

CHAPTER 3 - RESEARCH METHODS

This chapter explains about how the research will be conducted after initiation process (after proposal defense, January onwards) by elaborating the whole system designs concept and overview.

The design concept must fulfill the following objectives:

1. Precision dimensioning – precision cube with 12 mm width and length.
2. Time efficient – process cycle time has to be reduced from the default of 30 seconds and down time also has to be reduced by simplifying the blades construction for easier maintenance.
3. Full automation – the machine has to be able to be operated by one person only, without having to be monitored the whole time.
4. Early detection – there should be safety system to prevent the contamination by chips and to notify the operator when the blades are becoming dull.

There are also constraints in making the design:

1. The *nata* may not be exposed to heat.
2. The *nata* may not be exposed to any liquid but water and/or coconut water.
3. The *nata* may not be over compressed.
4. The *nata* may not be frozen.
5. The *nata* may not be contaminated by dust or any other foreign material.
6. The material for the machine has to fulfill most if not all food grade concerns.
7. The dimension of the machine should not exceed 5 square meters.
8. The sanitation of the machine has to be taken into consideration.

Not only conditional constraints as mentioned above, budget constraint also applies. The budget for this thesis with the amount as proposed by the researcher will be provided by the company, *PT. Coco*. The initial approved budget for this thesis is as follows:

Table 3.1 – Approved Budget Proposal for Nata Cutting Machine

Name	Cost	Qty	Total
Aluminum Profile	IDR 500,000	4	IDR 2,000,000
L Joints	IDR 5,000	20	IDR 100,000
Fasteners	IDR 2,000	100	IDR 200,000
Acrylic Parts	IDR 1,000,000	-	IDR 1,000,000
Stainless Steel Body	IDR 1,500,000	-	IDR 1,500,000
Stainless Steel Sheet	IDR 1,200,000	1	IDR 1,200,000
Blades	IDR 5,000	50	IDR 250,000
Blade Clamps	IDR 5,000	50	IDR 250,000
Guides	IDR 250,000	2	IDR 500,000
Short Stroke Pneumatic	IDR 1,000,000	2	IDR 2,000,000
Rodless Pneumatic	IDR 3,500,000	2	IDR 7,000,000
Unexpected Expenses	IDR 300,000	-	IDR 300,000
Total Budget			IDR 16,300,000

To keep the thesis well organized and all target can be achieved, a timeline for the project planning was made in the early preparation of the thesis (September 2016):



Figure 3.1 – Project timeline chart, inside blue box is thesis initiation process

3.1 Testing Plans

1. Test other methods of cutting – using stationary blades, blades moving instead of the *nata*, guillotine method (blades cut from above to bottom), using clamping device, place the cutting tools on the bottom side instead of the upper side of the *nata*.
2. Clamp force – find the optimum clamping force which can hold the *nata* in place, drag the *nata* along with, without exposing too much compression.
3. Slit width – find the optimum width of the slits of which the cutting blades will go through. It has to be big enough to prevent contact with the cutting blades, yet small enough to prevent the *nata* noodles get into the slit when moving.
4. Cutting speed – find the optimum cutting speed to produce a perfectly clean cut, with minimum force and time, by varying the pneumatic cylinder pressure.
5. Cutting angle – find the optimum angle of the cutting blades (if stationary linear blades are used) where the force necessary to cut is minimum, also the length of the blade is to be kept as minimum as possible.
6. Early detection – test the sensitivity and reliability of the detection of collision (blades make contact with clamp), and blades dullness (force to cut gets bigger).

3.2 System Design Overview

Referencing to the previous studies elaborated in sub-chapter 2.5, most if not all of the studies utilize rotating devices, be it for the rotating cutter blades, or the centrifugal raw material feeding. Therefore, this thesis wanted to take another approach: by utilizing stationary blades or cutters, assisted by sliding action. This thesis will also be the first thesis conducted in Mechatronics Engineering Department of Swiss German University that build a machine for cutting food product using multiple blades, although similar automated processing machines may have been researched before.

Not only trying a new method of cutting using stationary blades, many aspects of the machine will also be improved. The control of the machine will be made automatic using pneumatic actuators with PLC controller; the whole design will comply to food grade HACCP with easy sanitation access, and safety measurement system will be added to detect any collision or dull blade.

As a result of thorough research and consideration, the researcher has determined the best possible solution for each problem:

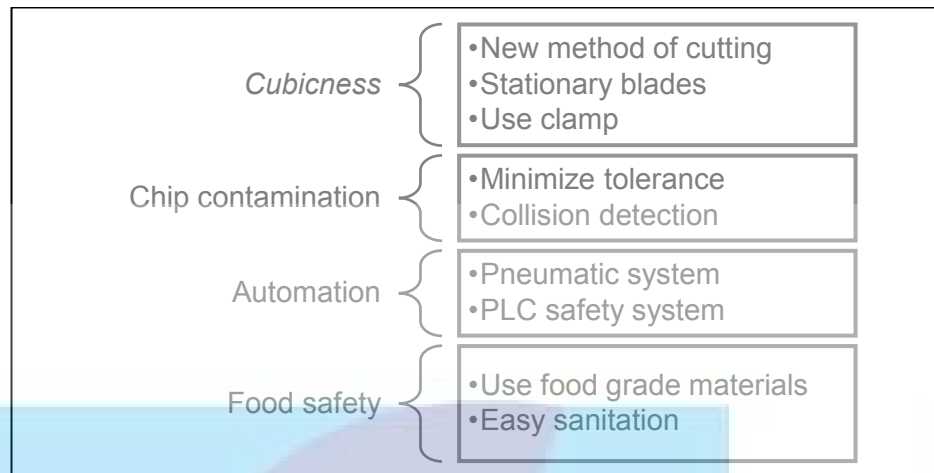


Figure 3.2 – Best possible solution for each problem

A preliminary design concept according to the figure above is then summarized in a single diagram:

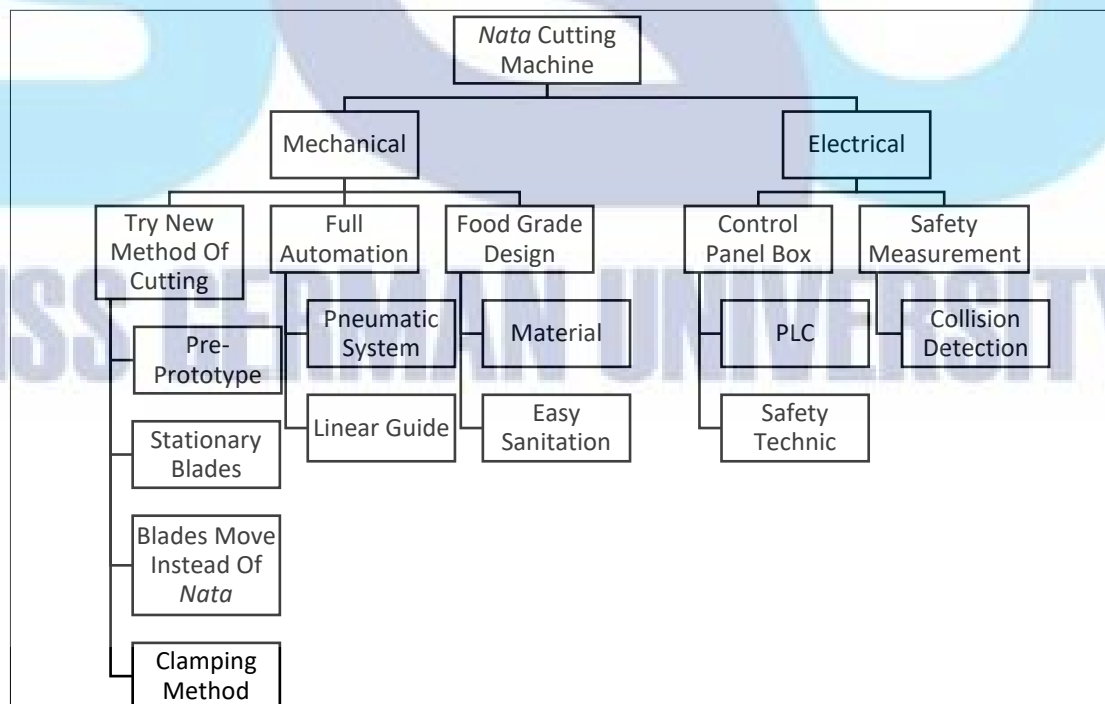


Figure 3.3 – Preliminary design concepts diagram

3.3 Product Sample



Figure 3.4 – Nata sheet sample, five nata sheets per pack

The product to be processed in the machine is *nata de coco* sheets. A single *nata* sheet is about the size of A4 paper or 200 mm x 300 mm with 30 mm tolerances. The height of the sample should be 12 mm, but it may be lower because of being compressed when being stacked during the delivery process from the company to the university. The samples are also preserved using certain acidic liquid for research purposes.

A testing using penetrometer will be conducted to the sample to determine and to compare the elasticity of the *nata de coco*. From this test, the researcher can determine the amount of pressure necessary to clamp the nata, the cutting force, and comparison between the *nata* sheet samples with commercial in-store *nata de coco* (there might be elasticity difference due to the acidic preservatives material).

3.4 Design Selection

In the initial concept formulation, there are various possible methods to be researched and made into a prototype. The researcher has listed every possible way of cutting that is different with the previous studies. In the end, the design selection can be summarized into three improvement concepts of the current machine. The first one being the nearest with current machine, labeled “*Nata Moves X and Y*”, the second one with a little “tweak”, labeled “*Nata Moves X and Cutter Moves Y*”, and the last one being almost totally different method labeled “*Cutter Moves X and Y*”. All of the three concepts are illustrated in 3D design using Solidworks program.

The letter X and Y in those labels refer to the direction of cutting. X-cut is the cutting along the longer side of the *nata* sheet (± 300 mm length) perpendicular to the shorter side, and Y cut is the cutting along the shorter side of the *nata* sheet (± 200 mm length). After one of the cuts has been made, for example, X cut has been made, the *nata* sheets will turn into long strains with supposedly 12 mm x 12 mm x 300 mm, hereinafter will be referred as “*nata* noodles”. If the two cuts have been made, supposedly the *nata* will be turned into 12 mm cubes, which hereinafter will be referred as “*nata* cubes”.

