NMBU

# Preface

This thesis was carried out to evaluate a new design for a combined vacuum coater and mixer, and was initiated by The Center of Feed Technology (FôrTek) and the Norwegian University of Life Sciences (NMBU). Its content addresses the process of building a prototype of the product, as well as tests and analyses to rate its functionality and prospects for the future. As this is considered the first step of many in development of the design, one of our most important goal is to make sure all flaws and errors are well documented for the next person who will continue the process of development.

We would like to thank our supervisor, Dr. Carlos Salas Bringas, for assisting us in our work with this thesis. He has helped us through motivating discussions, and provided us with helpful advice regarding prototyping, testing and writing the thesis.

We would also like to thank FôrTek, represented by head engineer and co-supervisor Dejan Miladinovic and head engineer Ismet Nikqi, for providing us with constructive advice regarding the design of the prototype and samples used for testing.

Furthermore, we would like to thank Eik Idéverksted and NMBUs workshop crew who have helped us during the process of 3D-printing and building the prototype.

Finally, we would like to thank our fellow students and friends at Fløy 5 for a lot of interesting discussions throughout this semester.

Ås, May 13th 2015

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Didrik H. Dolva

# Abstract

In this thesis, a new design for a machine for both mixing and vacuum coating has been evaluated. The idea of the design comes from FôrTek, a research laboratory for the food and feed industry owned by the Norwegian University of Life Sciences. The purpose of the idea is to make a simpler, less complicated product, compared to other similar products on the market. There is a lack of affordable, lab-sized vacuum coaters and mixers in the market, and the prototype designed in this thesis aims to fill this niche.

To conduct the evaluation, a prototype has been built mainly using 3D-printed parts of plastic. Each part was first modelled using the CAD software SolidWorks, and designed to fulfil the above-mentioned purpose.

Three tests were conducted to evaluate the performance of the prototype: a mixing test, a test of fluid dispersion in mixing, and a test of vacuum coating pellets. The mixing test, which consisted of mixing grain of various size distributions, showed promise with no significant difference between samples taken from different parts of the machine. The test of fluid dispersion in mixing was conducted by spraying a certain amount of water into flour. After the process, the water percentage in the flour was measured in samples from different areas inside the machine. The different samples showed no significant difference from one another and it was thusly concluded that the fluid dispersion in mixing was acceptable. The vacuum coating test were inconclusive, as the prototype and method used was unable to produce a satisfying result upon which to base a conclusion.

As the prototype had some flaws regarding its design, recommendation for work on further prototypes has been suggested.

Based on numbers from various sources, a cost evaluation of the product was conducted to compare against competitors' products. The evaluation showed that a finalized product developed from the prototype potentially could be less expensive than similar products. A brief market analysis showed promise for releasing the machine in the market.

## Sammendrag

Denne oppgaven omhandler utviklingen og evalueringen av en maskin til fôrindustrien, som skal kunne fungere som både en blander og som en «vacuum coater». Idéen til designet stammer fra FôrTek, et forskningslaboratorium for fôrindustrien under Norges miljø- og biovitenskapelige universitet. Hensikten ved idéen er å lage et mindre komplisert produkt sammenliknet med eksisterende løsninger. Markedet mangler et billig alternativ i laboratorium størrelse, og prototypen utviklet i denne oppgaven søker å fylle denne nisjen.

For å kunne evaluere maskinen ble prototypen i hovedsak bygget av 3D-printede deler i plastikk. Delene ble designet for å tilfredsstille kravene til maskinen og modellert i CAD programmet SolidWorks.

Tre tester ble utført for å evaluere egenskapene til prototypen: en test for blanding, en test for spredning av væske i blandingen og en test for å «vacuum coate» pellets. Testen av blandingsegenskapene ble utført ved å blande korn og mel med forskjellige partikkelstørrelser, for så å undersøke om blandingen var lik gjennom hele maskinen. Resultatene viste ingen statistisk forskjell mellom prøvene tatt fra ulike områder inne i maskinen, noe som indikerer tilfredsstillende blandeegenskaper. Testen av spredningen av væske under blanding foregikk ved å sprøyte en liten andel vann inn i mel, og deretter måle melets vanninnhold i forskjellige områder inne i maskinen. Prøvene viste ingen signifikante forskjeller, og det ble konkludert med at spredningen av vann i blandingen var akseptabel. Fra «vacuum coating» -testen ble ingen slutninger trukket, da prototypen og testmetoden ikke kunne produsere resultater å basere konklusjonen på.

Noen feil ved prototypen ble avdekket under testingen, og anbefalinger for videreutvikling har blitt foreslått.

En sammenlikning av produktet mot mulige konkurrenter ble gjort på bakgrunn av tall fra ulike kilder. Tallene viste at en fremtidig, ferdigutviklet versjon av maskinen har potensiale til å være mindre kostbar enn liknende produkter. En kort vurdering av markedet viste at en ferdigstilt versjon av maskinen hadde potensiale for markedsføring.

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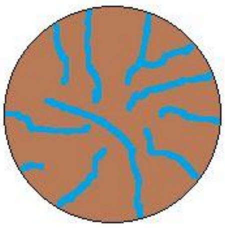
# 1 Introduction

This chapter provides background information for the thesis, together with motivation, objectives and limitations. The methodology and terminology are also described in this chapter.

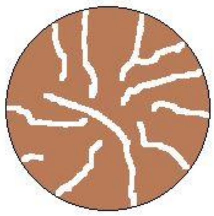
## 1.1 Background

### 1.1.1 Vacuum Coating

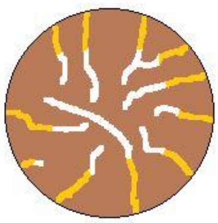
During the 1980's, research into the metabolism of marine species showed that an increase in the total fat content of the feed used in the Aquaculture Industry would be beneficial. The suggested value of up to at least 30 % began to reach the ceiling of what was possible to achieve with standard extrusion technology, and the process of Vacuum Infusion was developed (Young, Forte, & van Doore, 2007). The Vacuum Infusion Process will henceforth be described as vacuum coating. Vacuum coating, as the name implies, uses vacuum to evacuate air from the chamber where the feed pellets are to be infused with oil. The evacuation of air, even from the pores of the pellets, ensures that the oil is able to penetrate and saturate the product. This process enables production of feed with a higher content of fat, as the pellets absorb the oil.



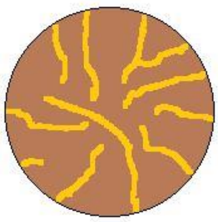
*Stage 1: Pellet before coating, air (blue) fills the pores of the pellet.*



*Stage 2: Pellet under vacuum, air has been evacuated from the pores.*



*Stage 3: Vacuum is released slowly, and the oil that has been covering the pellet starts to penetrate the pores.*



*Stage 4: Pellet after coating, oil has completely filled the pores that contained air before coating.*

*Figure 1.1: The vacuum infusion process shown at four different stages.*

### 1.1.2 Mixing

Mixing is the process of dispersing components, with the intent of making a heterogeneous system into a more homogeneous one. As mixing is an essential part of most chemical processes, several different types of mixers have been developed over the years to cover different needs. Such needs can vary from the required degree of mixing to a certain reaction of the materials. Usually when choosing a mixer type, it is useful to look at which state the material is in, either gases, liquids or solids. When mixing gases, the need for a specialized type of equipment is rarely needed (Sinnot, 2005). In liquids, different types of mixers can be used. Usually it varies with the liquid's properties, especially the viscosity. For low viscosity fluids, a static inline mixer can be used. This is one of the simplest form for mixing and relies on the turbulence of liquids in motion. The components are simply sent through some kind of pipe, often containing some element that will "disturb" the liquid's laminar flow and create turbulence as shown in Figure 1.2.

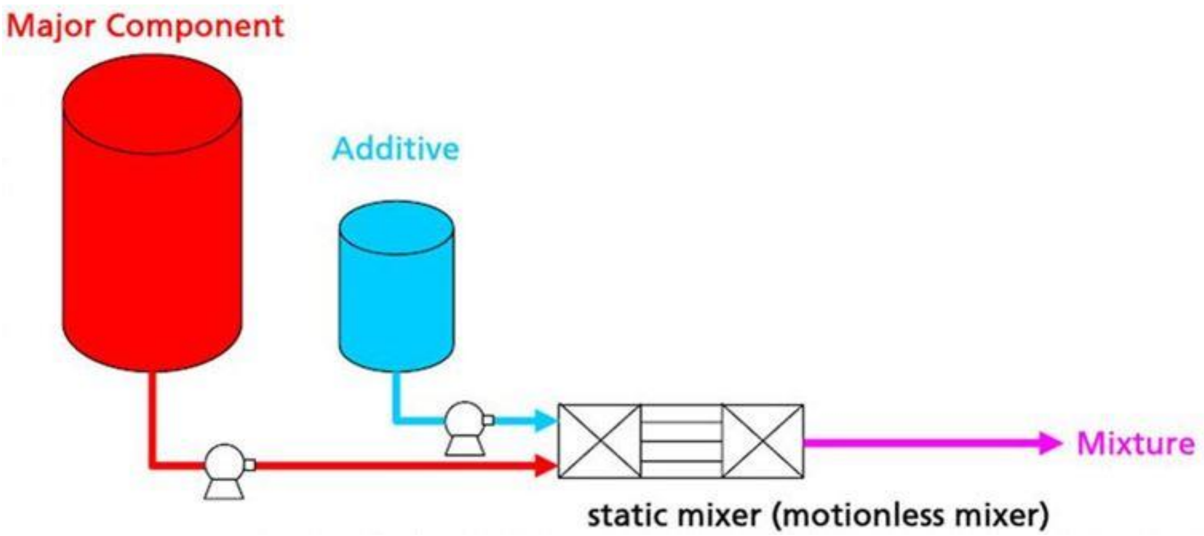



*Figure 1.2: Principle of a static inline mixer. (StaMixCo, 2015)*

For high viscosity liquids, it is more common with a static mixer with some form of agitator that stirs the mixture. Different types of agitators can be used, depending on the material properties. This is the most commonly used type of equipment for blending liquids and preparing solutions (Sinnot, 2005).


*Figure 1.3: Different types of agitators used in mixing. (Prism Pharma Machinery, 2015)*

In the feed industry, the majority of mixers are horizontal mixers with some type of agitator. They are again divided into three basic mixer styles: ribbon, twin shaft and paddle (Fairchild, 2013). The prototype discussed in this thesis is based on the latter style.

*Figure 1.4: Ribbon mixer (PEW, 2015)*

*Figure 1.5: Twin shaft paddle mixer (Bright Hub Eningeering, 2015)*

For solid and pastes there have been developed a variety of special equipment. The choice of mixer is again depending on material properties, and mixer types include different types of rotating drum mixers, screw mixers and static mixer with an agitator. Drum mixers are typical in a lot of industries, and are working by rotating the shell of the mixer around its axis. In later years, it has been experimented with different rotation patterns as well.

*Figure 1.6: Perhaps one of the most familiar drum mixers, the cement drum mixer. (Batchcrete, 2015)*

A screw mixer is typically a static mixer that uses a screw to stir the components together. This type of mixer exerts less shear force on the mixing product, as the screw is constantly in contact with the product. In design, screw mixers can be both horizontal and vertical, twin-screw, single-screw, and cone shaped.

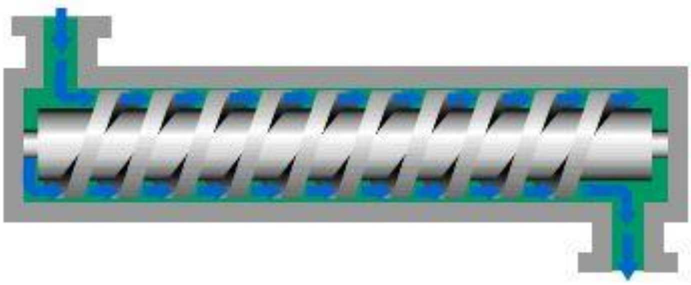


*Figure 1.7: Principle of a horizontal single screw mixer. (nationalvetcontent.edu.au, 2015)*

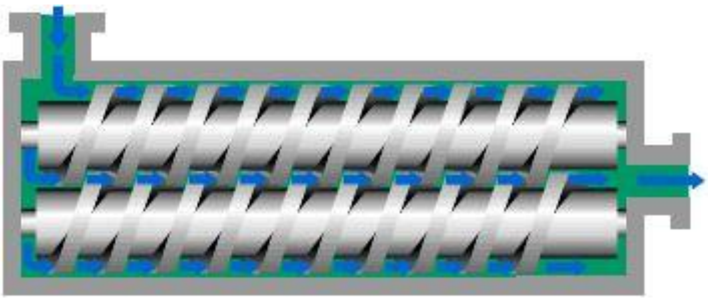


*Figure 1.8: Principle of a horizontal twin screw mixer. (nationalvetcontent.edu.au, 2015)*

## 1.2 Motivation

Mixers and vacuum coaters are two machines that are frequently used in the Feed and Food industry, amongst many others. There are a great number of different designs for both, according to what type of product that are to be mixed and under which circumstances the mixing occurs.

