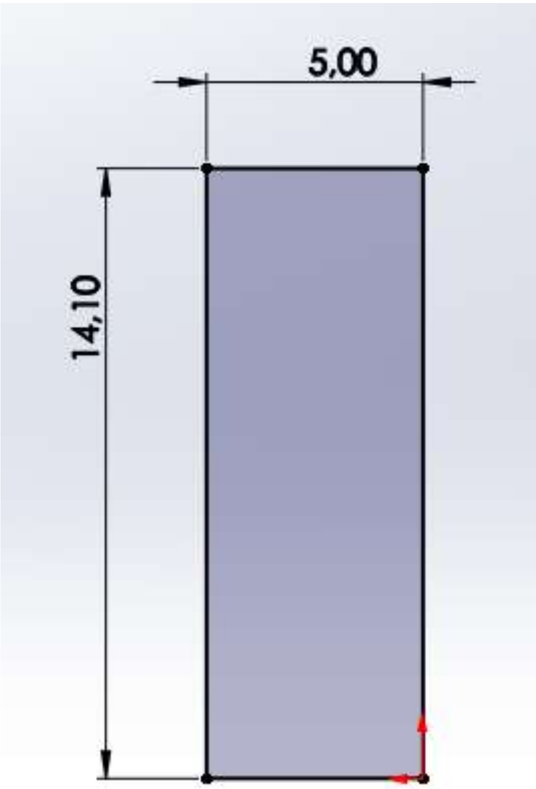

FIGURE 25. Dimensions of the middle support

The test adapter was connected to the PCB from the connectors, thus, the test adapter was 25.9mm above the PCB (Figure 26).

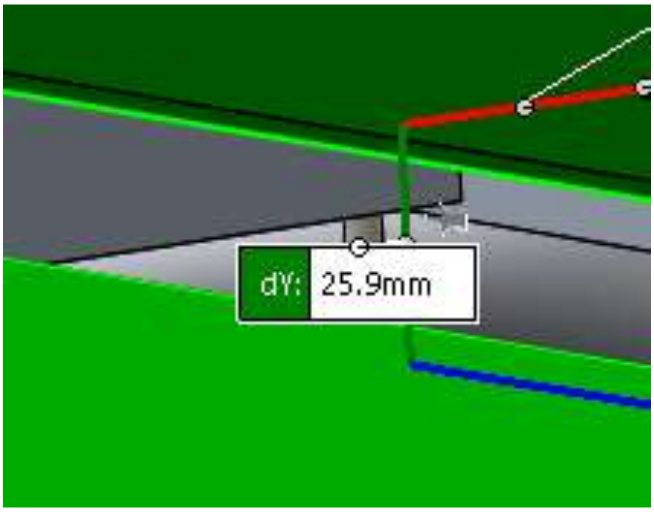

FIGURE 26. The height between the PCB and the test adapter

In addition, the test adapter did not have a slot for a middle support, consequently, the customized extension nuts were designed through the M3 clearance holes of the test adapter (Figure 27).