3.4.1 Nata Moves X and Y

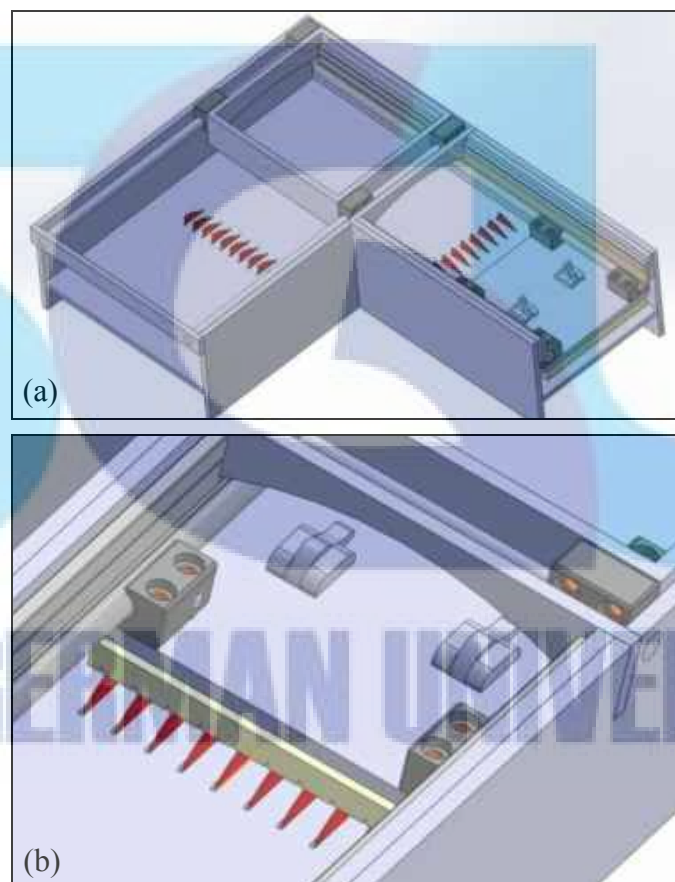


Figure 3.5 – The 3D design of concept “*Nata Moves X and Y*”: (a) whole machine and (b) close up of the blade in red color and clamp in yellow color

In this first concept, the concept is very similar to the current machine, only the whole process is switched upside down. In the current method, the *nata* lays on top of a slidable table and slid through sets of rotating blades positioned hanging above, but in this new first method, a component similar to the table will be utilized as a clamp and hanged upside down (see Figure 3.5c). In addition, the rotating blades are now stationary blades, positioned below the sliding base with small slits.

The clamp also has slits on the bottom side to allow the blades cut higher than the original height of the *nata*. The clamp can be latched down and up using two toggle clamps (with an eccentric circle or cam). However, this concept is not selected because it looks too similar to the current method, thus makes not much improvement can be implemented or researched.

3.4.2 Nata Moves X and Cutter Moves Y

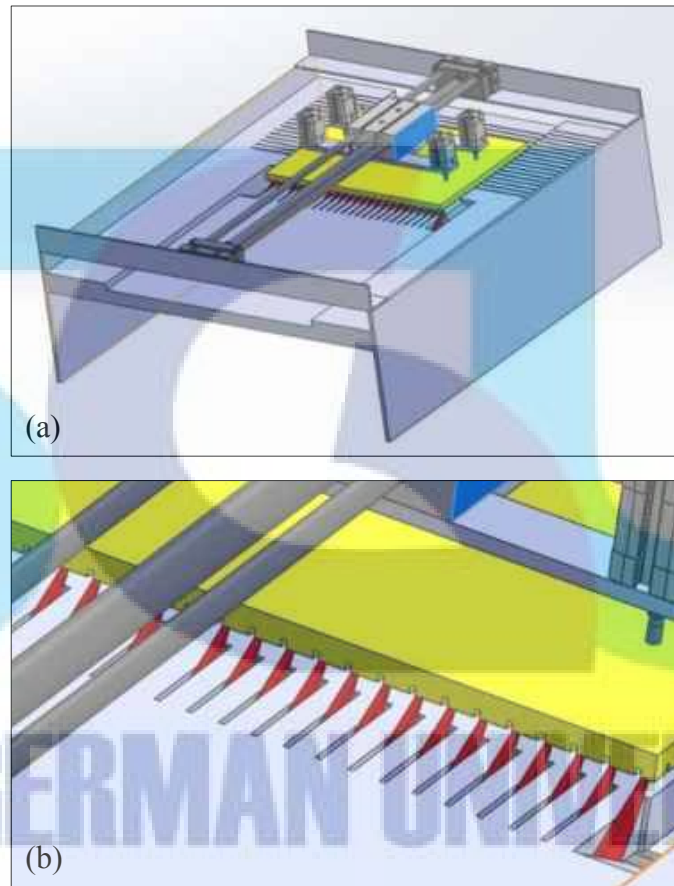


Figure 3.6 – The 3D design of concept “*Nata Moves X and Cutter Moves Y*”: (a) whole machine and (b) close-up of the blade in red color and clamp in yellow color

In this second concept, the X-cut is still the same with the previous concept (Chapter 3.4.1), only the Y cut is changed. After being cut in the X direction, the *nata* sheets go through a set of slits and stop. Then, the Y cut blades set moves, cutting the sheets to make the next perpendicular cut.

This concept is the one being selected to be built because it is a combination of two different concepts, the product goes through sitting knives, and the knives go through

the sitting product. It is hoped that the result can distinguish the effectiveness difference between the two methods.

3.4.3 Cutter Moves X and Y

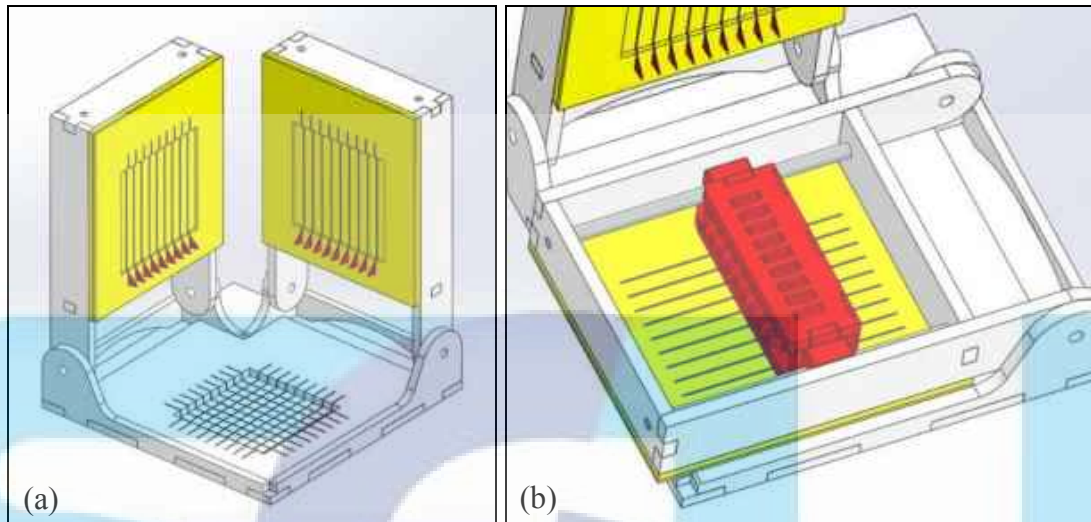


Figure 3.7 – The 3D design of concept “*Cutter Moves X and Y*”: (a) whole machine and (b) close up of the blades set in red color and clamp in yellow color

The last concept is almost different in total with the current method. It utilizes clamping lids. The *nata* sheet is being seated in the square jig on the base. Then one of the lids closes, clamping the *nata* below. Blades set then goes forward cutting the *nata*. The closing lid then opens, leaving the *nata* cut into noodles in the jig. The other lid then closes, cuts from the other side, and then opens again. The *nata* now is left diced.

This concept is not selected because it is feared that the cycle time can be extended since the closing and opening of each lid will need additional time, not to mention the complexity of the mechanics. Its size will also be a problem because if the machine is to be made wider or longer, the height will also increase in the same ratio of the new machine width and length.

3.5 Mechanical Design

The selected design is the second concept (*Nata Moves X and Cutter Moves Y*) as mentioned above. However, revisions have to be made for the design. It should comply with all of the constraints as mentioned above. The structures also need revisions and lots of study such as static simulations to ensure its safety. Picking material and

components also should be wisely done, since it has to comply with all constraints and limitations. Revisions have been made to the design, material and components study has been done. The first finalized design that was presented for proposal defense in December 2016 looks like this:

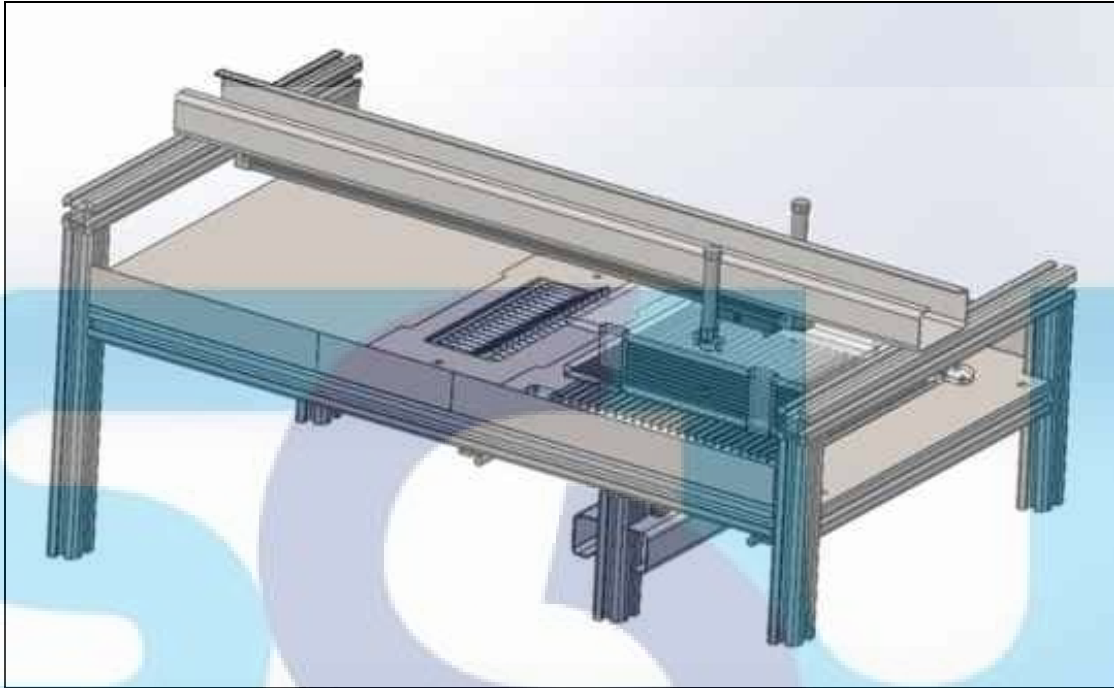


Figure 3.8 – Finalized 3D design until thesis proposal defense (December 2016)

After thesis proposal defense, some changes were made. The structure is strengthened, making the design more complicated:



Figure 3.9 – Revised 3D design to be manufactured (January 2016)

Then, the design is revised again. The usage of steel beams for center support is removed, thus the design is now simpler:

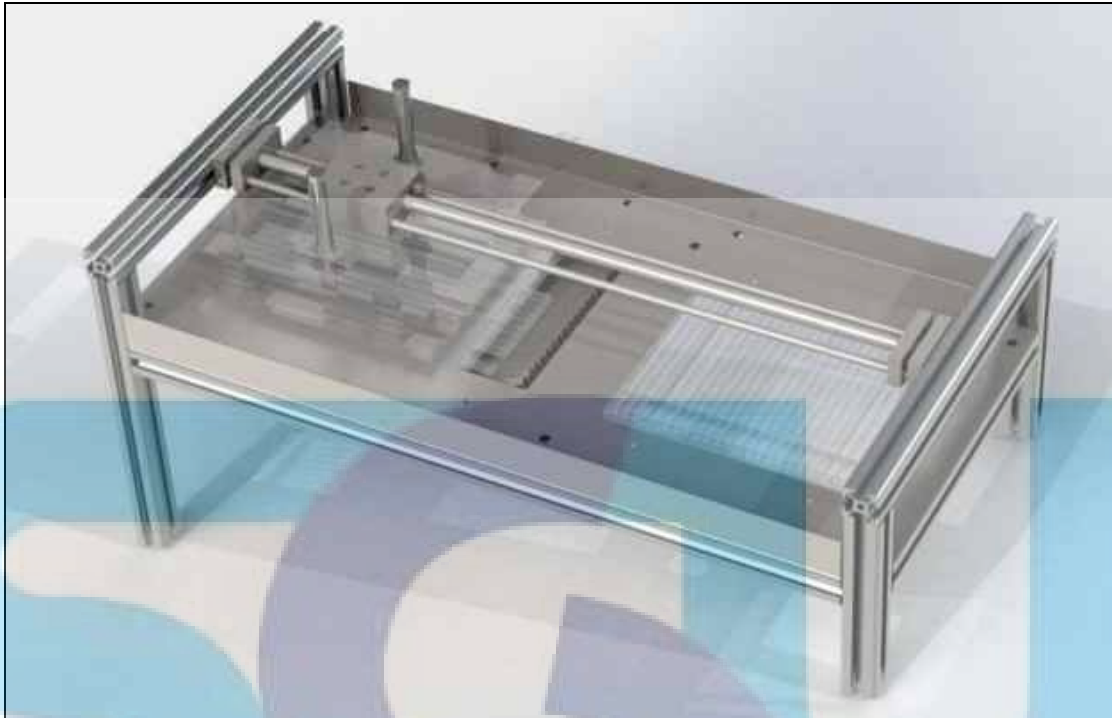


Figure 3.10 – Rendered revised 3D design after thesis proposal defense

3.5.1 Material Selection

Building a machine for food processing purpose is not as easy as building an ordinary machine. One of many aspects to take into concern is the material selection. The materials selected for this thesis should be easy and cheap enough to be manufactured because of the time and budget constraint. Referring to chapter 2.2.2 above, the materials to be used are:

- Food grade and RoHS compliance aluminum alloys for structure (food zone)
- Food grade stainless steel 304 for the machine bed and fasteners (food contact)
- Aluminum alloy 6061 for the clamp (food contact)
- Acrylic for the clamp, blade holders, slits bed, etc.
- Polyethylene plastics for pneumatic hose (food zone)
- Zinc alloy for the linear guide (food zone)
- Epoxy resin or fiber-reinforced plastic for blade holder (food zone)
- Rubber (Butyl) for clamp stopper (food zone)

3.5.2 Structure

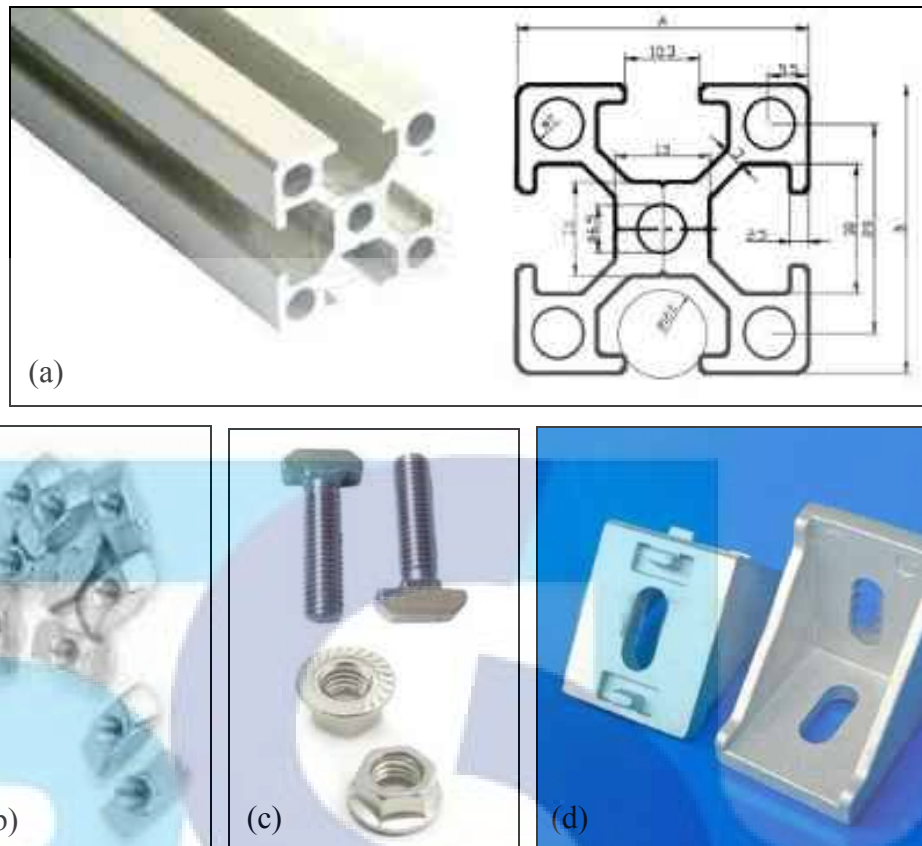


Figure 3.11 – (a) Aluminum profile, (b) T-nut, (c) T-bolt, (d) Bracket

The structure is designated to be built from 40 mm x 40 mm aluminum profiles bought from Infiniti Group Indonesia, Cikupa, Banten. Aluminum profiles are easy to be assembled and disassembled, making it simpler to revise when necessary. Sanitation also is faster because it can be re-assembled in short time. To assemble aluminum profiles, brackets must be used. The brackets must be fastened using T-nuts and ordinary bolts or T-bolts and ordinary nuts. For 40 mm x 40 mm profiles, the T-nut is M6 size, and the T-bolt is M8 size.



Figure 3.12 – Main structure made out of aluminum profile

The main structure will be built like the picture above. Its shape looks alike with a bed frame with longer rear legs, which makes it tilted. The tilt is necessary for easy sanitation where water can flow down along the bed (HACCP).



Figure 3.13 – Illustration of the structure from side view

To simplify the design, the longer rear legs are designed to be 400 mm, and the shorter legs are 250 mm. The rear legs are longer by 150 mm which makes the whole machine tilted to the front with a certain inclination. The length of the bed is 990 mm, so the angle of the tilt will be:

$$\theta = \arctan\left(\frac{(400 \text{ mm} - 250 \text{ mm})}{990}\right) \quad (\text{Equation 1.1})$$

$$\theta = 8.29^\circ \quad (1.2)$$

3.5.3 Machine Bed

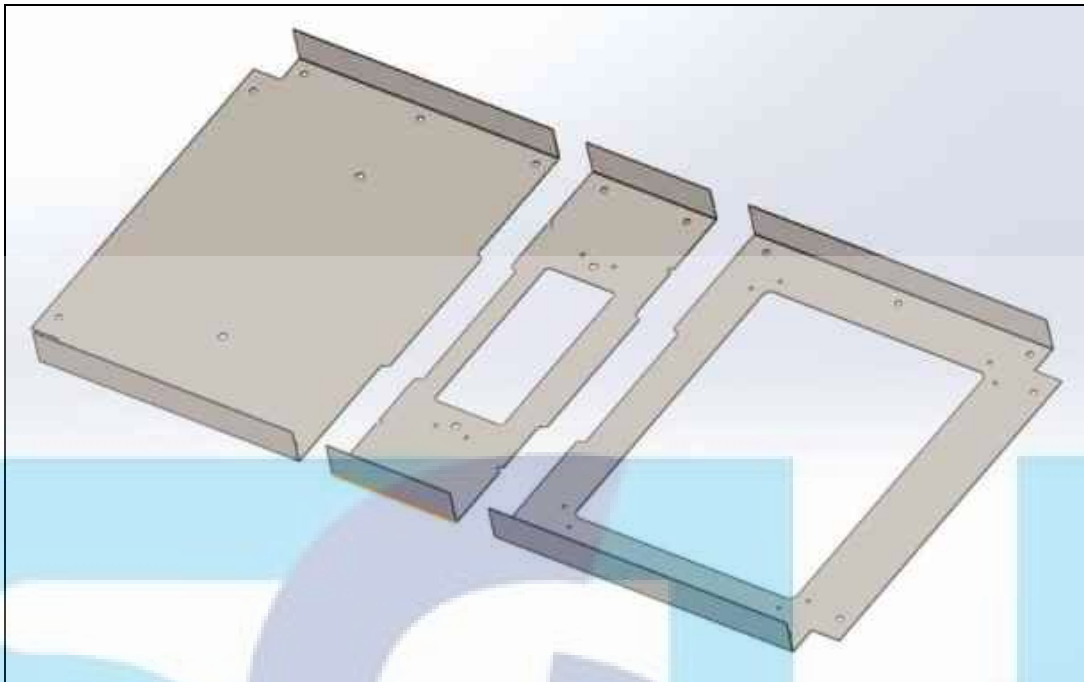


Figure 3.14 – Whole machine bed, divided into three parts

The machine bed will be made out of stainless steel 304 sheet with 1 mm thickness. It will be manufactured using laser cut. The whole machine bed is divided into three parts, to make it easier to change, remove, or modify if any of the three needs revision, not to mention the easiness of sanitation (HACCP). The first part, the most left in the picture above is called baseboard 1, the area where *nata* sheet is placed. The second part is baseboard 2, where the blades set for X-cut will be mounted. The third part is baseboard 3, where the *nata* noodles stop and Y-cut will be conducted.

Around the edges of the baseboard, holes with a diameter of 8 mm are placed for mounting with the aluminum profiles. For baseboard 3, there is a big square cut in the middle for placing the acrylic board with slits. This way, the slits can be modified easily if necessary, just remake the acrylic and then replace the old one. The acrylic board is mounted using eight M5 bolts, 2 for each corner. A similar thing also applies on baseboard 2 for mounting the blades set. However, the blades set will only need four M5 bolts, 2 for each side. There are also two 10 mm diameter holes, each located between the blades set mounting holes, as a jig for easy calibration of the clamp. Actually, there are four calibrating holes, with the two others being on baseboard 1.

3.5.4 Blades

Blades are very crucial since it is the determinant of whether the *nata* can be cut or not. The material opted for making the blades should conduct the principals of HAACP as mentioned before. Therefore, the most common option will be stainless steel for food grade, stainless steel 304L, and 316L. If necessary, ceramics will do very good to minimize the down time for the machine, as only minimum maintenance have to be done. Ceramics are a harder material than steel, but also more brittle. It will not need any sharpening for a very long time before it becomes dull. One of the most applicable ceramics for this thesis purpose is Zirconium Oxide (ZrO_2).

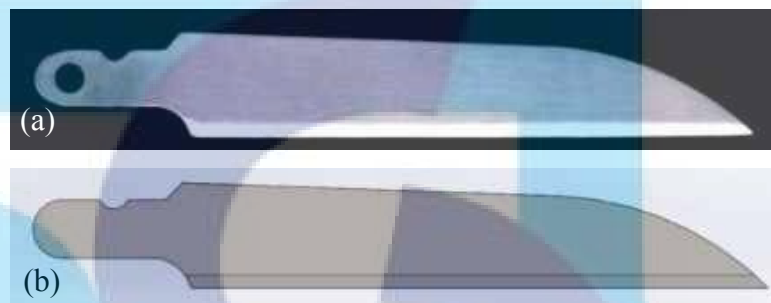


Figure 3.15 – (a) Stainless steel kitchen knife scanned and (b) converted into 3D design

Stainless steel kitchen knife is selected as the best solution because it is easy to find and affordable. The knife then being scanned using the ordinary scanner for document and then traced to make the 3D design to be simulated in the main 3D design of the whole machine.