The motivation for this thesis is based on an idea from Chief Engineer Ismet Nikqi who is an employee at FôrTek, which is owned by the University of Life Sciences (NMBU). Mr. Nikqi has years of experience within the feed industry, and is known for his creative solutions regarding new methods of food and feed processing.

The idea is to combine the two methods of processing, mixing and vacuum coating, into one machine. Furthermore, its basic design should be simplified compared too other mixers and vacuum coaters on the market. It should also be constructed in such a way that destruction of pellets is avoided.

In consultation with the principals, Carlos Salas Bringas from NMBU and Dejan Miladinovic from FôrTek, it was agreed that a way to test Mr. Niqki's idea within reasonable time and financial limits, was to build it using 3D-printed components. In addition, to further develop the skills acquired through the Industrial Economics studies and to evaluate the future product on the market, it was decided that a basic economic and market analysis was to be executed.

## 1.3 Objectives

The main objective with this thesis is to evaluate a laboratory sized prototype, which can function as both a mixer and a vacuum coater for feed ingredients and pellets. Included in this objective is the following:

- Design and development of the prototype.
- Necessary testing for both mixing and vacuum coating.
- Basic market and economical evaluation.
- Provide information and recommendations for further development.

## 1.4 Limitations

This thesis is written as a feasibility study, and therefore are some parts more extensive than others. Since the thesis contains design and development, complex calculations by hand, FEM analysis, 3D printing, testing, different types of analysis regarding the market aspect, economic analysis and writing a thorough report, it's necessary to make some limitations regarding how complicated each part will be.

## 1.5 Methodology

Being a product development thesis which utilizes rapid prototyping to physically build a machine, a significant amount of work will only exist in non-written form. The thesis consists of four work-phases which are estimated towards the time consumption:

1. Concept evaluation and design (20%).
2. Prototyping and construction (30%).
3. Testing of the machine (15%).
4. Writing of thesis (35%).

**Phase 1 (Chapter 2)**

The concept and requirements of the product to be developed in this thesis will originate from FôrTek. Their experience and knowledge from the feed industry has led to the idea forming the basis for the prototype development. As the vision of the product already exists, the product development phase will have less focus on evaluating different concepts, and more on building the specific concept the principal wants to test. Continuous meetings and discussions will lead to a concept that fulfils the initial requirements. The design phase will rely on hand sketches, calculations and SolidWorks to visualize and create the prototype.

**Phase 2 (Chapter 3)**

Upon achieving a design that satisfies the specifications of the principals, the application of rapid prototyping will turn CAD drawings into physical objects. 3D printing will be used to a large degree to keep the cost and time consumed by the prototyping phase to a minimum. The parts created by rapid prototyping will need some processing to fit together properly. Some components will most likely have to be machined in a workshop, as there will be a limit to the dimensions and strength of the 3D printed parts.

**Phase 3 (Chapter 4)**

Testing will commence once the prototype has been taken from the theoretical to the physical dimension. The goal will be to determine how well the concept works and give an indication of potential improvements in future prototypes. The principals will help define what needs to be tested and provide the specific test material.

**Phase 4**

Most of the written thesis will build on what has been done and achieved in the previous phases. Additionally, an evaluation of markets and cost will be done to show the potential for a lab-sized vacuum coater/mixer.

A progress schedule, presented in Figure 1.9 is showing the planned activities in the work with this thesis. Some of the activities are intertwined and does not necessarily reflect the estimated time consumption mentioned above. Unforeseen incidents may lead to some deviations from the plan.

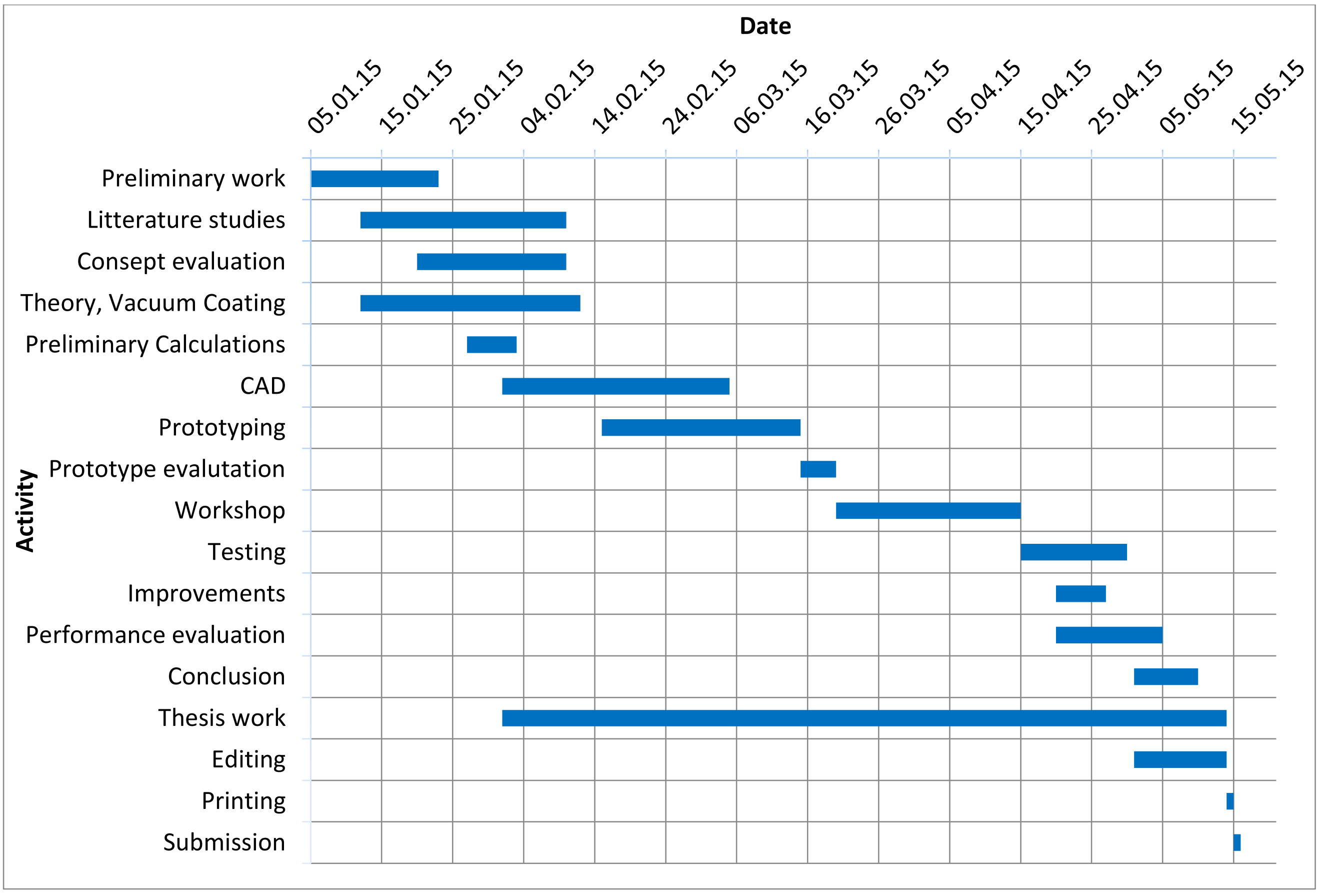



*Figure 1.9: Progress schedule.*

## 1.6 3D Printing

The 3D printer to be used in this project is the Stratasys Mojo (Stratasys, 2015).

*Table 1: Specifications of the Stratasys Mojo.*

| **Spesifications** | |
|---|---|
| **Model Material** | P430 ABS*plus* |
| **Support Material** | SR-30 Soluble |
| **Build Size** | 127 x 127 x 127 mm |
| **Layer Thickness** | 0,17 mm |

### 1.6.1 Materials

The Stratasys Mojo is printing in ABS*plus*, a production-grade thermoplastic. ABS*plus* has the following properties (Stratasys, 2015):

*Table 2: Properties of ABSplus.*

| **Property** | **Value** |
|---|---|
| **Tensile Strength, Ultimate** | 33 MPa |
| **Tensile Strenght, Yield** | 8 MPa |
| **Tensile Modulus** | 2200 MPa |

### 1.6.2 Procedure

Although 3D printing is straightforward method for rapid prototyping, some challenges may arise on the way from sketch to the finished part. First of all, it is important to know the dimensions of which the printer can handle. The Stratasys Mojo has a build size of 127x127x127 mm which limits dimensions of the parts. It is also important to be aware of which tolerance the printer uses, especially when parts with holes and fittings are printed. These things have to be taken into consideration when preparing the sketch for printing.

When the sketches are ready, they have to be organized on the printing plane. The main focus here is to be able to print as many parts as possible at once to lessen the costs of each print, as it can take up to twelve hours to complete one print. It is also important to be aware of the clearance between each part, as the printer need some extra space to create supporting material for the parts. When the sketch is ready for print, it is transferred into the Mojo Print Wizard. This computer program makes the final preparations, plans the support structures and the printing, and estimated the time until completion. It is also possible to choose printing plane and scaling.

The support material makes it possible to print intricate parts with overhangs, holes, etc., which is a necessity for the prototype. The material used is SR-30, which is a synthetic thermoplastic polymer that is soluble. After printing, the support material is easily removed using a support removal system called WaveWash 55. This system is dissolving the support material in a heated water-based solution and can use between 30 minutes and 5 hours, depending on the thickness of the support layer. After the supports are removed and the parts are dried in room temperature, the parts are ready for assembly. (Stratasys, 2015)

## 1.7 Symbols

*Table 3: Symbols used in the thesis.*

| Symbol | Meaning | Unit |
|---|---|---|
| **l** | Length | mm |
| **V** | Volume | l |
| **d** | Diameter | mm |
| $A_{cs}$ | Area, cross-sectional | $mm^2$ |
| $r_i$ | Radius, inner | mm |
| $r_o$ | Radius, outer | mm |
| $r_m$ | Radius, middle | mm |
| $s_o$ | Wall-thickness | mm |
| $P_i$ | Pressure, inner | MPa |
| $P_o$ | Pressure, outer | MPa |
| $P_r$ | Pressure, resulting | MPa |
| **F** | Force | N |
| **M** | Moment | Nm |
| **I** | Moment of inertia | $mm^3$ |
| $\sigma_a$ | Stress, axial | MPa |
| $\sigma_t$ | Stress, tangential | MPa |
| $\sigma_v$ | Stress, equivalent | MPa |
| $\sigma_{permitted}$ | Stress, permitted | MPa |
| $\tau_{xy}$ | Shear | MPa |
| $\tau$ | Torque | Nm |
| **E** | Elastic modulus | MPa |
| $\mu$ | Poisson’s ratio | none |
| $\varepsilon_s$ | Strain, radial | none |
| $\varepsilon_t$ | Strain, tangential | none |
| **m** | Mass | g |
| $\rho$ | Density | g/l |
| **P** | Power | W |
| **K** | Strenght | MPa |
| **S** | Safety factor | none |
| **A** | Reduction factor | none |

# 2 Design

This chapter presents the work that has been done regarding the design of the prototype, hereunder the specifications, concept evaluation and calculations. It also present all components designed or acquired for building the prototype.

## 2.1 Description of Concept

This section emphasizes the specifications of the machine and a discussion of different ideas, before making a selection for the concept that will form the basis of the prototype.

### 2.1.1 Requirements and Specifications

The specifications of the prototype listed below are made according to the principals' guidelines, and represents the boundary conditions for the design.

*Table 4: Table of specifications*

| Description | Target Value |
|---|---|
| **Pressure** | 0,02 MPa |
| **Volume** | 2 liters |
| **De-pressurization** | 0,01 MPa/10 s |
| **Mixing time** | As short as possible |
| **Cleaning** | As easy as possible |
| **Functionality** | Vacuum coating and mixing |
| **Oil content** | Varies with pellet type and mass |

### 2.1.2 Concept Evaluation and Designs

The first concept, based on quick drawings from FôrTek, consisted of two cylinders mounted to each other. During the vacuum coating of pellets, one is reliant on mixing to create a good dispersion of oil and pellets to make sure every pellet gets coated equally. An often used solution is to use a shaft with some form of paddle. The paddles in the machine needs to both gently mix the product in the case of vacuum coating and be able to fling the product into a separate shaft when operating as a mixer. The second cylinder would contain this separate shaft with pins rotating at high velocities, to break lumps when the machine is functioning as a mixer. The concept of the second cylinder is called a pin mill. A sliding door between the vacuum coater and the pin mill was included so that the second cylinder could be sealed off during vacuum coating. This first concept has been visualized in Figure 2.1. The details of the paddles and the pin mill were at an early stage.