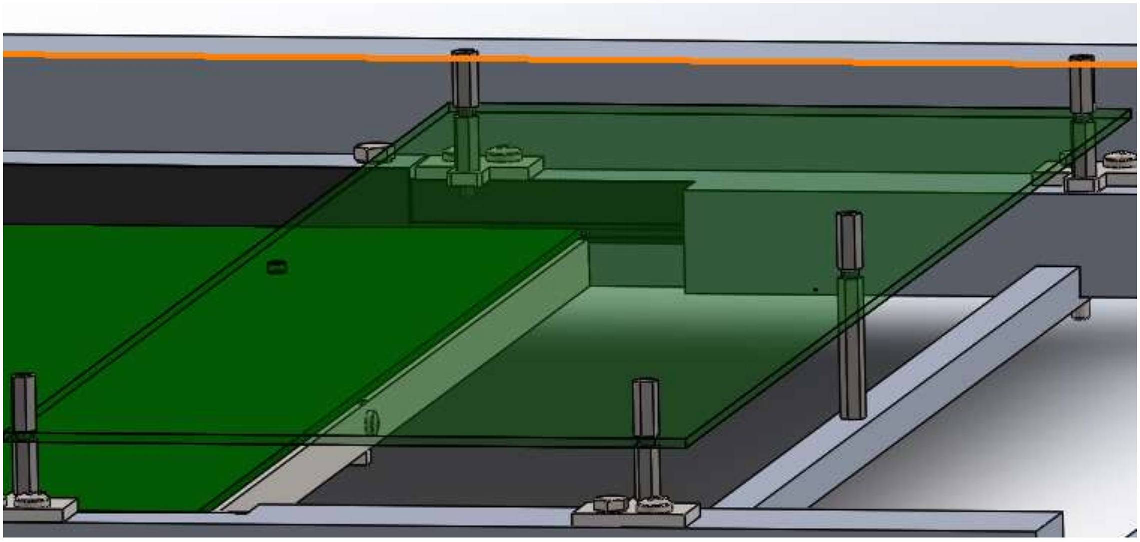

FIGURE 27. Extension nuts to support the test adapter

Since the M3 screws are relatively thin, it was discovered crucial to confirm the strength of the extension nut. In a meeting it was concluded that the thread is the weakest part and the maximum stress occurs during the rotational motion at the

90-degree angle. The appendix 2 shows comprehensive stress evaluation of a M3 thread. Figure 28 shows the results of the calculation

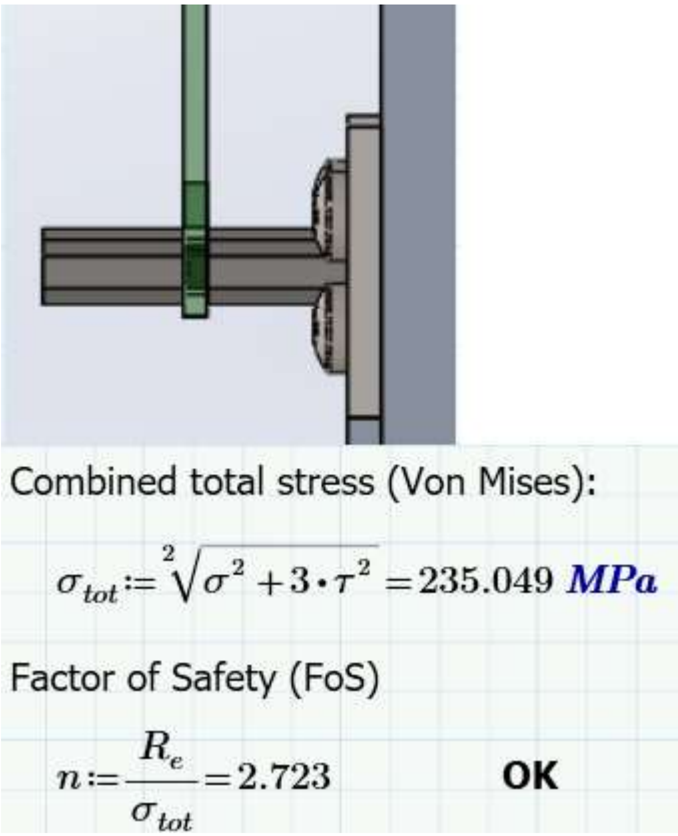

FIGURE 29. Conclusion of the M3 stress evaluation

The evaluation was calculated to a single M3 thread and according to the calculations, the FoS was 2.7 which means that the M3 thread is strong enough and can be used to support the test adapter.

5.2.4 The Shaft

Two shafts were modelled: the main shaft and the secondary shaft. The major difference between the main shaft and the secondary shaft was the torque transmission. The main shaft was connected to the shaft of the motor through a bush coupling with a wedge connection. The purpose of the secondary shaft was to support the assembly and allow rotational movement. Both shafts were connected to the jig with two M6 hex bolts (Figure 30). Figure 31 shows the model of the main shaft