3.5.5 Blades Holder

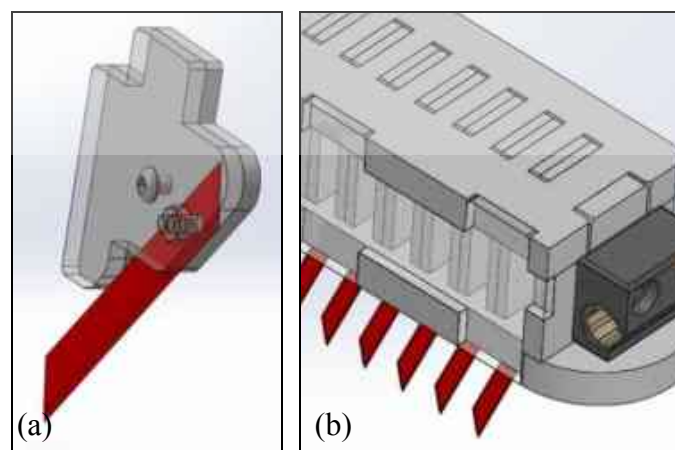


Figure 3.16 – (a) Blade insert assembly (b) when inserted into the rack

Initially, the blades holder is designed as pictured above. The blade is clamped using two acrylic plate with 3 mm thickness and then fastened using M3 bolts. Then the blades holder is inserted into the rack. This is the first design made for the first made concept: Cutter Moves X and Y. However, there are weaknesses using this holder concept. The blade is only “clamped”, not a hundred percent “held”. Acrylic raw material’s thickness also may vary and not uniform, resulting in the space between each blade may differ and unpredictable. The concept then improved:

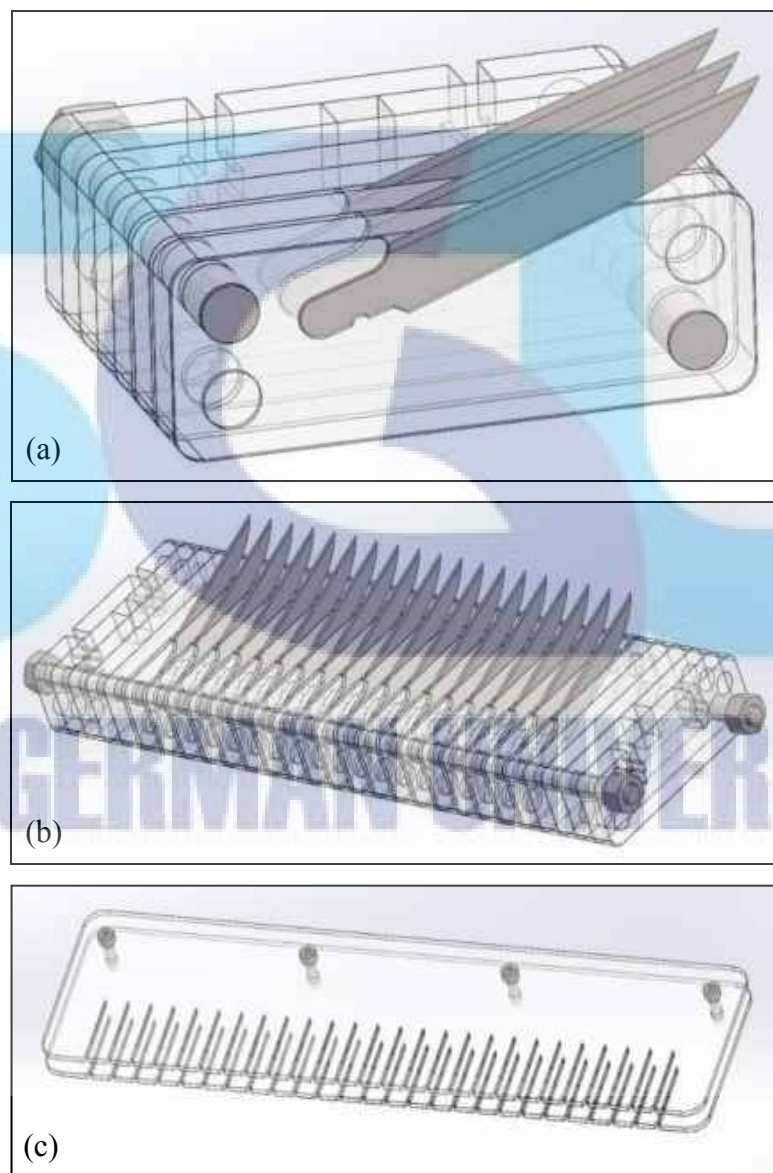


Figure 3.17 – (a) Section view, (b) complete set and (c) blades positioning jig of the improved concept

The improved concept can hold the blade entirely. As seen in Figure 18a, an acrylic plate with 2 mm thickness is cut following blade’s contour (with 0.1 mm clearance).

Ten millimeters thick acrylic plates then enclose both sides of the 2 mm plate. The blade is now can move freely within the 2 mm space. Blades positioning jig then used to keep the blade in intended position. It is better to rely on laser cut X and Y movement's precision than acrylic raw material's thickness. Then the free space will be filled using liquid clear epoxy plastic resin. When the resin dries, the blade will be retained and sit perfectly in place with uniform space between one and another, which is 12 mm.

3.5.6 Clamp

The clamping device is very important in ensuring the *cubicness* of the product results. As seen in Dicer Machine with Improved Squareness, an additional device to keep the product from “running” when being cut will improve the result's squareness. Therefore, a clamping mechanism with the size of *nata* sheet will be made.

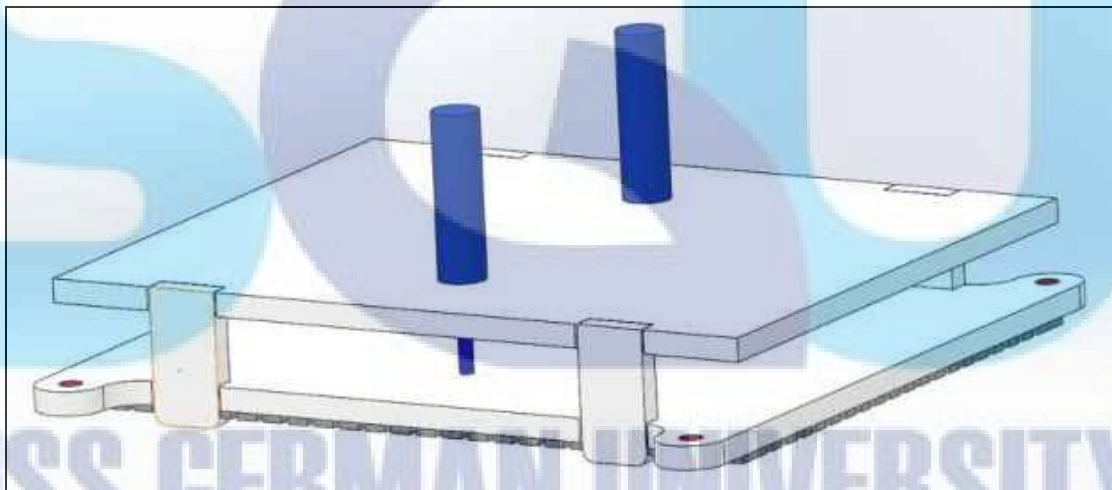


Figure 3.18 – Initial clamp design, blue color shows pneumatic cylinder

The initial clamp design uses two short stroke pneumatic cylinders CJ2B16-60Z; double acting stainless steel cylinder with 16 mm bore size and 60 mm stroke length from SMC. The upper plate and the bottom plate are made out of the acrylic plate with 10 mm thickness to ensure the load sustainability and simplify the manufacturing process (acrylic is manufactured using laser cut). Four acrylic guiding rails are glued to the sides of the upper plate, letting the bottom plate to slide along the guide rails. The calibrating holes colored with red in Figure 19 are used to calibrate the clamp's linearity with the machine bed (see chapter 3.5.3 above).

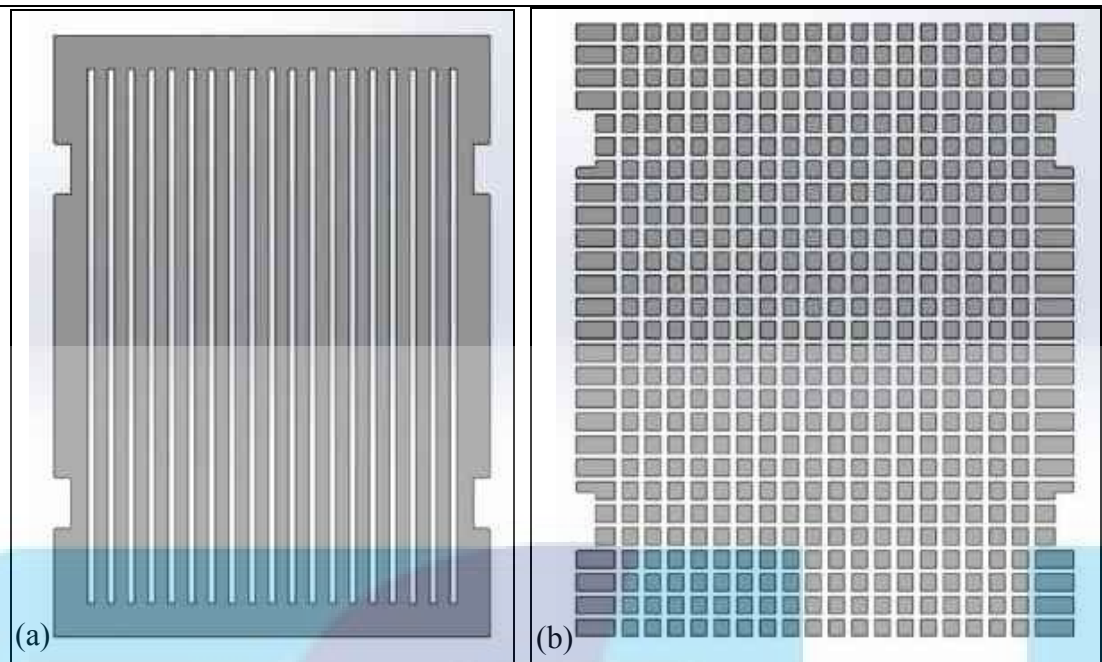


Figure 3.19 – Clamp contact plate (a) after laser cut and (b) after milling process

The product contacting bottom plate of the clamp will need special treatment because laser cut manufacturing process cannot cut slots to make the slits (3 mm width and 3 mm depth). To overcome this problem, an additional acrylic plate with 3 mm thickness will be manufactured separately and glued to the bottom side of the bottom plate. The additional acrylic plate is composed of many little squares, thus making the gluing a big problem. Therefore, the design to be laser cut will be as seen in Figure 21a, and then glued first onto the bottom plate, then milled according to the design in Figure 21b.

3.5.7 Actuators



Figure 3.20 – Pneumatic cylinders (a) rodless cylinder and (b) ordinary cylinder

Actuators planned to be used in the design of the movement actuator is rodless cylinder MY3A32-600 and MY3A32-300 from SMC. However, the price is too expensive, about IDR 11.2 million for both cylinders. Therefore, the actuator for X-cut movement is changed into the ordinary pneumatic cylinder. The choice comes to MCQV2-11-32-600M from Mindman Pneumatics, a 600 mm stroke double acting cylinder with 32 mm bore size (calculation about bore size will be explained in chapter 3.8.1 below). Without using a rodless cylinder, linear guides will be necessary to keep the movement precise and smooth (will be explained in chapter 3.5.8 below). The actuator for Y-cut movement is removed; making the Y cut movement must be manually operated. By operating the Y cut manually, cutting force and speed can be easily adjusted.