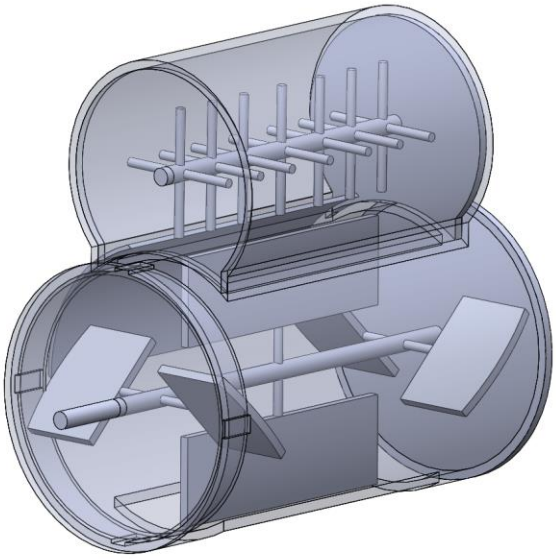


*Figure 2.1: First evaluated concept of a coater/mixer, showing the pin mill attached atop the main cylinder. The sliding door is located between the cylinders. The walls have been made transparent to show the internals.*

Although this concept lacked refinement, it is showing an idea for the configuration of the paddles in the vacuum coater. To minimize the crushing of pellets, it was suggested to use and test the mixing properties of as few paddles as possible. Existing products often use a row of paddles, which leads to more crushed pellets. At each end of the axle, the paddles were mounted at a 45° angle. This was done to make sure the mixing was effective, and to transport the product away from each end of the cylinder and into the middle section. In the middle section, a paddle parallel to the axle would both mix the product and be able to throw it straight into the pin mill (Figure 2.2). Mounting the middle paddles at a small angle to facilitate mixing was also considered at this stage (Figure 2.3). The whole axle was meant to be removable, to simplify cleaning.

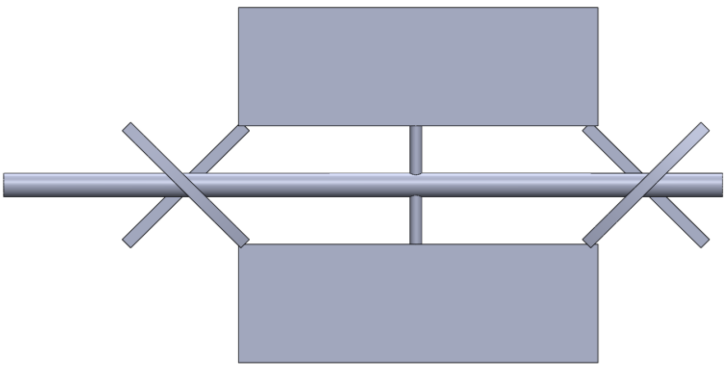


*Figure 2.2: Configuration of paddles showing the side paddles mounted at a 45° angle.*

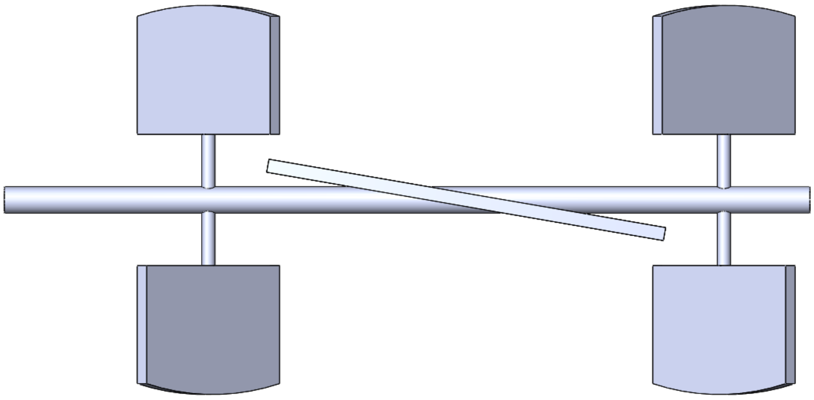


*Figure 2.3: Axle with the center paddles mounted at an angle.*

To find the ideal shape of the paddles, a quick-release system was developed, so that different solutions easily could be designed, 3D-printed, and tested. The quick-release system combined with the removable axle mentioned in the previous paragraph would simplify the deployment of different paddle-systems and further streamline the cleaning process. Paddle designs discussed include paddles with the shape of a plow, paddles at different angles, and special design for the paddles at each end of the vacuum coating cylinder.

Further refinement of the concept yielded a U-shaped pin mill (Figure 2.4). In addition, the pin mill was made in two halves to enable 3D-printing (because of dimensional limitations). To attach the two halves to each other, a row of screws was suggested as a solution.

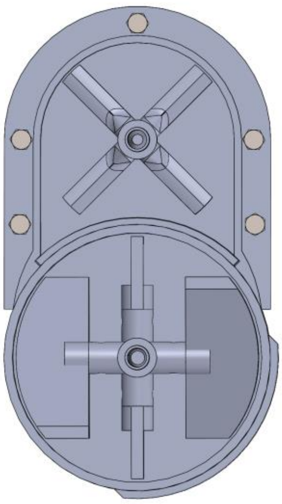


*Figure 2.4: The next step version of the pin mill, a U shape mounted upside down atop the main cylinder.*

This depiction of the prototype shows the pin mill as if it would be mounted directly atop the vacuum cylinder, but this would not necessarily be the case. The whole machine could be mounted at an angle so that powder would more easily get thrown into the pin mill during the mixing process. Another type of sliding door, sliding axially as opposed to radially, was used to seal off the mixer in this concept. A mill with sharp blades was created for maximum breakage of lumps. Also shown is the quick-release system for the paddles, discussed in the previous section (Figure 2.5). The idea was to attach a mount for the paddles to the axle, using a bolt to secure it in place. In turn, different paddle configurations could be attached to this mount.

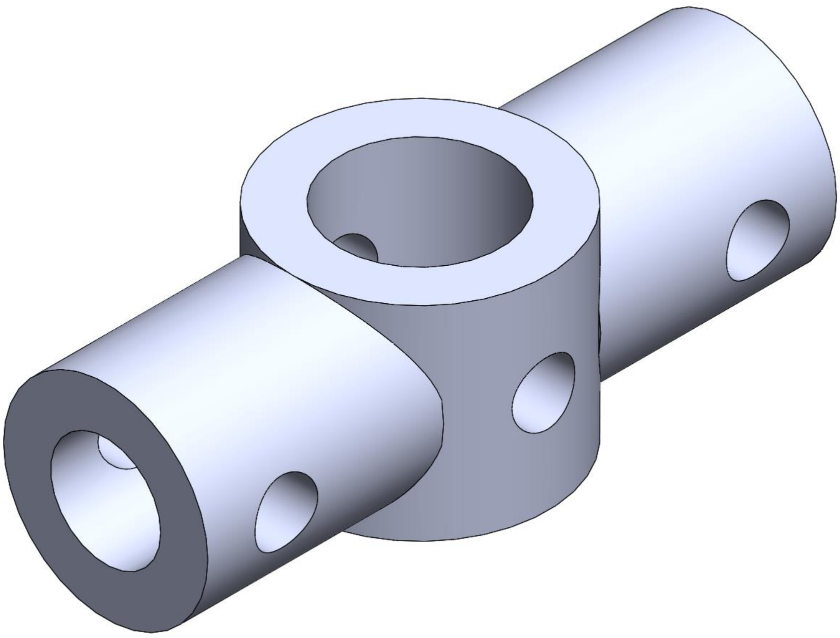


*Figure 2.5: Attachment for paddles, where various paddle solutions can be tested.*

To minimize gaps between the paddles and the walls of the cylinder, the shape of the paddles were developed to follow the walls of the cylinder perfectly, while still allowing the axle to rotate freely. This was done to avoid the crushing of pellets, by creating less space for the pellets to get jammed between the wall of the cylinder and the paddle. Again, the paddles at each end of the cylinder were developed to sit at a 45° angle with the rotating axle to enable maximum transportation of product away from the endcaps of the cylinder and into the middle section. Attachment of the paddles to the mount described above was done by a cylinder made to fit into the hole in the mount and securing it by a small bolt (Figure 2.6).

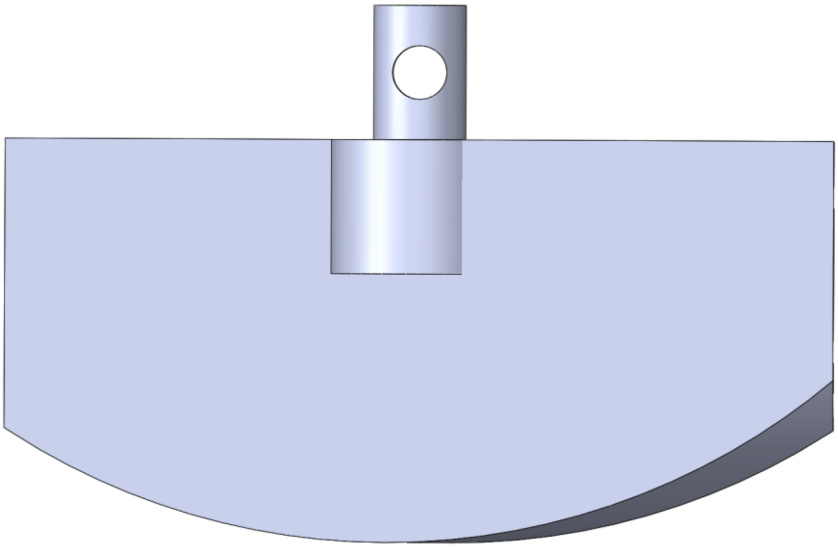


*Figure 2.6: 45 degree side paddle, the bottom edge made to follow the cylinder perfectly.*

Evaluating the U-shaped mixer deemed it too complicated, especially considering the functionality of the sliding door. Discussions with FôrTek also led to the addition of the capability to spray liquid onto a fine curtain of powder during the mixing process. These discussions lead to a redesign of the mixer.

The final concept had a more elegant solution for the attachment of a pin mill to the vacuum coating chamber. Instead of being added to the outside of the vacuum coater, the pin mill was smaller, and flowing more smoothly into the lines of the cylinder. This would facilitate the transportation of powder into and out of the pin mill, and would let the pin mill create a curtain of powder underneath the inlet. The machine would be oriented as shown in Figure 2.7, with both axles rotating counter-clockwise. When used as a mixer, the paddles in the cylinder would rotate at a higher velocity to fling powder into the pin mill directly above it. In turn, the pin mill would break any lumps in the powder and eject it back into the cylinder. Directly above the cylinder there would be an opening for feeding product into the machine (Figure 2.8). This opening would have a lid where a nozzle for spraying liquid onto the powder can be attached. Affixing the nozzle to the lid would create a distance between the nozzle and the powder, so that the liquid would have a good dispersion as it hits the powder.