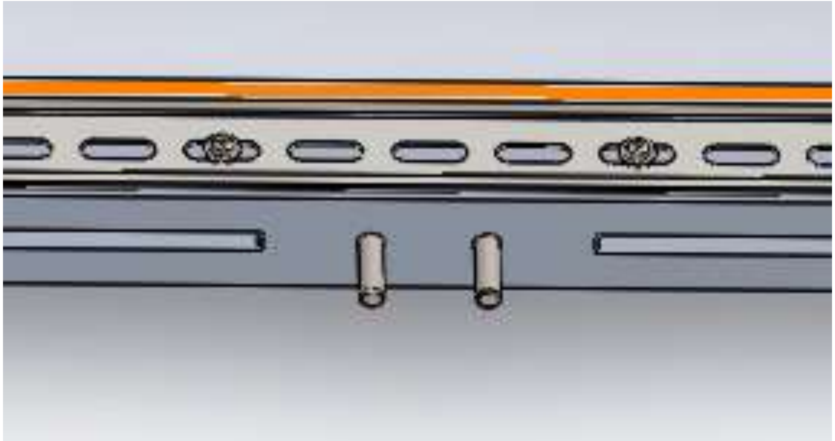

FIGURE 30. M6 hex bolts to attach the shaft to the jig

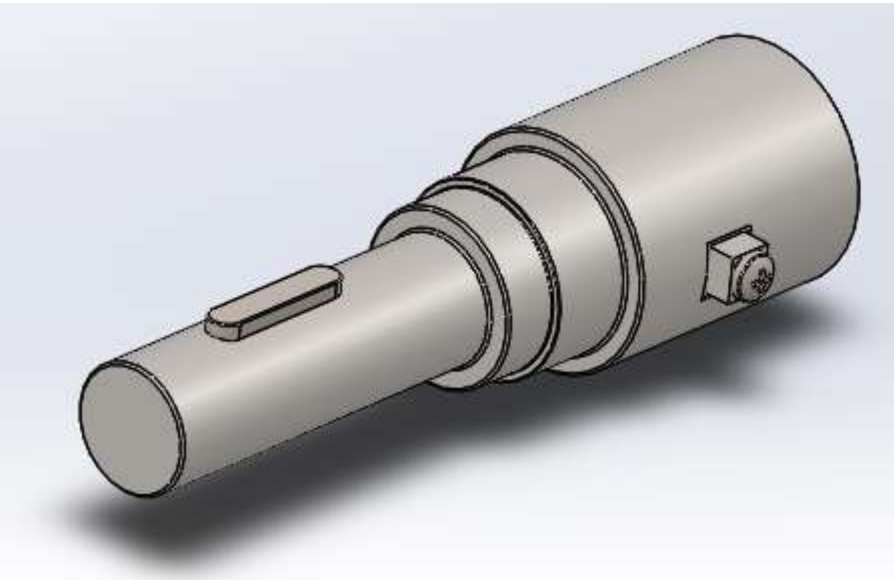

FIGURE 31. The model of the main shaft

The subassembly consists of the DIN 6885 parallel key A6 x 6 x 28mm key and the rotational lock attached to the shaft with M4 screw. The key and keyway have been sized according to the SFS 2636 (1971/05) for the shaft with a diameter of 22mm. The length of the key has been calculated completely in appendix 3. Figure 32 shows the results of the calculation.

Checking the length of the key:	$0.7 \cdot d < l < 2.5 \cdot d$ $0.7 \cdot d = 15.4\ mm$ $2.5 \cdot d = 55\ mm$
Chosen key length:	$l := 28\ mm$
maximum torque limit is:	$T_s = 93.24\ N \cdot m$ OK

FIGURE 32. The result of the calculations of the length of the key

The chosen length for the key is 28mm and is placed to the shaft with a P9 interference fit.

The diameters of the shaft are from 22, 30, 33 and 40mm. The diameter of the motor’s shaft was 22 millimeters and, therefore, it was used in the main shaft to simplify the connection elements. The diameter of the shaft was increased to 30mm to fit proper bearings and lock it into position with an interference fit and 33mm diameter. The thickness of the shaft was risen to 40 millimeters so that M6 tapped holes were able to be positioned 14mm away from the center and align with holes of the jig that connect the shafts and the jig.

The secondary shaft (Figure 33) is simpler because it only supports the jig and allows rotational movements.