For the clamp actuator, the initial design will utilize two short stroke cylinders with 16 mm bore diameter (see Chapter 3.5.6 above). When talking about two pneumatic cylinders working together in parallel, achieving uniformity is not easy. For example, to achieve a uniform movement of both cylinders, the hose length between the two cylinders must be the same, the amount of air flowing into both cylinders must be exactly the same, and so on. That is why using only one cylinder is preferable.

However, the compressor to be used can only supply air pressure up to eight bars. Considering a safety factor of two, the pressure limit that will be used for the machine will be four bars. With the limited pressure, the clamping force will also be limited. The clamping force when using the previous design with two cylinders must be determined using following calculation:

$$F_{clamp} = F_{actuator} \quad (\text{Equation 2.1})$$

When an actuator is pressurized with compressed air, the force will be generated on the piston. Then the force from the actuator ($F_{actuator}$) will be transferred to the clamp and distributed along the clamp surface area (A_{clamp}). However, because of the surface area difference between the clamp and actuator, the pressure working on the clamp will be different from the pressure working in the cylinder. This difference can be calculated by expanding the equation 2.1 above.

$$F_{clamp} = 2 \times F_{cylinder} \quad (2.2)$$

Because there are two cylinders, the cylinder force is calculated twice.

$$P_{clamp} \times A_{clamp} = 2 \times P_{cylinder} \times A_{cylinder} \quad (2.3)$$

$$P_{clamp} = \frac{2 \times P_{cylinder} \times A_{cylinder}}{A_{clamp}} \quad (2.4)$$

The cylinder surface area is the surface area of the piston, which in this case is 16 mm in diameter. The length of the clamp is 320 mm and the width is 260 mm. The operating pressure of the cylinder is assumed four bars in average.

$$P_{clamp} = \frac{2 \times (4 \text{ bar} \times 100,000 \frac{N}{\text{bar} \cdot \text{m}^2}) \times \{\pi \times (8 \times 10^{-3} \text{ m})^2\}}{(260 \times 10^{-3} \text{ m} \times 320 \times 10^{-3} \text{ m})} \quad (2.5)$$

$$P_{clamp} = \frac{2 \times (400,000 \frac{N}{\text{m}^2}) \times (2.01 \times 10^{-4} \text{ m}^2)}{8.32 \times 10^{-2} \text{ m}^2} \quad (2.6)$$

$$P_{clamp} = 1,932.69 \frac{N}{\text{m}^2} = 0.1932 \text{ N/cm}^2 \quad (2.7)$$

The force acting on the *nata* sheet per square centimeter does not even reach 0.2 Newton. It is as if a weight of approximately 20 gram is put onto each *nata* cube, which is far less than enough.

The surface area of the clamp is just too wide to be powered by the ordinary pneumatic actuator. There are three solutions possible: change the actuator into the hydraulic system, change the pneumatic cylinder with the bigger bore size, or design a custom pneumatic cylinder.

Changing the actuator into hydraulic which can supply higher pressure is not a good option since it will make the mechanism too complex, not to mention the contamination probability because hydraulic uses oil.

Changing the actuator with bigger bore size is possible. However, the targeted clamping is 42,708.33 N/m² (calculation in chapter 3.8.2 below), the minimum bore size diameter will be:

$$F_{clamp} = F_{cylinder} \quad (\text{Equation 3.1})$$

$$P_{clamp} \times A_{clamp} = P_{cylinder} \times A_{cylinder} \quad (3.2)$$

$$A_{cylinder} = \frac{P_{clamp} \times A_{clamp}}{P_{cylinder}} \quad (3.3)$$

$$A_{cylinder} = \frac{\left(42,708.33 \frac{N}{m^2}\right) \times (260 \times 10^{-3} m \times 320 \times 10^{-3} m)}{(4 \text{ bar} \times 100,000 \frac{N}{bar \cdot m^2})} \quad (3.4)$$

$$A_{cylinder} = \frac{42,708.33 \frac{N}{m^2} \times 8.32 \times 10^{-2} m^2}{400,000 \frac{N}{m^2}} \quad (3.5)$$

$$A_{cylinder} = 8.9 \times 10^{-3} m^2 \quad (3.6)$$

Calculating the diameter using circle area equation,

$$A_{cylinder} = \pi \times \left(\frac{d_{cylinder}}{2}\right)^2 \quad (\text{Equation 4.1})$$

$$d_{cylinder} = 2 \times \sqrt{\frac{A_{cylinder}}{\pi}} \quad (4.2)$$

$$d_{cylinder} = 2 \times \sqrt{\frac{8.9 \times 10^{-3} m^2}{\pi}} \quad (4.3)$$

$$d_{cylinder} = 2 \times 0.053 m \quad (4.4)$$

$$d_{cylinder} = 0.106 m = 106 \text{ mm} \quad (4.4)$$

From the calculation above, the bore diameter must be a minimum of 106 mm. A pneumatic cylinder with a short stroke (60 mm) with more than 106 mm bore size is very uncommon. In addition, due to budget constraint, the researcher cannot order a custom cylinder to the manufacturer. Therefore, the researcher designs a custom cylinder for the pneumatic system with as low budget as possible.

The custom pneumatic system design should be simple enough to be manufactured. It also has to have a bore size of more than 106 mm. After some consideration, it is decided to make the pneumatic system directly embedded inside the clamp unit. A revision of the design then takes place.

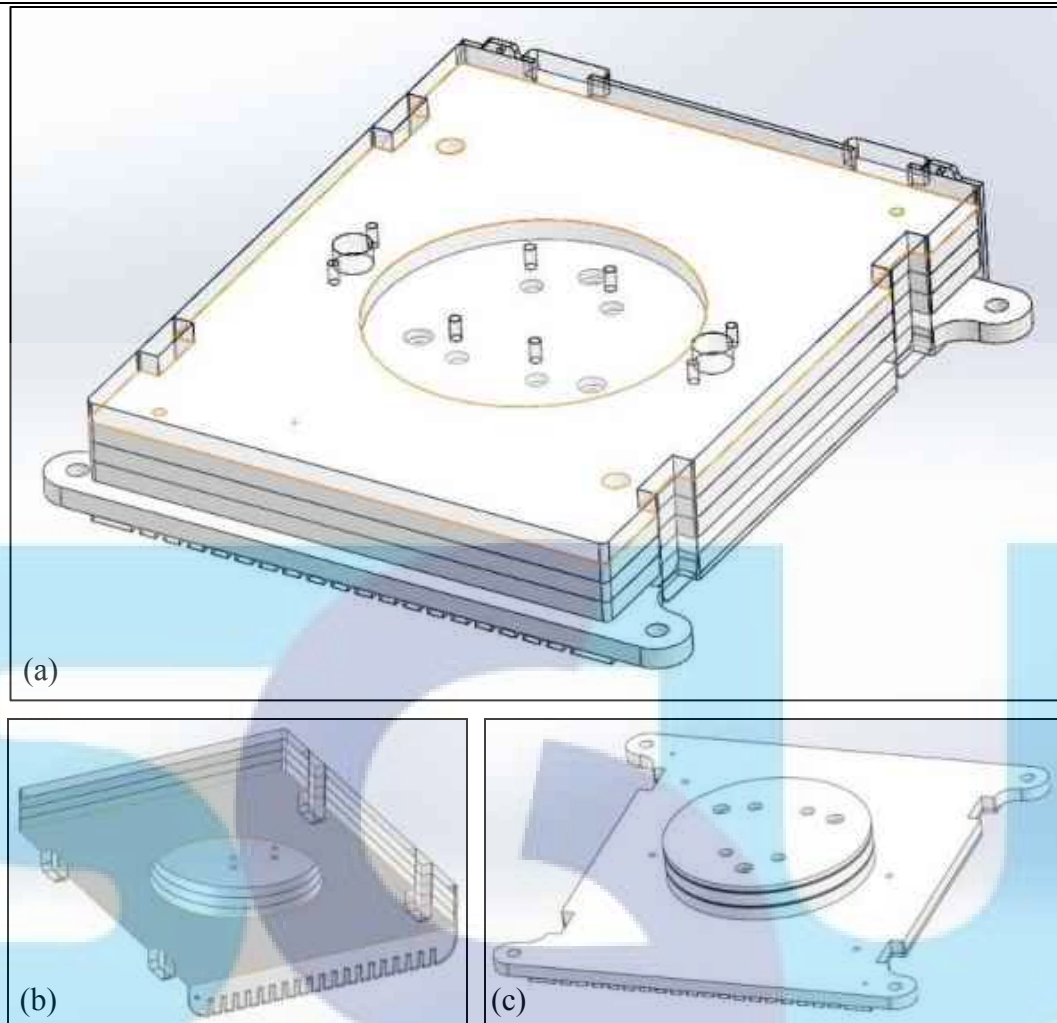


Figure 3.21 – (a) New concept of the clamp with (b) embedded pneumatic cylinder inside the top clamp part and (c) piston connected to the bottom part

The new clamp design above has already had its own embedded pneumatic system in it. The top part of the clamp is adjusted to be the cylinder and the bottom part is designed to be the piston. All of the parts will still be made out of acrylic with various thickness. The piston will be made out of 10 mm thick acrylic stacked with 2 mm thick acrylic twice, then topped with 4 mm thick acrylic. The diameter of the piston is 150 mm (for better range of clamping pressure) and sealed using 2 mm diameter rubber O-Ring. For 2 mm diameter O-Ring to be able to act as an airtight sealing, the O-Ring must be compressed into 1.6 mm. The clearance gap between the walls will provide the condition, so the O-Ring spacer for the piston has a diameter of 146.8 mm. Stroke of the piston is set to 8 mm so that the O-Ring never pass the boundary between two 10 mm plates for the cylinder wall. The piston will be spring loaded for returning back into position.

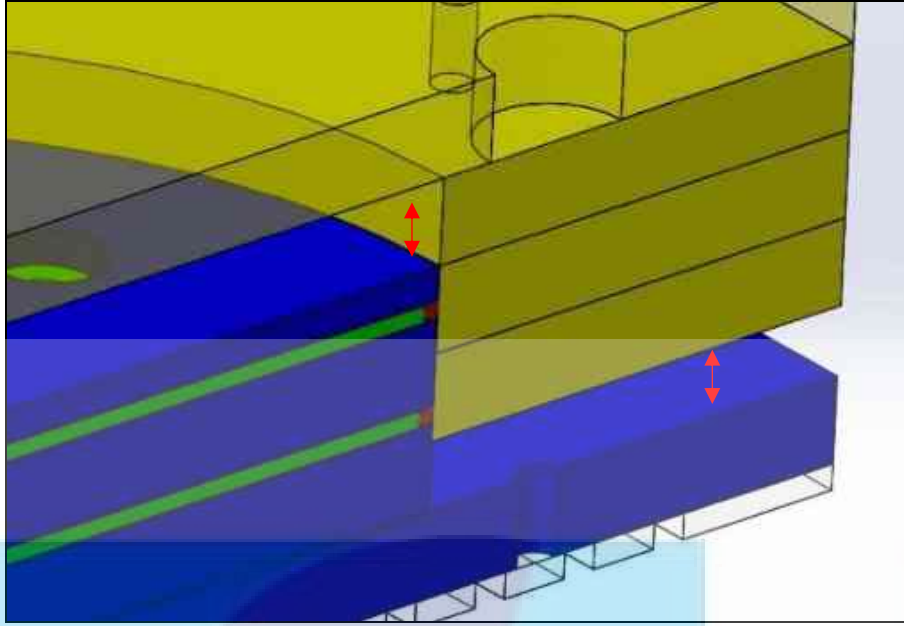


Figure 3.22 – Illustration of the manufactured pneumatic cylinder

The illustration above has been color coded to help the reader understand easily. The cylinder wall is color coded with yellow, will be made out of stacked four 10 mm acrylic plate with the top one for the enclosure. The blue one is the piston altogether with the clamp plate will be made out of three acrylic plates, two of them 10 mm and the enclosure is 4 mm thick. Between the piston plates, a 2 mm thick acrylic plates color coded green will be placed for O-Ring spacer, to fit the O-Ring (labeled by red color).