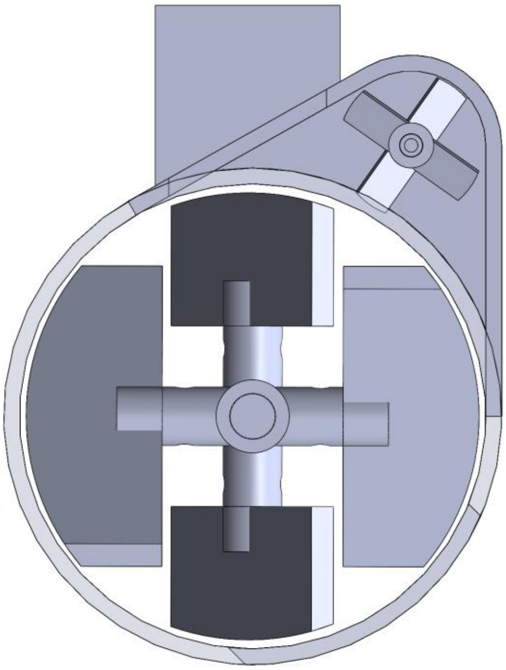


*Figure 2.7: A vacuum coater/mixer with a smaller pin mill attached to the cylinder. During mixing, the main axle with paddles would be rotating counter-clockwise at high velocity to throw the powder up along the right wall and into the pin mill.*

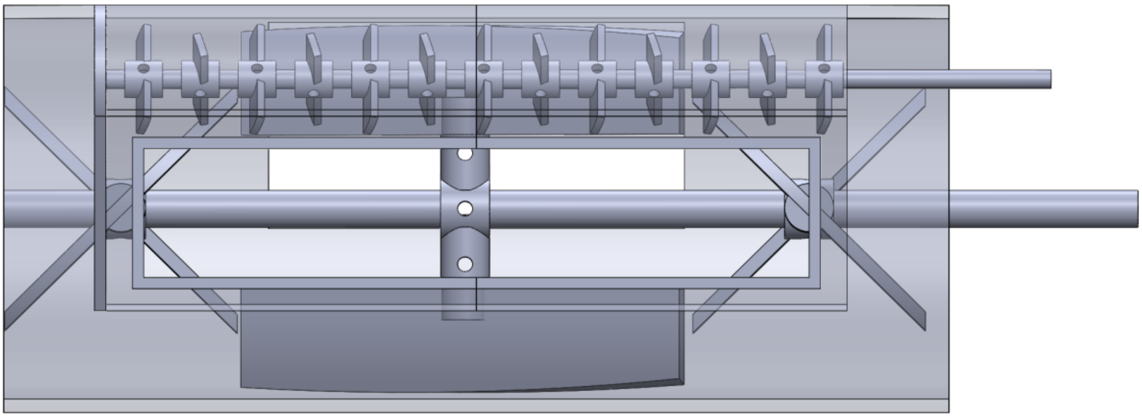


*Figure 2.8: The concept viewed from above, with transparent walls to show the internals. The pin mill is situated at the top of the picture, with the inlet below it.*

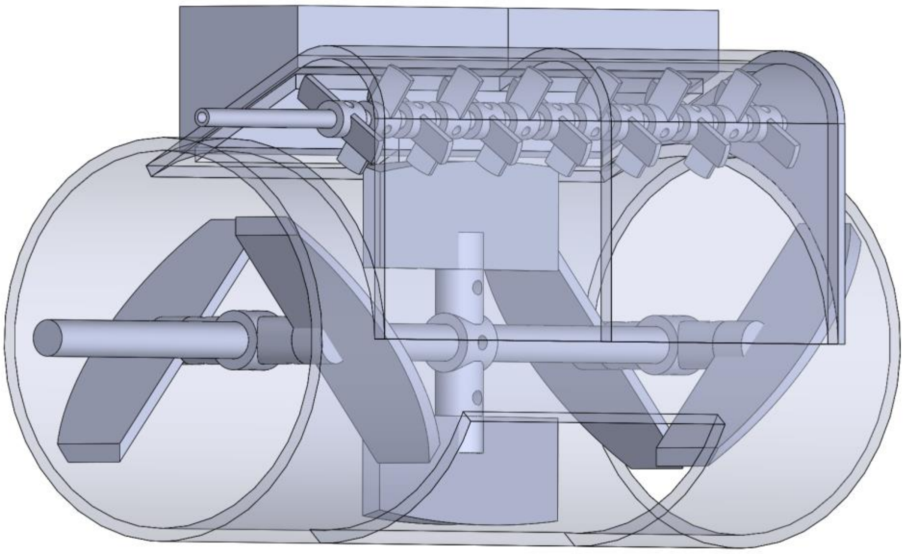


*Figure 2.9: The machine with transparent walls to show the paddles and the pins.*

When functioning as a vacuum coater, the pin mill would not be sealed off as in previous designs. Rather than having a complicated door mechanism, the cavity for the pin mill would always be open from the inside. During the vacuum coating process, the axle with paddles would only be rotating at a high enough velocity to adequately mix the pellets and oil. This lowered velocity would ensure that few pellets would be thrown into the pin mill, which in turn would not be rotating. At the bottom of the cylinder there would be a door for emptying the machine after the completion of a mixing or vacuum coating process. Rotating the paddles slowly would transport the product to the opening and out of the machine.

## 2.2 Calculations for Design

This section contains calculations done to determine the necessary dimensions of plastic parts, to ensure that they can withstand the forces in critical areas of the machine.

### 2.2.1 Cylinder Dimensions

With a given volume of 2 liters, a suitable tube to create the vacuum coating chamber had to be found. As the 3D-printer to be used in this project could only create parts limited to a size of 127 mm in every direction, this was the absolute maximum diameter the cylinder could have. A standard PVC pipe with an outer diameter of 110 mm and an inner diameter of 103 mm was found.

Using formula (2.1) and solving for $l$, it is possible to calculate the requisite length of the cylinder:

$$l = \frac{V}{\pi r_i^2} = \frac{2000000}{\pi \cdot \left(\frac{103}{2}\right)^2} = 240\ mm \qquad (2.1)$$

To compensate for the potential loss of volume due to the axle and paddles, the length was set to 250 mm, which gave us a volume of:

$$V = \pi r_i^2 l = \pi \cdot 51{,}5^2 \cdot 250 = 2083072\ mm^3 = 2{,}08\ L \qquad (2.2)$$

Hence, the main chamber of the machine were given the dimensions $l$ = 250 mm, $r_i$ = 51,5 mm.

### 2.2.2 Stress and Deformation on Cylinder

Under normal atmospheric conditions, the machine will operate under an outer pressure of $P_o$ = 1 atm = 0,101325 MPa. During the vacuum coating process, the target operating pressure inside the cylinder is $P_i$ = 0,02 MPa. This gives a resulting pressure on the machine of:

$$P_r = P_o - P_i = 0{,}101325 - 0{,}02 = 0{,}081325\ MPa \qquad (2.3)$$

The following data for the cylinder is acquired:

$r_o$ = 55 mm, $r_i$ = 51,5 mm, $s_o$ = 3,5 mm.

This gives us a middle radius of:

$$r_m = \frac{r_o + r_i}{2} = \frac{55 + 51{,}5}{2} = 53{,}25\ \text{mm} \qquad (2.4)$$

Checking if thin-walled theory (Terjesen, 2014) can be used:

$$\frac{s_o}{r_m} = \frac{3{,}5}{53{,}25} = 0{,}066 < \frac{1}{10} \qquad (2.5)$$

As long as the ratio of wall thickness on middle radius is smaller than one tenth, thin-walled theory is OK.

Axial stress:

$$\sigma_a = \frac{-P_r \cdot r_m}{2 s_o} = \frac{-0{,}081325 \cdot 53{,}25}{2 \cdot 3{,}5} = -0{,}619\ \text{MPa} \qquad (2.6)$$

Tangential stress:

$$\sigma_t = \frac{-P_r \cdot r_m}{s_o} = \frac{-0{,}081325 \cdot 53{,}25}{3{,}5} = -1{,}237\ \text{MPa} \qquad (2.7)$$

For a thin-walled cylinder the radial stress is equal to zero.

PVC has an elastic modulus of E = 2750 MPa, and a Poission's ratio of μ = 0,410. These are conservative values.

Radial strain:

$$\varepsilon_s = \frac{-\mu}{E}(\sigma_t + \sigma_a) = \frac{-0{,}410}{2750}\big(-1{,}237 + (-0{,}619)\big) = 0{,}00028 \qquad (2.8)$$

Tangential strain:

$$\varepsilon_t = \frac{1}{E}(\sigma_t - \mu\sigma_a) = \frac{1}{2750}\big(-1{,}237 - 0{,}410 \cdot (-0{,}619)\big) = -0{,}00036 \qquad (2.9)$$

Change in inner diameter:

$$\Delta d = 2r_i\varepsilon_t = 2 \cdot 51{,}5 \cdot -0{,}00036 = -0{,}037 \text{ mm} \qquad (2.10)$$

The deformation of the cylinder is essentially negligible.

Axial strain:

$$\varepsilon_a = \frac{1}{E}(\sigma_a - \mu\sigma_t) = \frac{1}{2750}\big(-0{,}619 - 0{,}410 \cdot (-1{,}237)\big) = -0{,}00004 \qquad (2.11)$$

Volumetric change:

$$\Delta V = (2\varepsilon_t + \varepsilon_a) \cdot \mathrm{V} = \big(2 \cdot -0{,}00036 + (-0{,}00004)\big) \cdot 2{,}083 \text{ L} = -0{,}0016\, L \qquad (2.12)$$

The change in volume of the cylinder because of the lower inner pressure is very small. This calculation is a simplification, as modifications to the cylinder will be done to fit the pin mill.

### 2.2.3 Calculation of Mass

The prototype should be able to vacuum coat 1 liter of pellets with oil. The bulk density of pellets is approximately 750 g/l and the density of oil is approximately 1000 g/l. To calculate the mass, 1 liter of pellets are used. In addition, oil equal to 40% of the pellets weight are added, thus giving the total mass:

$$m = \rho_{pellets} * V_{pellets} + \rho_{oil} * V_{oil} = 750 * 1 + 750 * 0{,}4 = 1050 \text{ grams} \qquad (2.13)$$

The weight of the powder is given by the principal and is about 1000 grams.

### 2.2.4 Stress on Paddle and Paddle Attachment

The mass calculated in the previous section makes it possible to calculate the forces on the rotating paddles. The strength of the plastic can be calculated using the following formula:

$$\sigma_{permitted} = \frac{K}{S * A} \tag{2.14}$$

In this formula the allowed stress is depending on the strength of the material K, the safety factor S and the material-specific reducing factor A. The strength of the material, K, is given by the yield stress of 8 MPa found in section 1.6.1. Since the machine will perform dynamic operations it is necessary with a safety factor S equal to 3. The material-specific reduction factor A is taking all environmental impacts into consider, such as temperature, moisture, etc. and can be set to 1.3. The strength can then be calculated (Erhard, 2006):

$$\sigma_{perm} = \frac{8}{3 * 1{,}3} = 2{,}05 \text{ MPa} \tag{2.15}$$

Using von Mises yield criterion, it is possible to calculate the von Mises stress of the most critical area of the pedal. Since the largest momentum will occur at the attachment between the paddle-mount and the axle, this will be the area of investigation. The von Mises stress hypothesis states that as long as the equivalent stress is at a value below the permitted stress (formula 2.15), it will not break. The equivalent stress, $\sigma_v$, can be calculated with the following formula:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x * \sigma_y + 3\tau_{xy}^2} \tag{2.16}$$

Since this will be a one-dimensional calculation, $\sigma_y$ is equal to zero. $\sigma_x$ represents the bending stress, which is calculated using the bending moment M, the area moment of inertia I and the distance from the y-axis. Checking if a diameter of d = 13 mm will hold:

$$\sigma_x = \sigma_b = \frac{M * Y}{I} = \frac{(1{,}05 * 9{,}81 * 40) * 6{,}5}{\frac{\pi * 13^4}{64}} = 1{,}91\ MPa \tag{2.17}$$

The shear stress component, $\tau_{xy}$, is calculated with the formula:

$$\tau_{xy} = \tau_{shear} = \frac{F}{A_{cs}} = \frac{1{,}05 * 9{,}81}{\frac{\pi * 13\hat{}2}{4}} = 0{,}08\ MPa \tag{2.18}$$

Using formula 2.16, inserted with 2.17 and 2.18, it is possible to calculate the equivalent stress (Terjesen, 2014):

$$\sigma_v = \sqrt{1{,}91^2 + 3 * 0{,}08^2} = 1{,}91 \text{ MPa} \tag{2.19}$$

As $\sigma_v < \sigma_{perm}$, a diameter of 13 mm will hold.

### 2.2.5 Torque and Power Calculations for Main Axle motor

Torque and power calculations are important considering the choice of motor. It is important that the motor is strong enough to rotate the pellets during the coating process, but also have a high enough rotational velocity so that powder can be thrown into the pin mill during mixing.

Using the weight of the pellets-oil mix, it is possible to calculate the necessary torque during the coating process:

$$\tau = force * arm = (9{,}81 * 1{,}05) * 0{,}05 = 0{,}51\ Nm \qquad (2.20)$$

The torque necessary when mixing the powder will be less then when coating pellets, so 0,51 Nm will be the critical value when evaluating different motors for the main axle. The necessary rotating speed of the main axle are acquired from similar machines at FôrTek, and are set to 250 RPM. This, combined with the torque from equation (2.20), makes it possible to calculate necessary power:

$$P = torque * revolutions\ per\ second * 2\pi = 0{,}51 * 4{,}2 * 2\pi = 13{,}4\ W \qquad (2.21)$$

*Table 5: Table of necessary motor specifications*

| Description | Minimum demanded value regarding motor capacity |
|---|---|
| **Torque** | 0,51 Nm |
| **RPM** | 250 |
| **Power** | 13,4W |

## 2.3 FEM Analysis

To verify that the prototype won't collapse or break when exposed to pressure and forces, a FEM analysis has been executed at the areas seen as most critical for stress and deformation. FEM is an abbreviation for Finite Element Method, which is a numerical method for solving engineering problems. In this chapter, FEM is used to calculate the stress and deformation of the main cylinder and the pin mill housing, as they will be exposed to a lowered inner pressure during the vacuum coating process.

### 2.3.1 Main Cylinder

This calculation has already been done by hand in section 2.2.2, but while the calculation in that section is based on a complete cylinder, the FEM calculation takes into consider that a portion is cut out to fit the pin mill housing. When analyzed, the cylinder is locked in a position with the help of constraints at both ends (green arrows). The inside pressure is set to 0,02 MPa: the working pressure of the prototype (red arrows).