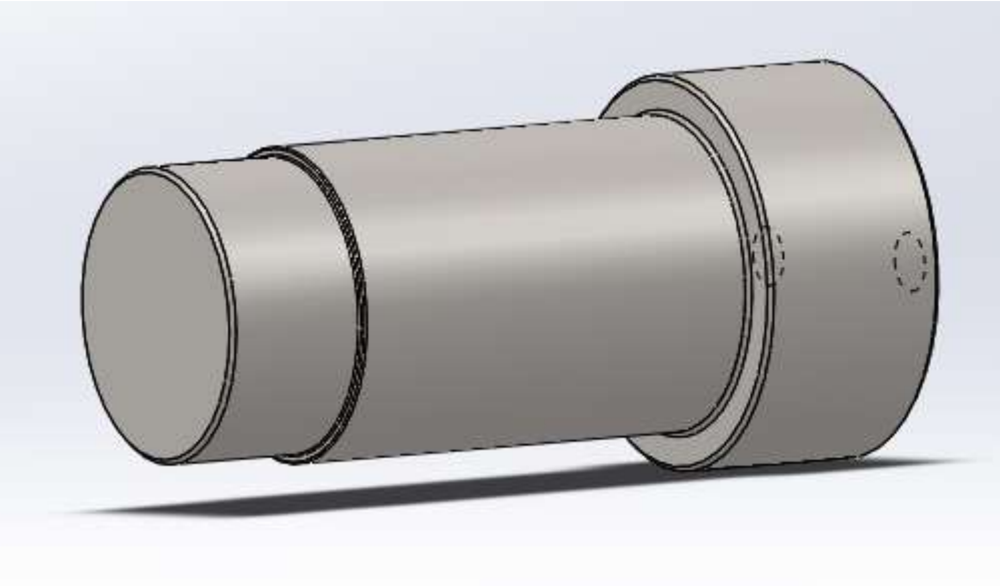

FIGURE 33. The secondary shaft

The secondary shaft did not need a key or keyway, only the bearings are placed to allow a smooth rotation.

5.2.5 The bush coupling

As it was defined that the total torque demanded from the motor was approximately 0.6 Nm, it was not found necessary to design gears to multiply the output torque but a straight shaft to shaft connection by using a bush coupling (Figure 34).

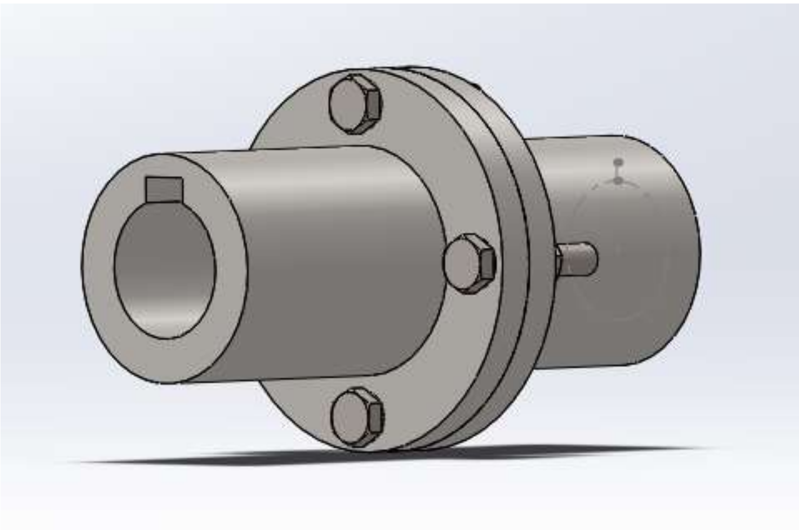

FIGURE 34. A bush coupling for the shafts

The bush coupling connects the main shaft and motor's shaft so that the torque is transmitted from the motor to the jig. The bush coupling has a key hub with a P9 interference fit for both shafts to ensure that there does not exist any small unintended rotational movement caused by tolerances. S355J2G3 steel is specified as a material of the coupling to ensure its strength and ability to withstand loads and stresses. The couplings are attached to each other with M5 hex bolts. The output torque is the same as the input torque when the bush coupling is applied.