By changing the pneumatic piston rod into the new design, the clamping force will be significantly increased, with calculation as follows:

$$F_{clamp} = F_{cylinder} \quad (\text{Equation 3.1})$$

$$P_{clamp} \times A_{clamp} = P_{cylinder} \times A_{cylinder} \quad (3.2)$$

$$P_{clamp} = \frac{P_{cylinder} \times A_{cylinder}}{A_{clamp}} \quad (3.3)$$

$$P_{clamp} = \frac{(4 \text{ bar} \times 100,000 \frac{N}{\text{bar} \cdot m^2}) \times \{\pi \times (75 \times 10^{-3} m)^2\}}{(260 \times 10^{-3} m \times 320 \times 10^{-3} m)} \quad (3.4)$$

$$P_{clamp} = \frac{(400,000 \frac{N}{m^2}) \times (1.76 \times 10^{-2} m^2)}{8.32 \times 10^{-2} m^2} \quad (3.5)$$

$$P_{clamp} = 84,625.38 \frac{N}{m^2} = 8.4 N/cm^2 \quad (3.6)$$

The force acting on the *nata* sheet per centimeter is now multiplied by 43.95 times (quadratic relation from 75 mm piston radius and two 8 mm piston radius) as if an approximately 800-gram weight is put on top of each *nata* cubes.

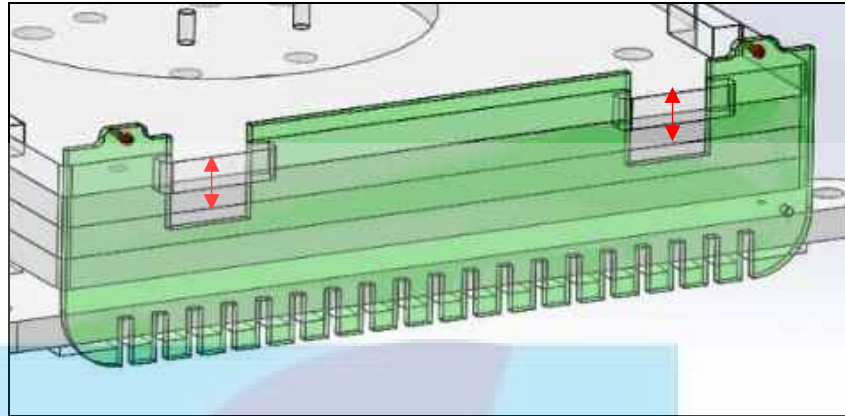


Figure 3.23 – Back scraper of the clamp illustration

In addition, the new design of the clamp also has a manually driven back scrape to help to keep the *nata* sheet from left behind. The scrape will be made out of 3 mm thick acrylic (green color in the figure above), and it can slide freely along the guide on the rear side of top clamp enclosure. As a stopper, two M3 bolts (color code red) are inserted.

3.5.8 Linear Guides

Because rodless cylinders cannot be used, linear guides are necessary to keep the movement system precise and smooth. Using linear guides will also reduce the possibility of the blade touching the clamp slits. It is because the clamp slits are 3 mm wide, yet the tolerance of linear guide movements can be as low as 10 microns.

The linear guides will also have to fulfill the food grade requirements. Most of the linear guides use lubricant. It is not suggested as a lubricant may contaminate the food product. Not to mention, if the user skipped lubricant maintenance unintentionally, the guide may stop working, scratches can occur and contaminate the product. Therefore, it is preferable to use the non-lubricant linear guides.

In this case, one of the linear guides suppliers that fulfilled the criteria, reachable, and often used by other thesis researchers in SGU, is IGUS. IGUS has linear bushings made out of Teflon or any similar plastic polymers that are already FDA approved and

applicable for the food industry. Using linear bushings will also reduce maintenance and downtime.

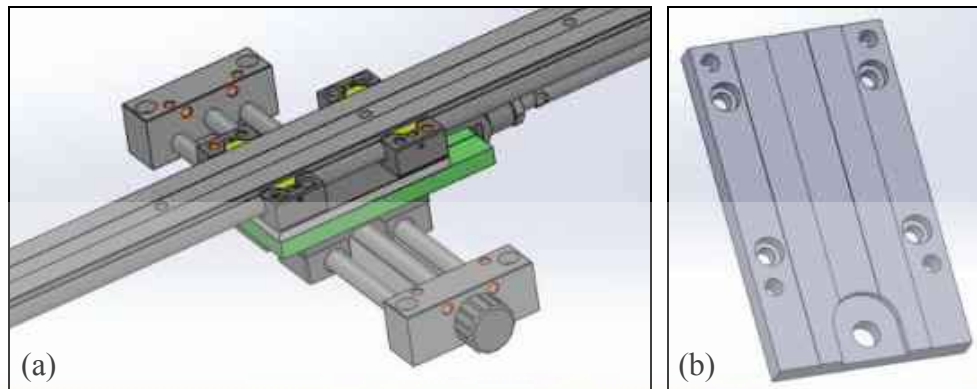


Figure 3.24 – (a) IGUS linear guide and adjuster and (b) custom adapter

For X cut movement, a 960 mm long linear guide with a double rod of 10 mm diameter, WS-10-40-960, will be used with its complementary bracket, WKE-10-40-10-01 (as seen in Figure 26a, from the green part above). The bracket then will be connected into linear adjuster, SLW-1040-150-HR (as seen in Figure 26a, from green part below) using a custom designed adapter (Figure 26b). This complete set will be mounted on the aluminum profile, opposite of the bed, where it will sustain the reaction force when clamping. The linear adjuster will also provide convenience when adjusting the slits in relation to the mounted X blades.

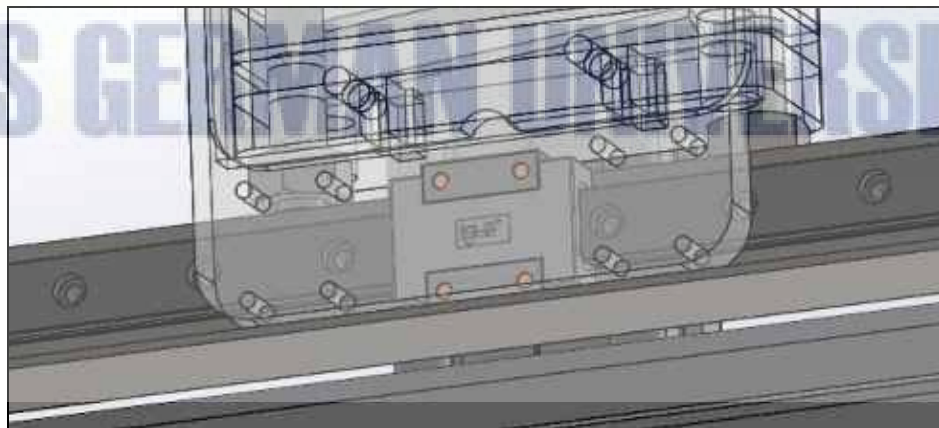


Figure 3.25 – IGUS linear guide for Y-cut movement

For Y-cut movement, two linear guides (one for each side) will be used. These linear guides are smaller than the one used in X movement system. The linear guides used are 500 mm length and 12 mm width T-shaped rails, TS-04-12-500, with its complementary bracket, TW-04-12.

3.5.9 Final Design

After lots of considerations and revisions, the design starts to come into the final form. The latest design will have 600 mm pneumatic cylinder instead of a rodless cylinder, embedded pneumatic system in the clamping system, linear guides with updated structures, and any other minor improvements. The changes can be seen in the rendered final 3D design below.

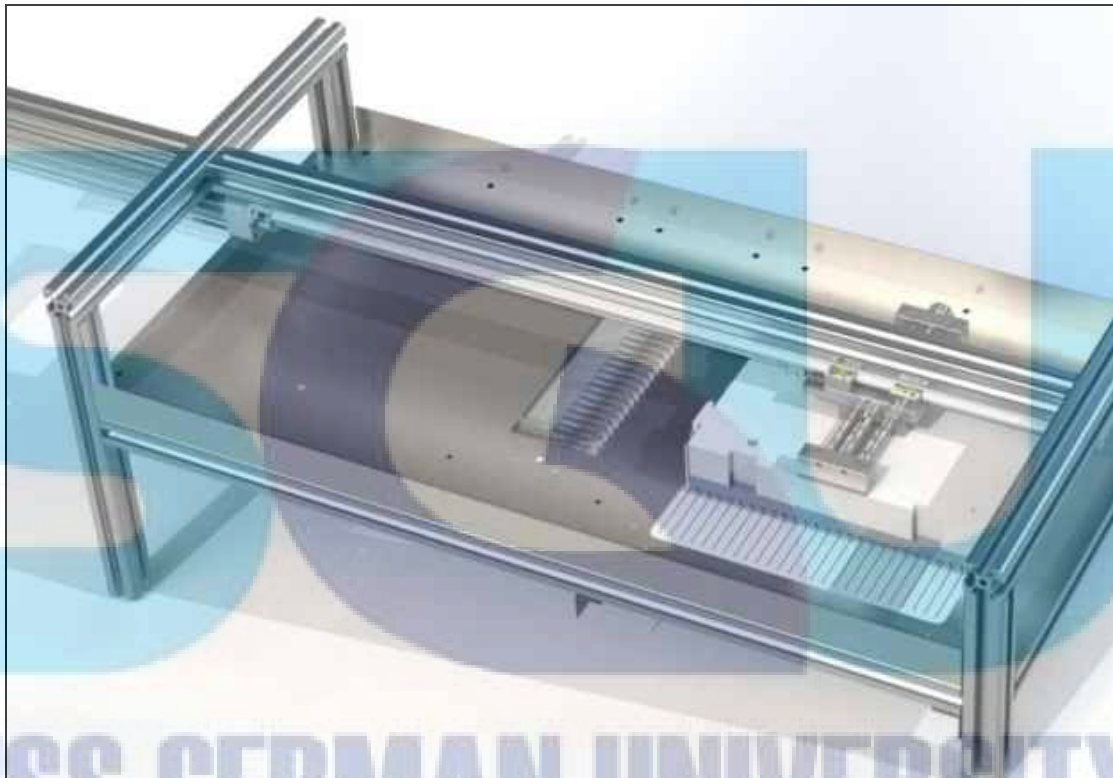


Figure 3.26 – Final design of the *nata* cutting machine

3.6 Electrical Design

The *Nata* cutting machine will be controlled using PLC and an actual control panel box will be made, complete with its safety measures and logic.