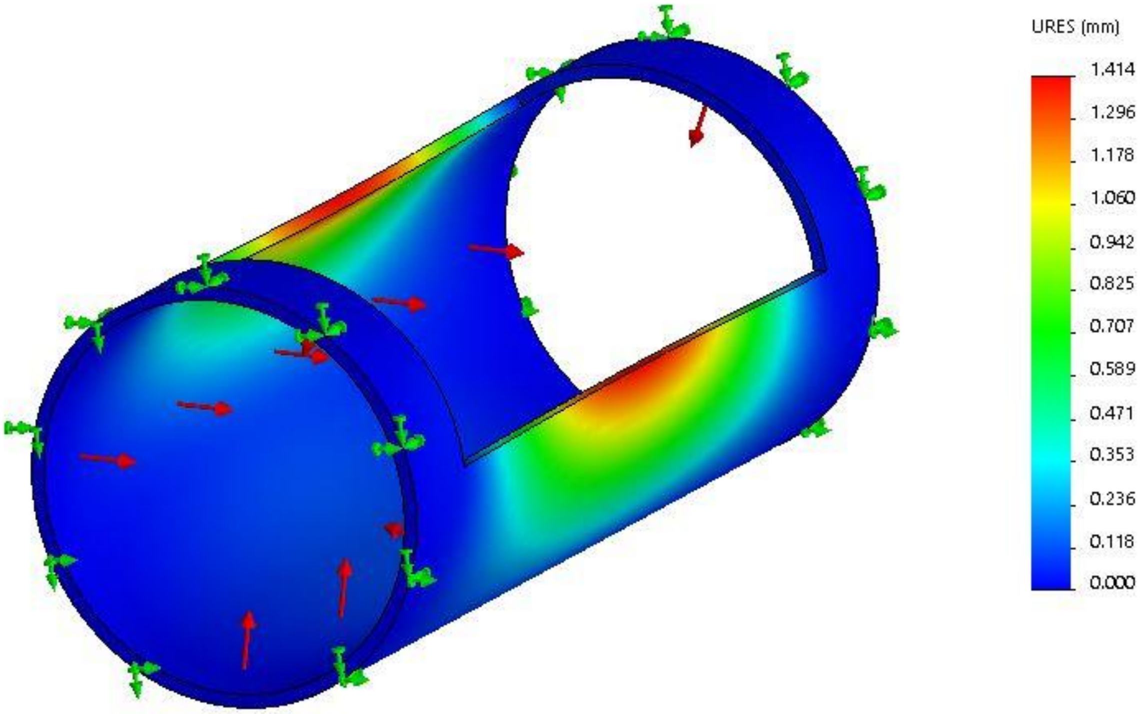



*Figure 2.10: FEM analysis that shows the deformation of the main cylinder. Red arrows indicate how the working pressure is added (0,02 MPa), and green arrows marks where the cylinder is mounted.*

The picture shows that the maximum deformation will occur where the cutout for the pin mill housing is made (red area), and that it is 1,414 mm. This is more than the hand calculation showed, and is due to the new geometry taken into account. However, a deformation of 1,414 mm doesn't create any problems, as the pedals of the main axle are still able to rotate without crashing into the cylinder. Furthermore, the deformation will most likely be less, as the mounted pin mill housing will support the places with large deformation.

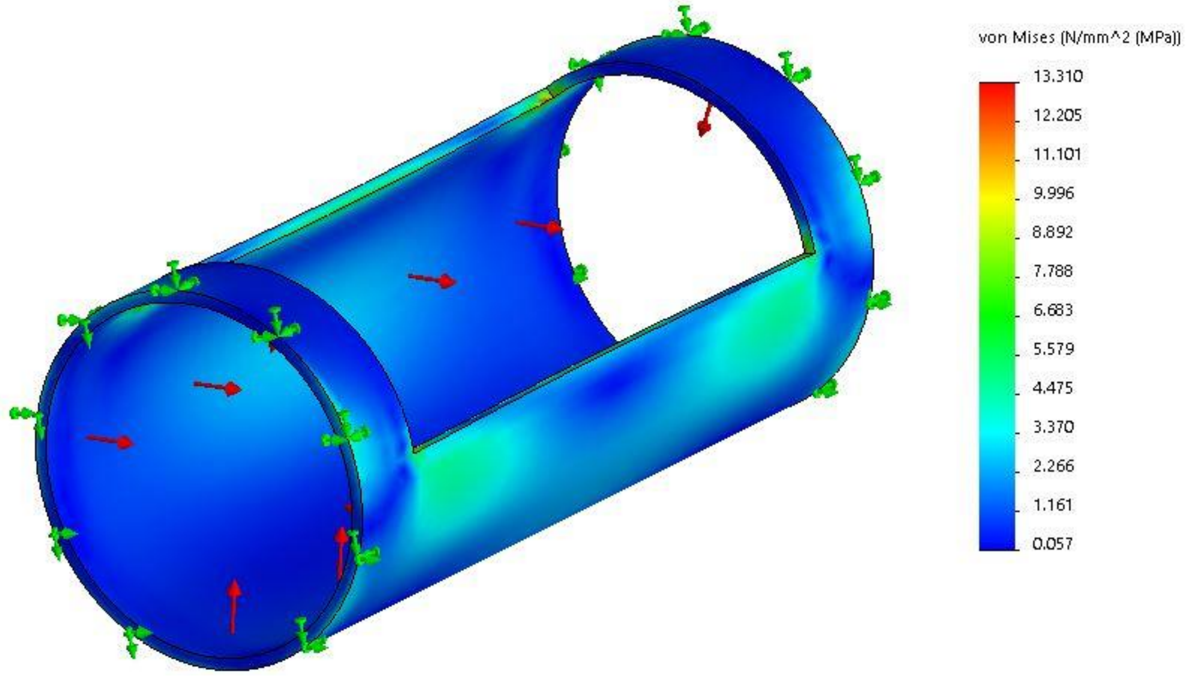



*Figure 2.11: FEM analysis that shows the von Mises stress on the main cylinder. Red arrows indicate how the working pressure is added (0,02 MPa), and green arrows marks where the cylinder is supported.*

The stress analysis shows that the maximum von Mises stress will be 13,31 MPa and will appear at the corners where the hole has been cut out. Since the allowed stress for PVC plastic is 20-70 MPa (Patrick, 2005), the conclusion is that the cylinder will not break when exposed to the working pressure.

### 2.3.2 Pin Mill Housing

The deformation and equivalent stress of the pin mill housing has not been calculated by hand due to its geometry, which means that the results from the FEM analysis will be the only indication to what is going to happen when the cylinder is exposed to the lowered pressure. The deformation of the pin mill housing is showed in Figure 2.12.

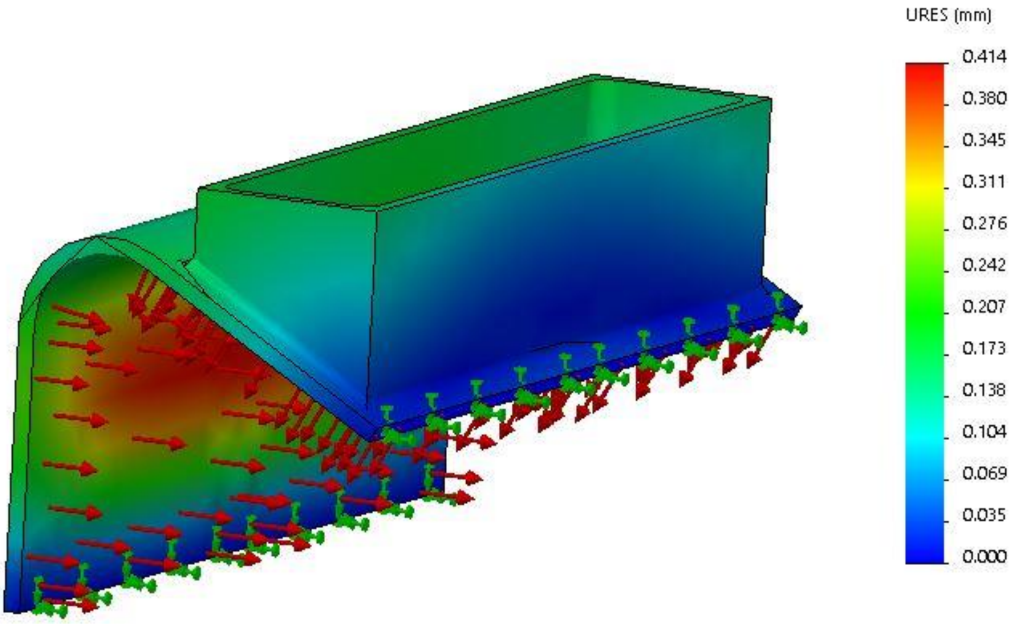



*Figure 2.12: FEM analysis that shows the deformation of the main pin mill housing. Red arrows indicate how the working pressure is added (0,02 MPa), and green arrows marks where the cylinder is mounted.*

The critical area of deformation is the large rear surface (red area). This is however a small value of 0,414 mm, which is not going to create any trouble for the rotating pin mill axle.

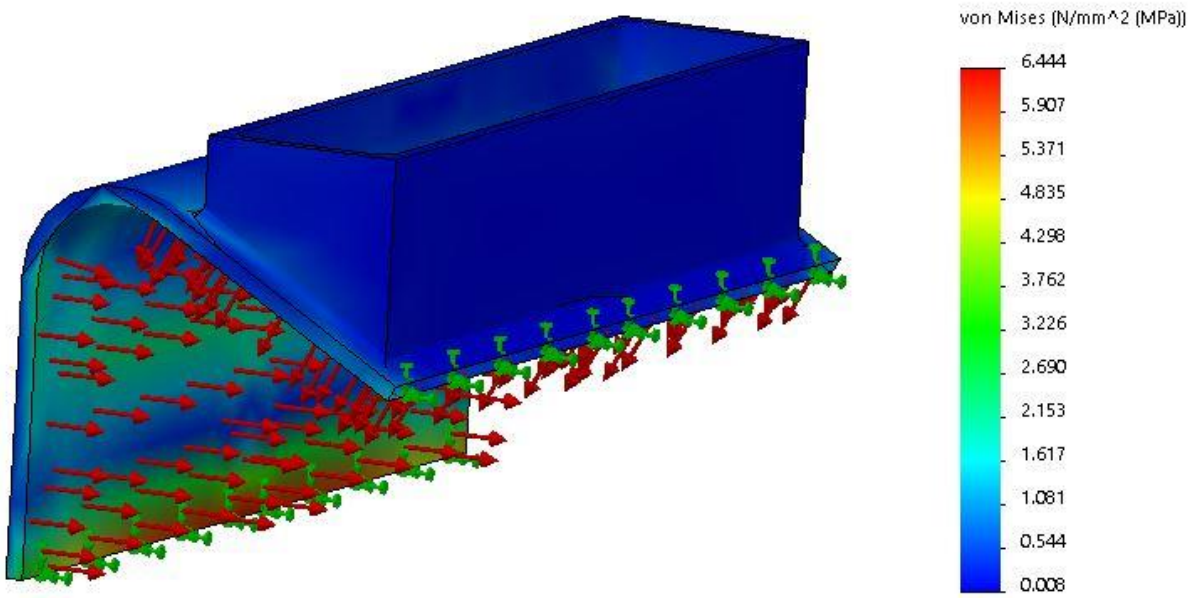



*Figure 2.13: FEM analysis that shows the stress on the pin mill housing. Red arrows indicate how the working pressure is added (0,02 MPa), and green arrows marks where the cylinder is mounted.*

As Figure 2.13 shows, the largest stress according to the von Mises hypothesis is calculated to be 6,444 MPa, and occurs in the middle bottom area of the straight surface (red area). As the ABS plastic should be able to handle up 8 MPa (see chapter 1.6.1), the dimensions should be sufficient for the pin mill not to collapse. In addition, the calculation is done without the pin mill supports (see chapter 2.5.1.4), which will further increase and stabilize the critical area.

## 2.4 Complete Assembly

To create a clear understanding of how the machine works, the first section explains the complete machine, which design has been through numerous iterations. The figures in this section will give a rough picture of how the machine looks, and where the different parts are located. One level deeper, the subassemblies the machine is comprised of are explained. Lastly, an explanation of the parts in each subassembly and their functionality will complete the picture.

The complete assembly of the machine is shown in the figures below, except for a few preexisting components that it was unable to obtain CAD files for.