5.2.6 Selecting the bearings

Bearings had to be sized and selected properly to ensure smooth rotation as the load is relatively minor and, therefore, it must be confirmed that the bearings are not too robust, and the balls of the bearing are rotating. The selected bearing is the SKF W 61706 deep groove ball bearing which works as both, free and controlled bearing. Appendix 4 shows the full sizing of the bearings.

5.2.7 The cooling unit

The cooling unit (Figure 35) had already been designed by an employee of Nokia and it was, with a few modifications such as the number of fans were increased and height of the cooling unit changed, used in this project as the cooling unit.

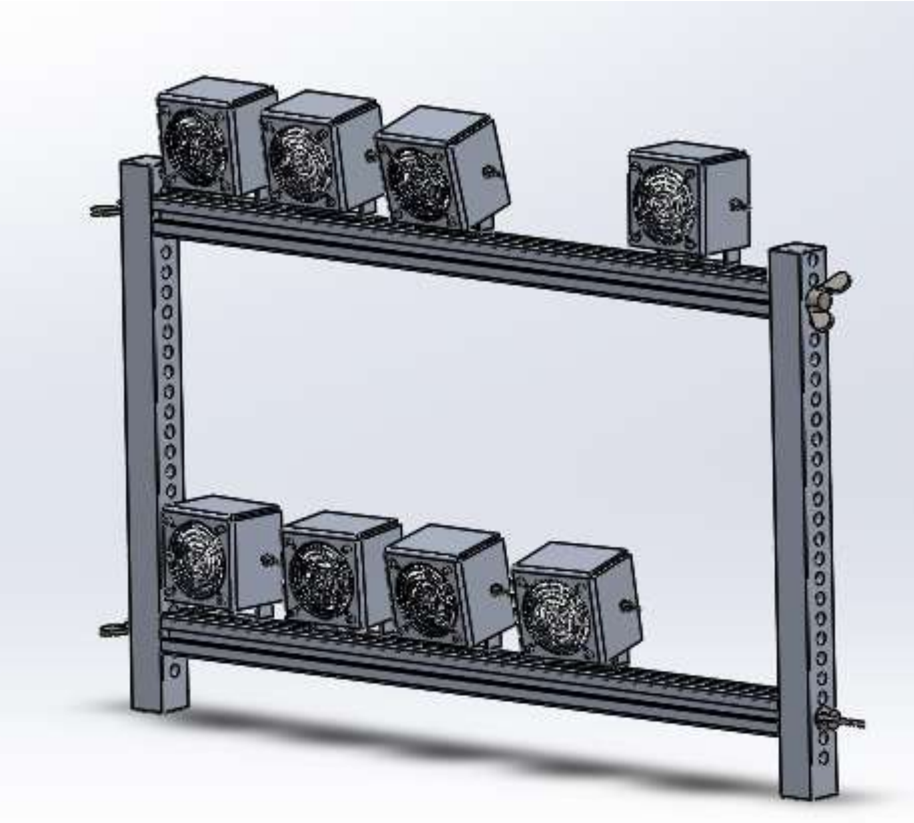

FIGURE 35. The cooling unit

Eight fans were estimated to be efficient enough to cool down the entire unit. Nevertheless, the actual operation of the test cell will indicate whether the eight fans can thoroughly cool down the unit and, therefore, there are additional space for inserting more fans if necessary.

5.3 Selecting the servo motor

There were two demands for selecting the servo motor: it must be remotely controllable and must be able to produce a torque of at least 4.5 Nm as a rated torque. Omron’s R88M-K90010(H/T) servo motor from the Accurax G5 servo motor family was selected. It is a 900 W 230 VAC servo motor with a rated torque of 8.59 Nm which is over 10 times the required torque for rotating the jig and, thus, applicable for this design. Such a powerful motor was chosen in case the future PCBs are heavier than the current products as they have been enlarging continuously.

5.4 The final assembly

Finally, the main assembly was built from all the subassemblies and accessories. Figure 36 shows the main assembly of the automatically rotating jig for the PCB.