3.6.1 Safety Measures

For safety measures, the first thing will be implemented is placing limit switches to tell the PLC about the machine condition. There will be four limit switches:

- Limit Switch 1 is located in the initial position of X cut movement, which will be triggered if the cylinder for X-cut movement has been fully retracted.

- Limit Switch 2 is located in the final position of X cut movement, which will be triggered if the cylinder for X-cut movement has been fully advanced.
- Limit Switch 3 is located in the initial position of Y-cut movement, which will be triggered if the blades rack for Y-cut movement has been pushed back (manually) to the starting position.
- Limit Switch 4 is located in the final position of Y-cut movement, which will be triggered if the blades rack for Y-cut movement has been pulled forward (manually) to the end position.

Solenoid valves will be used so that it can be automatically and electrically controlled by the PLC. Dump valve will also be implemented, in such manner that if the system fails (emergency), the dump valve will automatically dispense all remaining pressure in the pneumatic system and piping.

3.6.2 Control Panel

A control panel box will be used for containing all electrical components. The control panel must comply with the common electrical standard, such as:

- Emergency button must be accessible
- All wires must be crimped using lug and/or ferrules
- All wiring must be tidy and cable ducting should be used
- Miniature Circuit Breaker (MCB) must be used as main power switch
- Grounding terminal and grounding wires must be implemented
- Power input from outside panel box should be using power plug socket
- Signal exchange between the panel box and the machine should be using proper connector

For the control itself, the control panel will have following inputs and outputs.

Inputs:

- Emergency Button for emergency situation, it will turn off the whole system
- On/Off Button for turning on and off the machine
- Clamp Activation Selector to activate the clamping mechanism
- X Cut Advance Button to execute X cut movement (main cylinder advances)

- X Cut Retract Button to get the clamp back into initial position (the main cylinder retracts)
- Four Limit Switches for position acknowledgment by the PLC
- Collision Detection Sensor to detect if any collision happens
- Power input (220 VAC) for power supply

Outputs:

- Power supply (24 VDC) for powering the machine
- Three Solenoid Valves for controlling the pneumatic system
- Buzzer Alarm to notify the user whenever an error happens
- Activation Lamp to notify the user that the machine is in ON condition.

3.6.3 Safety Control Logic

Primarily, MCB must be turned on to power the whole control system hardware. MCB is the main power gate from the external power source into the control panel (control panel powers all instruments in the machine too). Emergency Button will also have to be released, otherwise, all software will not function (PLC program will not start). Considering the two previous conditions are fulfilled, the program will start according to this logic:

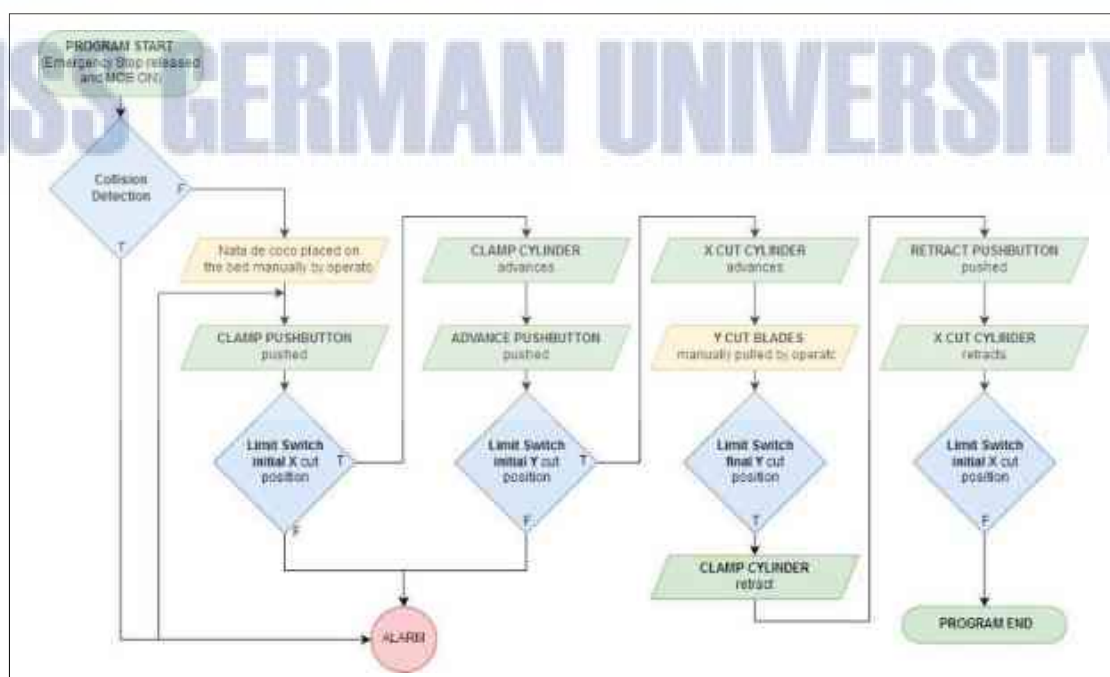


Figure 3.27 – Safety control logic flowchart

3.6.4 Collision Detection

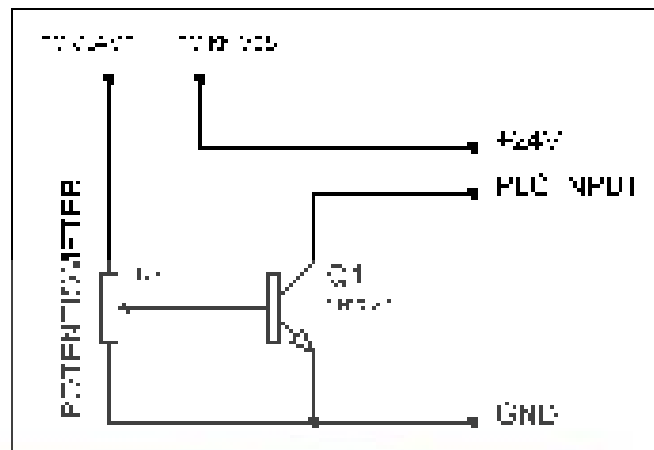


Figure 3.28 – Simple Conductive Sensor schematic

To detect collision between clamp and blades, a conductive sensor will be implemented. A simple schematic of the conductive sensor has been made using ARES Program. The voltage source of +24 VDC will be connected with the knives. Another probe reader then connected to the clamp. The voltage source should be connected to the knives rather than the clamp because the knives are less exposed, thus reducing the chance of the user being electrocuted.

The potentiometer will work as a voltage divider, so the threshold of the sensor can be adjusted. When the reading of the material conductivity exceeds a certain threshold, the transistor Q1 will be “switched ON”, resulting in a contact between PLC INPUT pin and GND. The contact then will be understood by PLC as a signal. In short, the concept of the sensor will be like a switch. When a certain condition is met, it will work exactly like a switch going to Normally Open mode.

If the sensitivity of the sensor is not enough, the potentiometer resistance must be increased, from initial 10k Ω maybe to 100k Ω . It will also be better if it is changed into multi turn potentiometer.

3.7 Preliminary Concept Testing

As mentioned in Figure 3.3 – Preliminary design concepts diagram, a simple pre-prototype apparatus should be made to prove whether the machine that is going to be built would work or not. This apparatus bears a sole purpose: to prove that cutting *nata de coco* using multiple uniformly patterned stationary blades is possible. That is why,

on 1 December, just before proposal defense, an apparatus has been made as a proof of concept.

3.7.1 The Apparatus

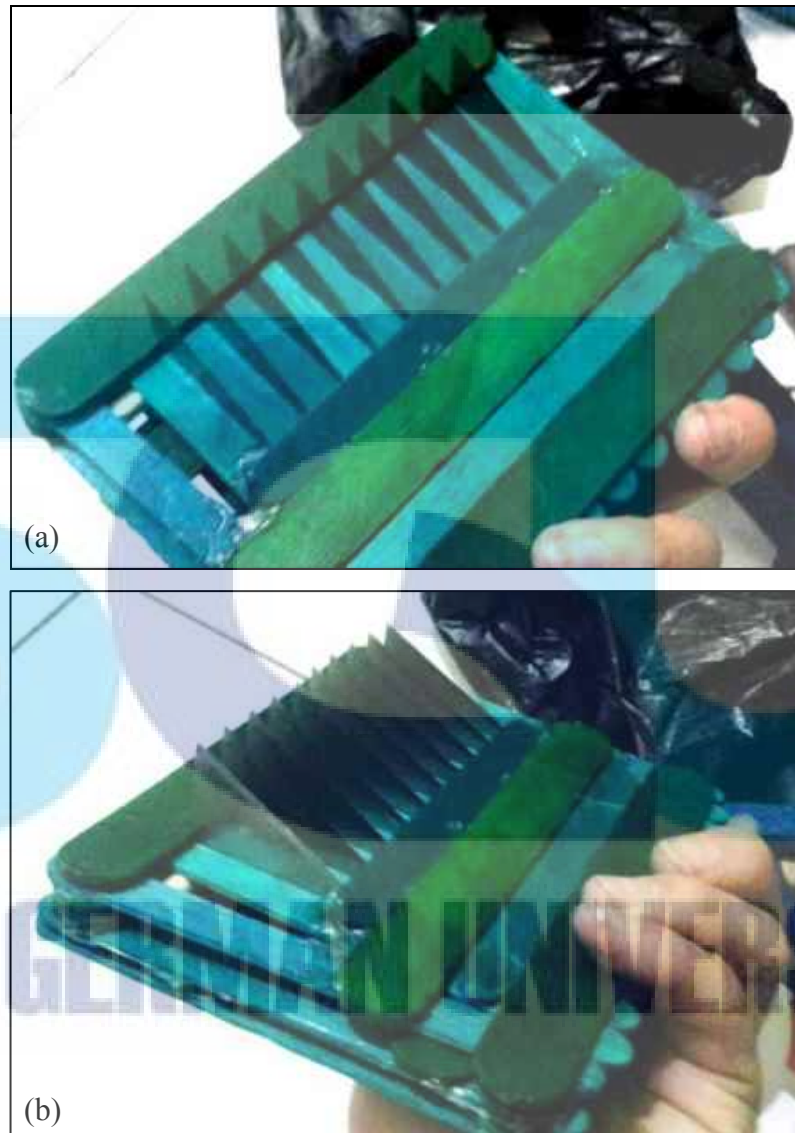


Figure 3.29 – Pre-prototype apparatus (a) top view and (b) side view

The apparatus is made out of wooden sticks (usually used for handicraft), chopsticks, and paper cutter blades. Ten paper cutter blades are used to simulate the cut, which is uniformly arranged and bracketed using wooden sticks. The space between one blade and another is about the same as the width of the wooden stick, 10 mm. The cutting edge of the blades is also positioned at an angle of 30 degrees, normal from the knife holder surface.