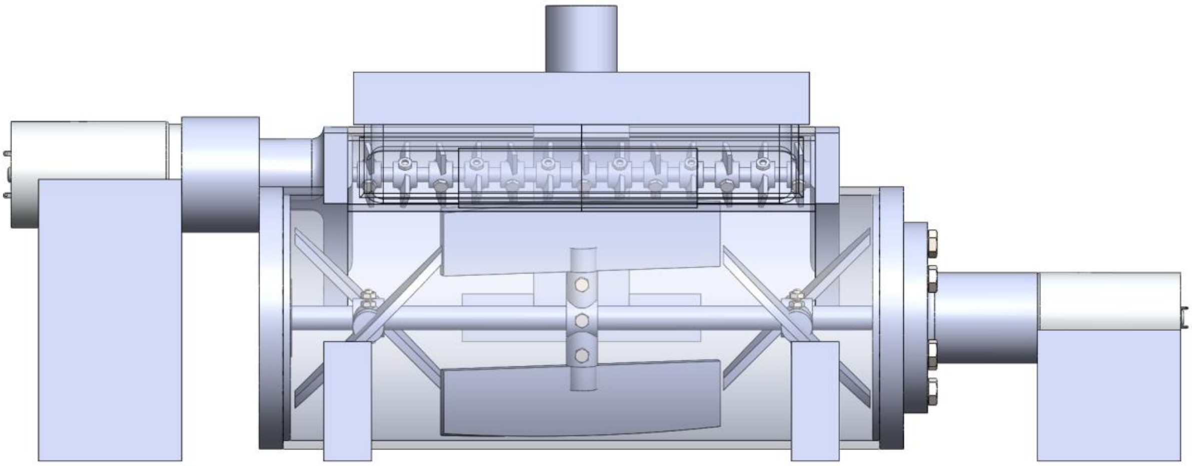


*Figure 2.14: Front view of the complete assembly. The walls of the cylinder have been made transparent to show the internals.*

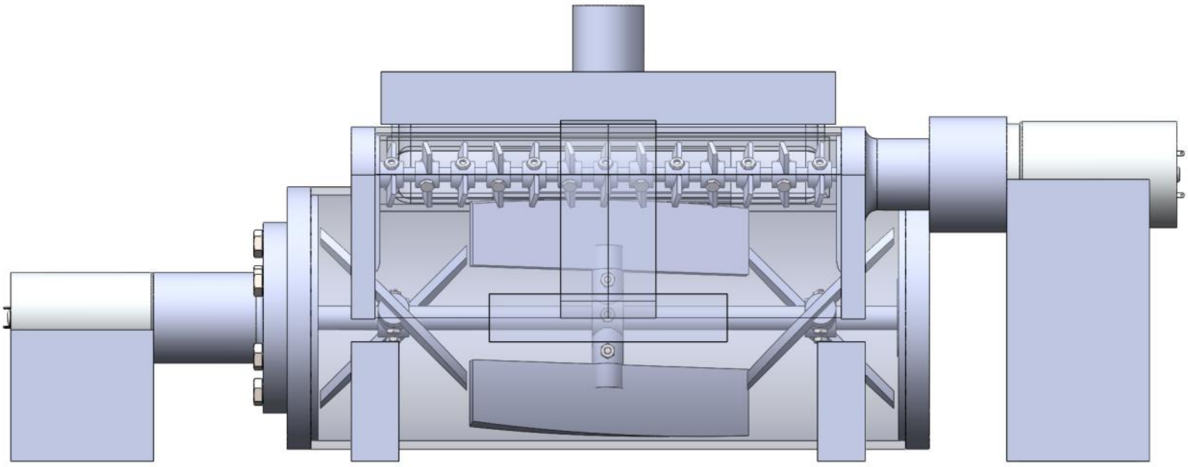


*Figure 2.15: Rear view of the complete assembly.*

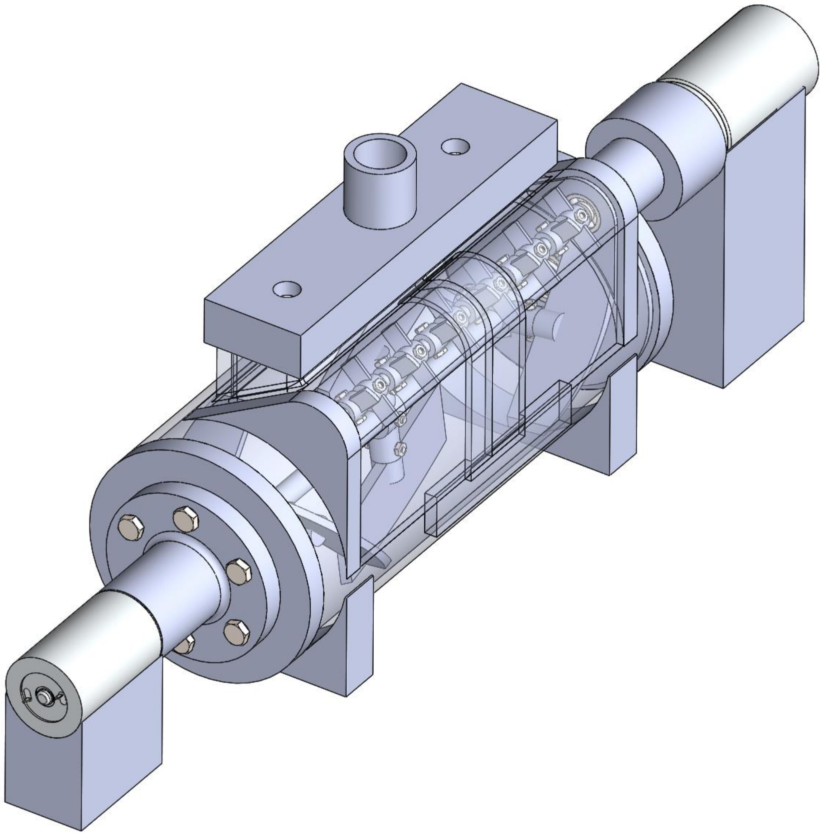


*Figure 2.16: Isometric view of the complete assembly.*

## 2.5 Subassemblies

This section presents each of the four subassemblies the machine is comprised of, with a description of every part underneath. Most of the parts have been 3D-printed, unless otherwise stated.

### 2.5.1 Main Housing

The outside shell of the prototype is made up of a cylinder with the housing for the pin mill attached to a cutout. One end of the cylinder will be open (Figure 2.17), so that the main axle assembly can be inserted. This is also the case for the pin mill housing (Figure 2.18), which will have an opening where the pin mill assembly goes.

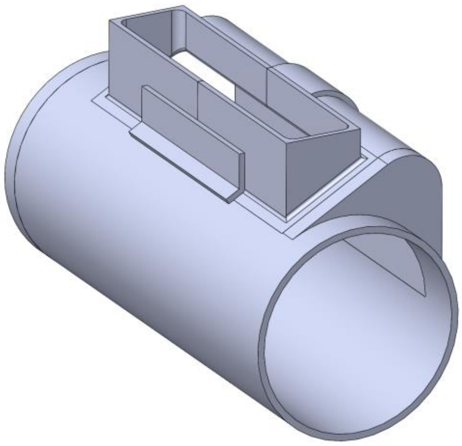


*Figure 2.17: Main housing assembly front. The circular opening for the main axle is shown. The inlet can be seen at the top.*

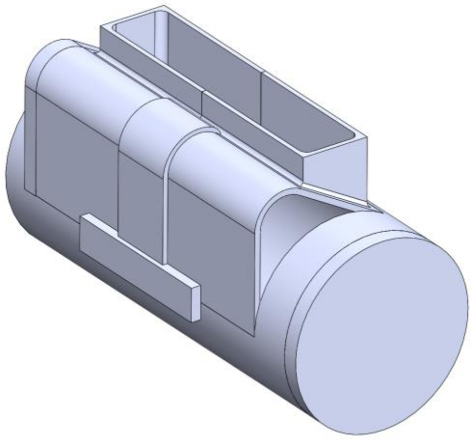


*Figure 2.18: Main housing assembly back. The opening for the pin mill axle is shown at the end of the pin mill housing, above the cylinder.*

#### 2.5.1.1 Cylinder

The main cylinder is a 250 mm long PVC plastic tube with an outer diameter of 110 mm and a wall thickness of 3,5 mm. These tubes are standard tubes in many applications, such as sewer systems, which makes them easy to obtain and affordable. A section of the wall has been removed to create an opening for the pin mill housing.

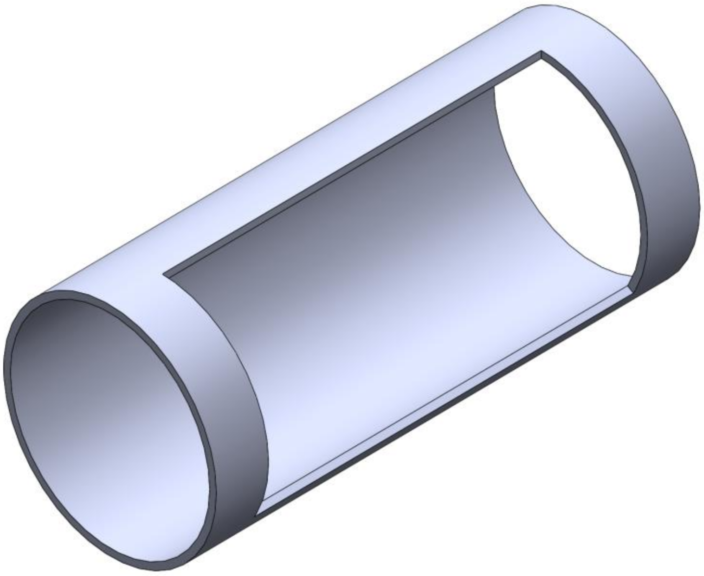


*Figure 2.19: Main cylinder with the cutout for the pin mill housing.*

#### 2.5.1.2 Cylinder Endcap

One end of the cylinder will be permanently closed off with an endcap. A hexagonally shaped cutout into the inside wall will work in tandem with the bearing capsule, described in 2.5.2.11, to make the axle and bearing removable.

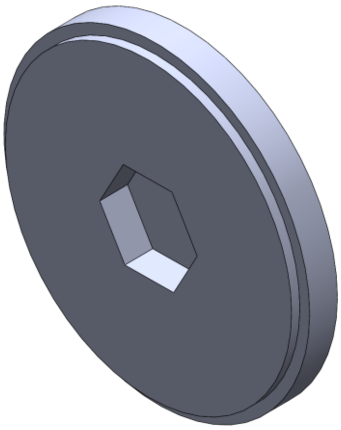


*Figure 2.20: Endcap inside, showing the hexagonal cutout.*

#### 2.5.1.3 Pin Mill Housing

The pin mill housing attached to the cylinder is made out of two mirrored halves, because of 3D printing limitations. These halves are glued together, and to the main cylinder to form the housing for the pin mill and the inlet.

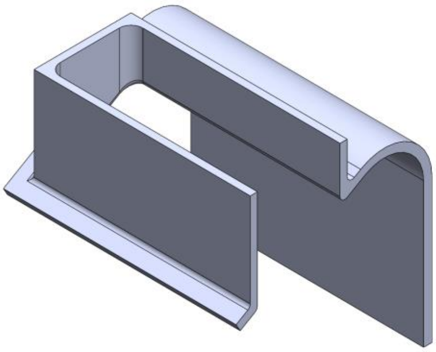


*Figure 2.21: One half of the pin mill housing.*

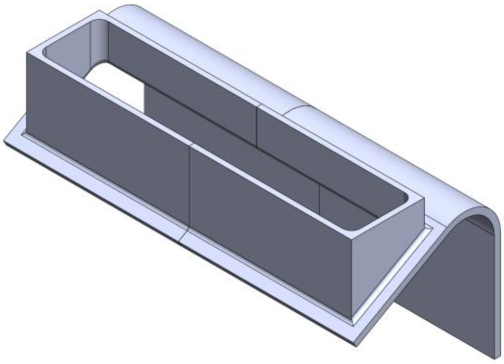


*Figure 2.22: Complete pin mill housing.*

#### 2.5.1.4 Pin Mill Support Plates

Three support plates are made to support the interface between the two halves of the pin mill housing and the cylinder. They are glued to the outside of the machine along the edges between the cylinder and pin mill housing to reinforce the construction.

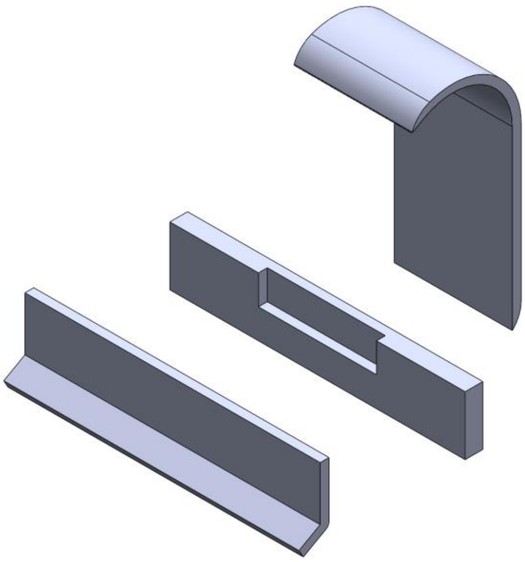


*Figure 2.23: Pin mill support plates.*

#### 2.5.1.5 Pin Mill Endcap

One end of the pin mill housing will be permanently sealed off. The inside wall of the endcap has an edge to secure it to the pin mill. Utilizing the same system as the main axle for removal of the pin mill axle, a hexagonal cutout will let a smaller version of a bearing capsule to be inserted and removed with ease.