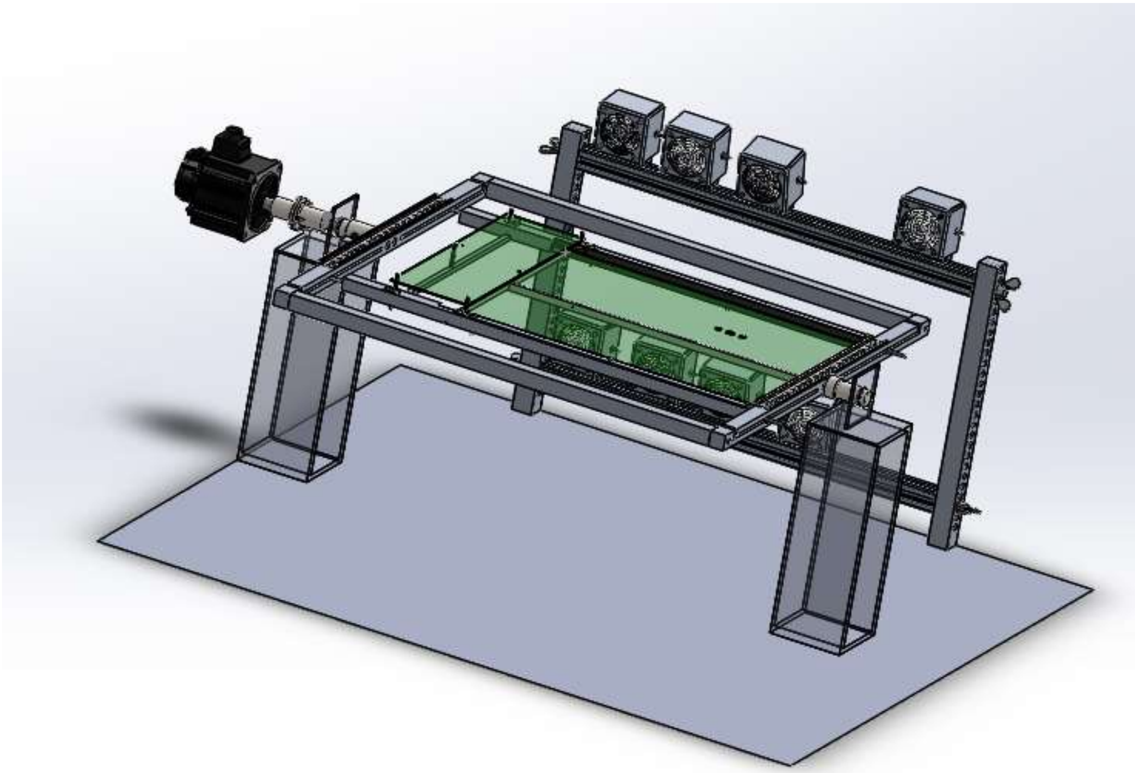

FIGURE 36. The main assembly of the automatically rotating jig for the PCB

The supports that are holding the entire assembly will later be designed when the rest of the test cell has been specified and, therefore, the supports are only drafted versions to visualize how the automatically rotating jig is installed in general.

5.5 Drawings

When the detailed model of the main assembly was modelled, the drawings were created from each part and assembly. Appendix 5 shows each drawing.

6 CONCLUSION

Measuring and verifying digital signals is a very time-consuming phase in the development process as, currently, it is carried out manually by engineers. Therefore, it is being automated, and for that purpose this automatically rotating jig is designed for.

The goal was to design an automatically rotating jig for different sized printed circuit boards. However, it was decided later in the designing process that certain parts are to be designed for a specific product. A detailed assembly was modelled, and drawings created for manufacturing as a result.

As this was a completely new unit, no one had any experience from this sort of jig, even though, conversations were held with experienced mechanical engineers. Therefore, mathematics and machine elements were even more important in creating a fully functional device. The modelling and calculations take only to a certain point after which a prototype must be manufactured to notice possible flaws, malfunctions and, also, areas that operate properly.

Manufacturing was not involved into this thesis work but to create complete drawings for manufacturing. In the further development, though, manufacturing the protype would be the next step in the designing process and then further develop and upgrade the unit.