3.7.2 Testings

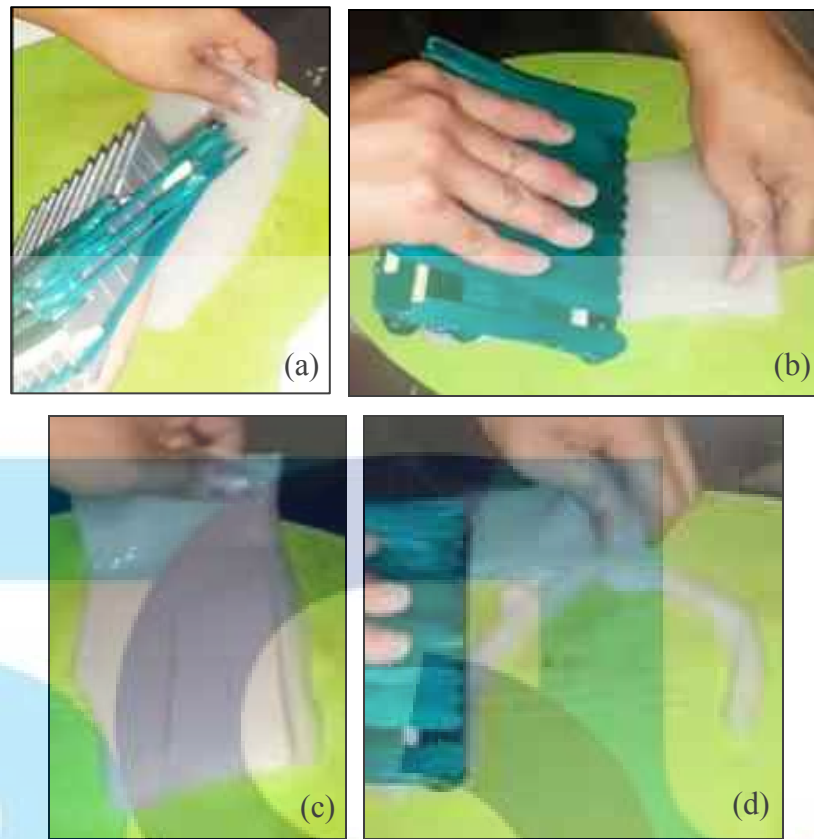


Figure 3.30 First testing (a) initiation, (b) process X cut, (c) result X cut, (d) try Y cut

In the first testing, a sample of *nata* sheet is tried to be cut in two directions. The result of the first cut (X cut) is very good, all of the *nata* turn into noodles with uniform dimension. In contrary, the next cut (Y cut) doesn't work out very well. It is because the noodles are not held when being cut.



Figure 3.31 Second testing (a) cutting process, (b) result, (c) result hanged

For the second testing, the focus is only for one direction of cut, but the sample is now being uniformly held using a kitchen knife, as seen in Figure 3.28a. This way, the result

is better than before. The cutting also feels lighter, even though the sample is wider than before (all of the blades are used).

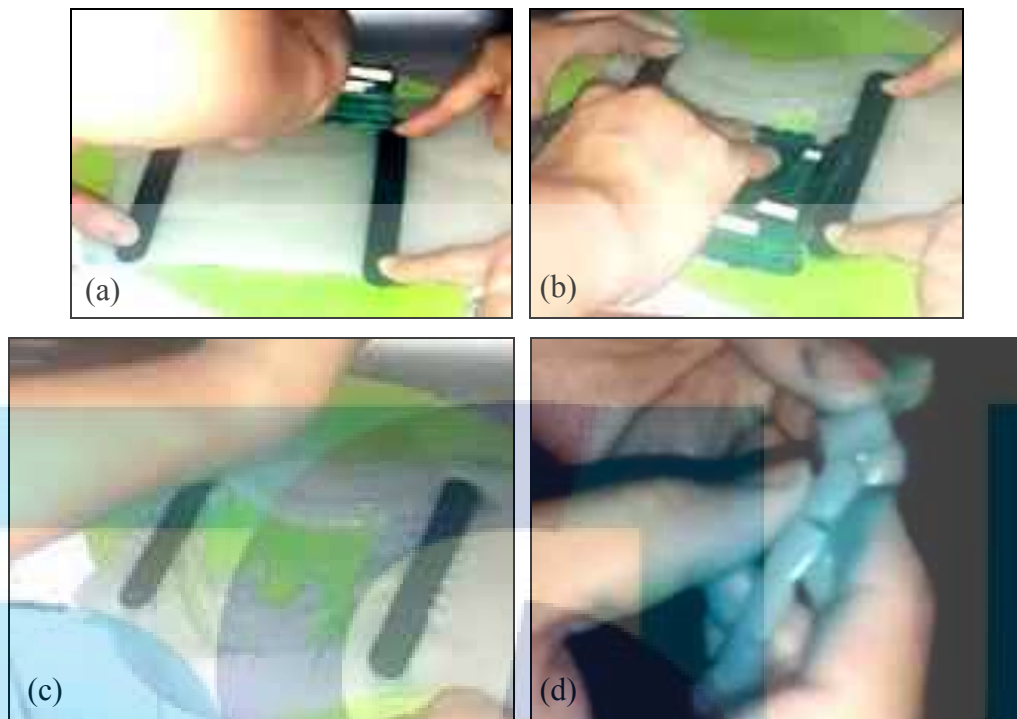


Figure 3.32 Third testing (a) cutting start, (b) midway, (c) finished, and (d) result

The third testing tests the Y cut. The previously cut sample from second testing is held using two wooden sticks on its both sides. The blades then make a cut perpendicular with the previous cut. As expected, the result is not good, because when cutting perpendicular, the edge parts where the corner most blades are, will be detached completely before the other blades in the middle have time to cut (Figure 3.29b). These fully detached noodles then come along with the blade and push the rest of the noodles. The results are *nata* noodles with the same length as the distance between the two corner most blades, only with sets of half cuts with uniform distance one and another in the middle (Figure 3.29d).

The conclusion is, the method of cutting is legit because it can cut very well, given the *nata* can be fully clamped and prevented to come along with the blade.

3.8 Experimental Calculations

Some calculations are achieved through experimentation. One of the experiments is even conducted after the machine is existing (in relation with **CHAPTER 4 - RESULT AND DISCUSSION**)

3.8.1 X Cut Bore Size Calculation

To calculate the minimum bore size diameter necessary for the X-cut cylinder, a minimum cutting force has to be known. The researcher has done a set of experiments using Y-cut blades (which can be manually pulled) to get an approximation of the cutting force.



Figure 3.33 – Luggage scale

A luggage scale is used to calculate the force needed to pull the Y-cut blades for cutting a nata sheet. The researcher can only do three trials because the sample is limited. The result is 16.24, 19.51, and 17.63 kilograms for each trial (the luggage scale measures in kilogram), with an average of 17.793... kilograms, or approximately 177.63 Newton (coefficient of gravity is considered 10 m/s²).

The number of blades in Y cut is 25 blades, but in X cut there are only 19 blades. Therefore, the cutting force in X cut will be in a ratio of 19 : 25 with the Y cut. The cutting force for Y cut is 177.63 Newton, divided by 25 and then multiplied by 19; the cutting force of the X cut will be approximately 134 Newton.

Then, calculate the minimum bore size diameter with the following equation,

$$F_{cylinder} = P_{cylinder} \times A_{cylinder} \quad (\text{Equation 5.1})$$

$$F_{cylinder} = P_{cylinder} \times \pi \times \left(\frac{\phi_{cylinder}}{2} \right)^2 \quad (5.2)$$

To calculate the diameter,

$$\phi_{cylinder} = 2 \times \sqrt{\frac{F_{cylinder}}{P_{cylinder} \times \pi}} \quad (5.3)$$

If the pressure to be used is considered four bars in average and the cutting force is compensated with the safety factor of two, then:

$$\phi_{cyl} = 2 \times \sqrt{\frac{2 \times 134 \text{ N}}{400,000 \frac{\text{N}}{\text{m}^2} \times \pi}} \quad (5.4)$$

$$\phi_{cyl} = 2 \times \sqrt{2.133 \times 10^{-4} \text{ m}^2} \quad (5.5)$$

$$\phi_{cyl} = 0.0292 \text{ m} = 29.2 \text{ mm} \quad (5.6)$$

The closest standard bore size diameter for pneumatic cylinder will be 32 mm.

3.8.2 Clamping Force Calculation

An experiment needs to be done for determining the clamping force. Because of the properties of *nata, de coco* is elastic to some extent; the clamping force must not exceed certain point that can cause plastic deformation of the *nata*. Now, the question is how much force the *nata* can sustain before going into plastic deformation (yield point).

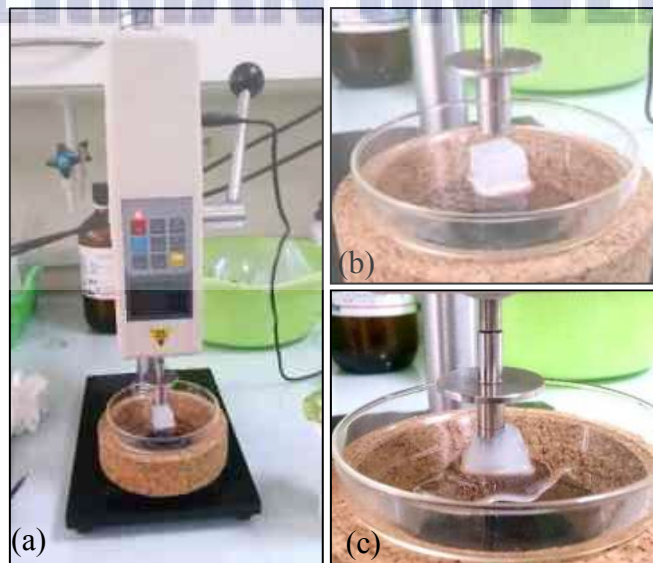


Figure 3.34 – (a) The penetrometer, (b) before measurement, (c) plastic deformation

A penetrometer is a device to measure how much force is acting on the plunger (a cylindrical metal rod with some kind of disk as can be seen in Figure 3.34c above). Using this device, the researcher measures the yield point of *nata de coco*. The sample from *PT. Coco* is preserved in acid and by observation; it is softer than the real *nata de coco* (which will actually be cut in the real application). A small experiment is conducted using penetrometer. A sample from *PT. Coco* that is preserved in acid, another sample that has been soaked in water for 24 hours, and a real *nata de coco* product from the mini market is to be measured. All samples are tested 3 times; each one is plunged until one millimeter above the testing bed. The result is as follows:

Table 3.2 – Sample Comparison

Trial	Force (N)		
	Acidic	Soaked	Real <i>nata</i>
1	22.8	24.6	46.8
2	20.1	23.7	39.7
3	28.2	21.6	35.2
Average	23.3	26.87	40.57

As shown in the table above, the real *nata* needs higher force to “clamp” rather than the existing sample. Since the machine’s clamping system must be able to hold the real *nata*, the yield point experiment must use the real *nata*. An experiment with 10 trials is conducted with the sample of real *nata* cubes (approx. 12 mm x 12 mm x 12mm), and a data set is acquired:

Table 3.3 – Yield Point Experiment

Trial	Force (N)	Trial	Force (N)
1	3.97	6	3.46
2	5.01	7	4.26
3	3.94	8	3.52
4	4.68	9	4.01
5	4.49	10	3.21
Average		4.055	

From the experimental data set above, it is concluded that the approximate yield point of *nata de coco* is 4.055 N. The penetrometer plunger surface area is circular with

diameter of 11 mm or 95.03 mm^2 , and the *nata* cubes surface area is 12 mm x 12 mm or 144 mm^2 , meaning the ratio of the area is approximately 95 : 144. In conclusion, the clamping force necessary for a single *nata* cube is approximately 6.15 Newton.

To calculate the clamping pressure, the clamping force necessary of 6.15 N must be divided by the area of a single cube: 144 mm^2 . Solving for N/m^2 , the result will be $42,708.33 \text{ N/m}^2$.