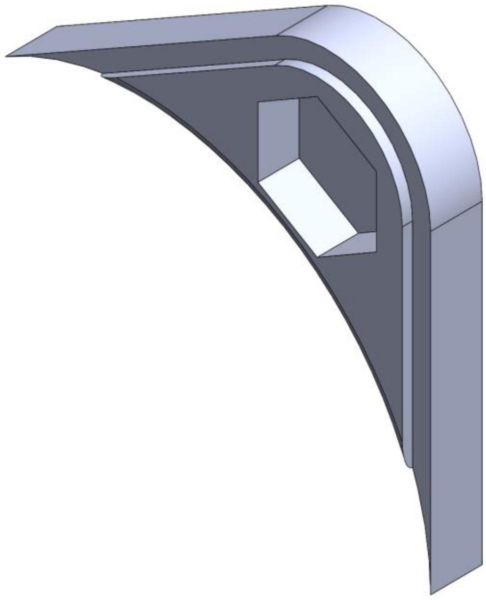


*Figure 2.24: Inside face of pin mill endcap, showing the hexagonal cutout for the smaller bearing capsule.*

#### 2.5.1.6 Cradles

Various cradles are used to support different parts of the machine, one for each of the electrical motors, and two underneath the cylindrical container of the machine.

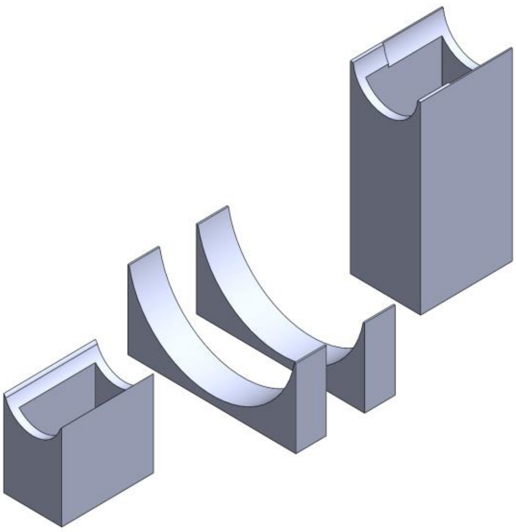


*Figure 2.25: Cradles for (from left to right); main motor, cylinder, and pin mill motor.*

### 2.5.2 Main Axle Assembly

The main axle assembly is the rotating part that goes into the cylinder, shown in Figure 2.26. It is comprised of a stainless steel axle with six paddles, bearings, a lid, the motor, and the housing for the motor.

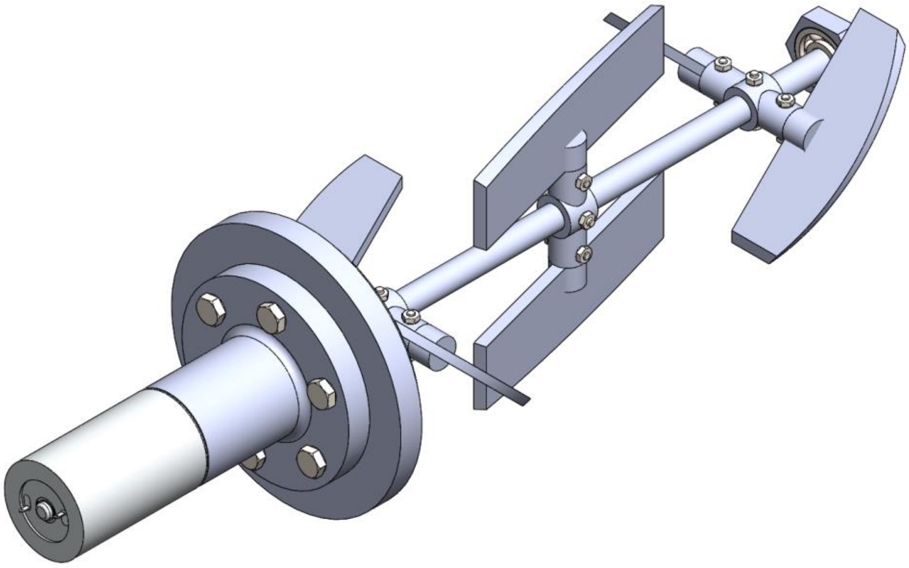


*Figure 2.26: Main axle assembly.*

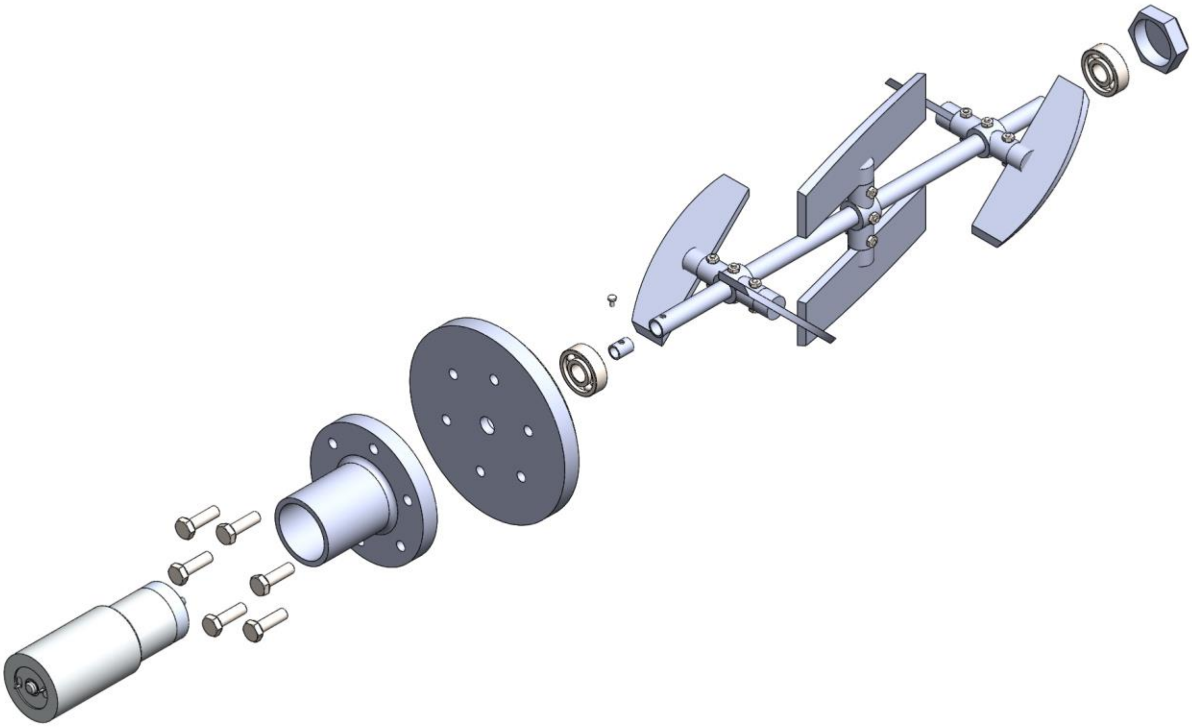


*Figure 2.27: Main axle assembly exploded view.*

#### 2.5.2.1 Motor for Main Axle

As discussed in section 2.2.5, the motor that operates the main axle has to satisfy a number of requirements regarding RPM and torque. It has to be strong enough to operate at a low RPM with a high amount of torque during the coating process, but also be fast enough to throw the powder into the pin mill during the mixing process. To meet the necessary specifications and to be able to control the speed using a voltage regulator, a direct current (DC) motor from Trident with model number 3-38/14 was bought. This is a 12 V motor with a power output of 13.9 watts, 1660 mA, a rated speed of 5 400 RPM and a rated torque of 0.0245 Nm. As the RPM range is from 0 to 250 RPM and the output torque has to be at least 0.51 Nm, the motor is supplemented with a gear unit from the same producer. The gear model number is GP32.19, and has a ratio reduction of 19.2:1. This gear changes the output RPM to 284 RPM, and changes the output torque to 2.25 Nm which makes it suitable for the prototype. Figure 2.28 shows the motor and gear combined and more information can be found following the reference (RS-online, 2015). The motor axle has a flat section so that it can be fastened to an axle by a bolt.

*Figure 2.28: Motor and gear unit for main axle.*

### 2.5.2.2 Power Supply

A GW laboratory DC power supply unit, of the designation GPS-3030, is used to control the motor. These units make it possible to regulate both the current and voltage, which adjusts the velocity of the electrical motor. The current is controlled so as to never exceed the maximum current rating of the motor while it is running.


*Figure 2.29: Power supply unit.*

### 2.5.2.3 Motor Housing

The motor is held in place by the motor housing, secured by six bolts to the lid. Extending from the wall is a tube, shown in Figure 2.30 and Figure 2.31, with the same inner diameter as the outer diameter of the motor, to ensure a tight fit. Attachment of the motor to the main axle will take place inside this tube, by means of a small screw.

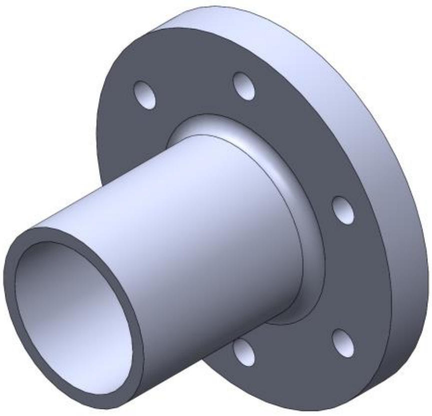


*Figure 2.30: Outer face of the motor housing.*

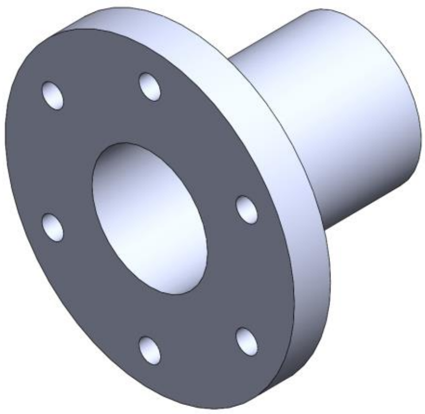


*Figure 2.31: Inside face of the motor housing, that will be connected to the outside of the motor side lid.*

#### 2.5.2.4 Lid

To close of the cylinder at the end where the motor is situated, a circular lid is used. This lid has the same outer diameter as the cylinder and an edge that lets it protrude into the cylinder, to help secure it in place. A 10 mm hole in the center of the lid lets the axle exit the cylinder, so that it can be attached to the motor inside the motor housing. To fit a bearing between the axle and the lid, the hole has been expanded on the inside wall so that the bearing can be mounted flush with the wall. On the outside wall six holes are located radially around the center hole so that the housing for the motor can be attached.

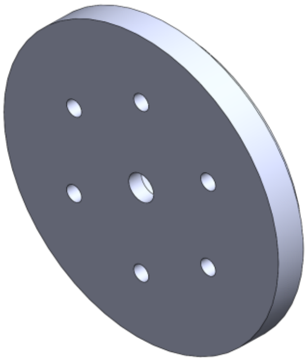


*Figure 2.32: Outside face of the lid.*

*Figure 2.33: Inside face of the lid, showing the hole for a bearing.*

#### 2.5.2.5 Main Axle

The axle for the rotating paddles in the cylinder is made of a stainless steel pipe with an outer diameter of 10 mm. Holes for securing the paddle attachment points are drilled at three places, one of them oriented at 90 degrees with the others. A smaller hole closer to the edge allows the motor to be attached.