To conclude, the automatization project is an ongoing process and the automatically rotating jig for PCBs is only the first prototype which can still be further developed in several areas and bring the automatization to a next level.

REFERENCES

1. Employees, Digital Engineers, 2019 – 2020. Oulu: Nokia Solutions and Networks, MN RF RD OUL BB 2 SG. Conversation between June 2019 to March 2020.
2. NOKIA. Available at:
   https://nokia.sharepoint.com/sites/TerminologySG/Lists/MOT_List/DispForm.aspx?ID=99.
   Date of search 20.1.2020
3. Tektronix, DDR PHY Test Solution, PDF.
   Date of search 22.1.2020
4. Tektronix, Probing Techniques for Accurate Voltage Measurements on Power Converters with Oscilloscopes, PDF.
   Date of search 22.1.2020
5. Will Kenton. Feasibility Study. Available at:
   https://www.investopedia.com/terms/f/feasibility-study.asp.
   Date of Search 22.1.2020
6. Employee, RF BB Test Automation Project Manager, 2020. Oulu: Nokia Solutions and Networks, MN RF RD OUL BB 2 SG. Conversation between January 2020 to March 2020.
7. Ulrich, Karl T. – Eppinger, Steven D Fifth Edition. Product Design and Development. Available at:
   https://www.academia.edu/35451150/._product_design_and_development_ulrich_karl_srg.
   Date of search 24.1.2020
8. Tuomaala, J. 1999. Department of Mechanical Engineering, Oulu. Creative engineering design. Available at:
   http://jultika.oulu.fi/files/isbn951425130X.pdf.
   Date of search 28.1.2020
9. IEC 61340-5-1:2016. Protection of electronic devices from electrostatic phenomena – General requirements
10. Groover, Mikell P, Professor of Industrial Engineering. Automation, article. Available at:
    https://www.britannica.com/technology/automation/Feedback-controls.

Date of search 30.1.2020

11. Employee, Local Product Owner, Integration, 2020. Oulu: Nokia Solutions and Networks, MN RF RD OUL BB 1 SG. Conversation in January 2020.

12. Employee, Specialist Automation, 2020. Oulu: Nokia Solutions and Networks, NOK OPS SNE OU MS Autom & Indust Eng. Conversation in January 2020.
13. Kammet, Joel. CORC 3303 – Exploring Robotics. Available at: http://www.sci.brooklyn.cuny.edu/~kammet/gear_notes.pdf. Date of search 4.2.2020
14. Kontio, Esa 2018. T318208-3004 Tuotekehitys 8 op. Lectures of the course in Autumn 2018. Oulu: Oulu university of applied sciences, unit of technology.
15. Types of Bearings – Types of Bearings -A Thomas Buying Guide. Available at: https://www.thomasnet.com/articles/machinery-tools-supplies/bearing-types/. Date of search 2.4.2020
16. Deep groove ball bearing. Picture. Available at: https://fi.rsdelivers.com/product/skf/6005-c3/deep-groove-ball-bearing-c3-25mm-47mm/1440827?gclid=EAIaIQob-ChMIgOvugcPJ6AIVhhUYCh2ijwXBEAYYASABEgLo5PD_BwE&gclsrc=aw.ds. Date of search 2.4.2020
17. Gordon R. Slemon, Emeritus professor on electrical engineering. Electric motor, Article. Available at: https://www.britannica.com/technology/electric-motor. Date of search 2.4.2020
18. Gear. Article. Available at: https://www.britannica.com/technology/gear. Date of search 3.4.2020
19. Screw. Article. Available at: https://www.britannica.com/technology/screw. Date of search 3.4.2020
20. PTC Mathcad – Show Your Work! Article. Available at: https://www.mathcad.com/en. Date of search 19.03.2020

APPENDICES

Appendix 1. Moment of inertia of an assembly

Appendix 2. M6 hex bolt torque load

Appendix 3. Shaft keyway and key sizing

Appendix 4. Bearings

Appendix 5. Manufacturing drawings

For the classificational reasons, all the appendices are left out from this thesis.