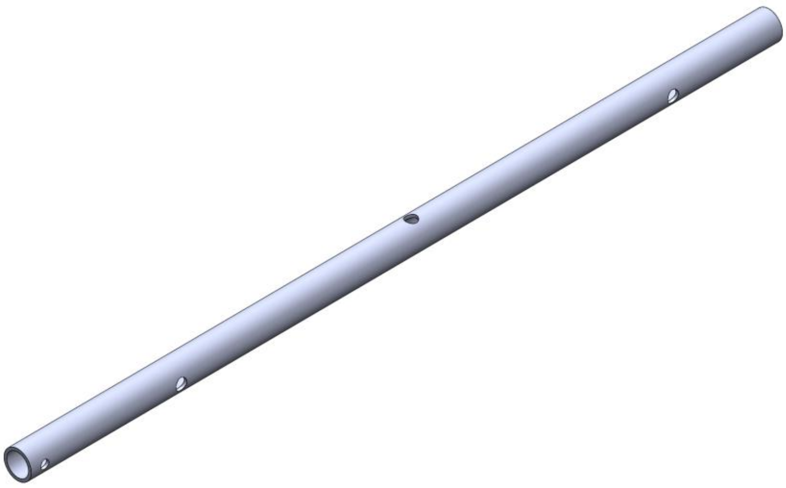


*Figure 2.34: Main axle with holes.*

#### 2.5.2.6 Bushing

To fit the motor to the main axle, a bushing is used to eliminate the gap between the inner diameter of the main axle (8 mm) and the motor axle (6 mm). A threaded hole through both the axle and the bushing with a 3 mm diameter will enable a bolt to connect with the flat section of the motor axle. The part has been machined out of a steel cylinder.

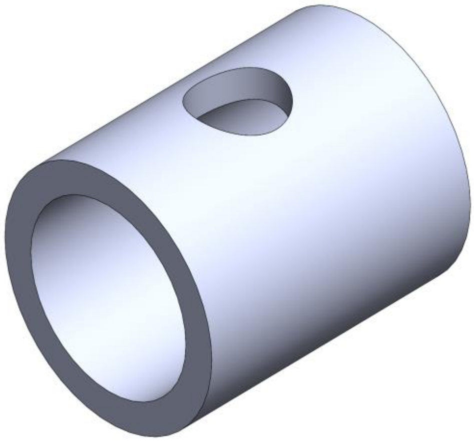


*Figure 2.35: Bushing.*

#### 2.5.2.7 Paddle Attachment

Three mounts are secured to the axle by M4 bolts and nuts for attachment of the paddles to the main axle. The paddle attachment (Figure 2.36) is made up of a short cylinder concentric with the axle, with two cylinders extending from this cylinder. These cylinders are hollow to enable the inserting of paddles, which in turn will be held in place by another set of M4 bolts. By using this system, testing different paddles and servicing will be simplified.

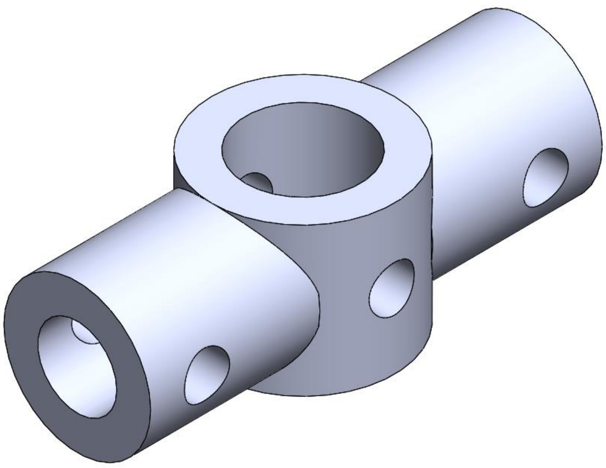


*Figure 2.36: Paddle attachment*

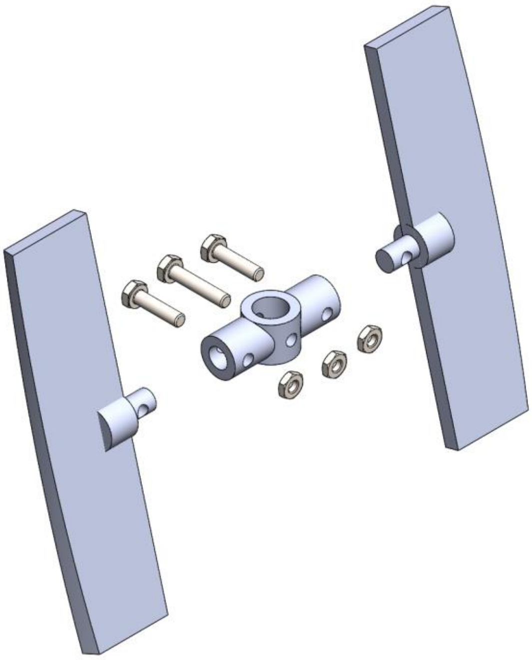


*Figure 2.37: How the paddles will be inserted into the paddle attachment. Lining up the holes will ensure the correct angle. Bolts through the holes will fasten the parts to each other.*

#### 2.5.2.8 Center Paddle

The paddle in the middle section is mounted on a 15º angle degree with the main axle. The small angle of the paddle is made to prevent the paddles from crushing pellets against the cylinder walls, to facilitate mixing, and to still allow the center paddle to throw product into the pin mill. Two different center paddles at opposite angles are made, so that they are facing the same direction when viewed from above. This configuration of the center paddles moves the product inside the machine in an alternating pattern from side to side.

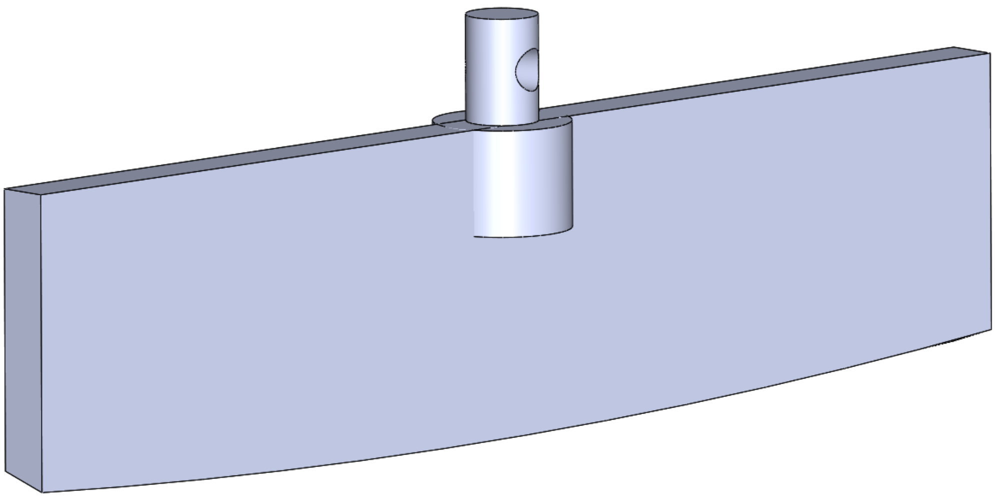


*Figure 2.38: Middle paddle, with the cylinder on top to connect to the paddle attachment.*

### 2.5.2.9 Side Paddles

At each end of the cylinder, the paddles are mounted at a 45° angle to maximize mixing and the transportation of product away from the cylinder sidewalls. Two different types of side paddles have been designed, so that they are oriented correctly at each end of the cylinder. A total of four side paddles are mounted to the main axle via the paddle attachments.

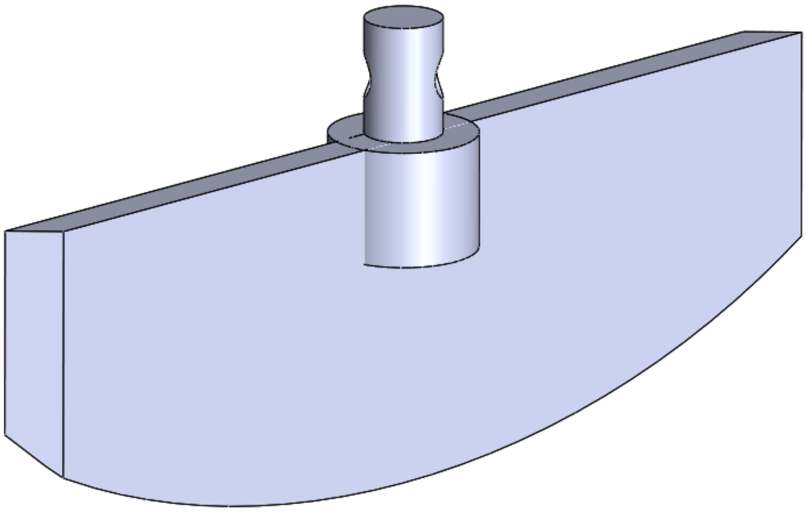


*Figure 2.39: Side paddle.*

### 2.5.2.10 Bearings

The main axle is supported by two SKF deep groove ball bearings, single row, of designation 6000. These bearings are located outside of the paddles at each end of the main axle. One is pressed into the lid; the other is pressed into a bearing capsule, described in the next section. The bearings are dust proof, with a plastic ring covering the balls depicted in Figure 2.40.

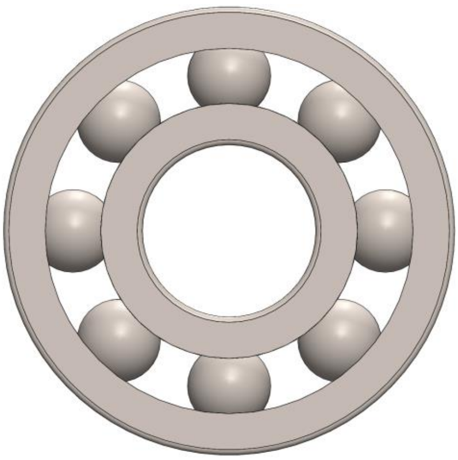


*Figure 2.40: Illustration of the bearing.*

#### 2.5.2.11 Bearing Capsule

The hexagonal bearing capsule was devised to make it possible to easily insert and remove the main axle. As the bearing is fitted to the end of the axle, it has to be removable from the wall. The hexagonal shape press fitted over the bearing ensures that the bearing is rotating inside the capsule, not the capsule inside the wall. The back of the capsule has filleted edges so that it can be easily inserted into the corresponding cutout in the cylinder endcap described in section 2.5.1.2.

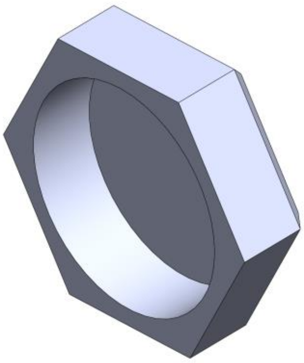


*Figure 2.41: Front of the bearing capsule, where a bearing can be press fitted.*

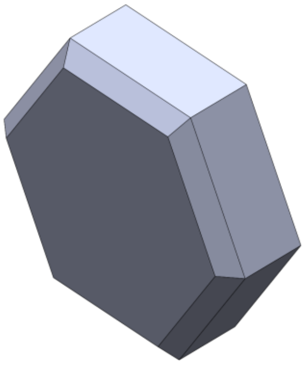


*Figure 2.42: Rear of the capsule, showing the filleted edges.*

### 2.5.3 Pin Mill Assembly

The rotating axle in the pin mill is made up of a stainless steel axle with pins. Every other pin is rotated 90 degrees to form an alternating pattern. As for the main axle, two bearings are fitted to the axle, one on each side of the row of pins. The pin mill is utilizing smaller bearings, of the designation 626. The bearing at opposite end of the axle is pressed into a smaller version of a bearing capsule.

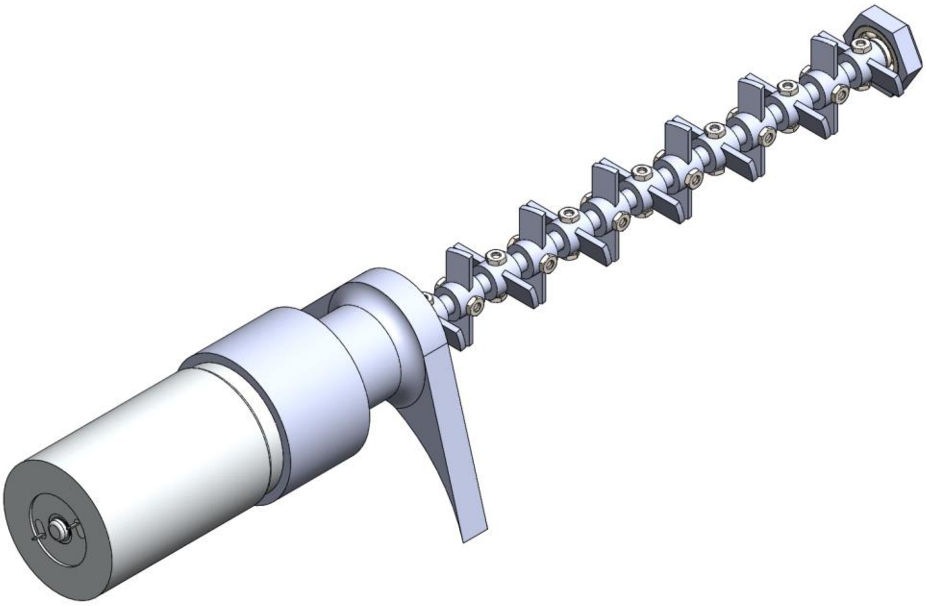


*Figure 2.43: Pin mill assembly.*

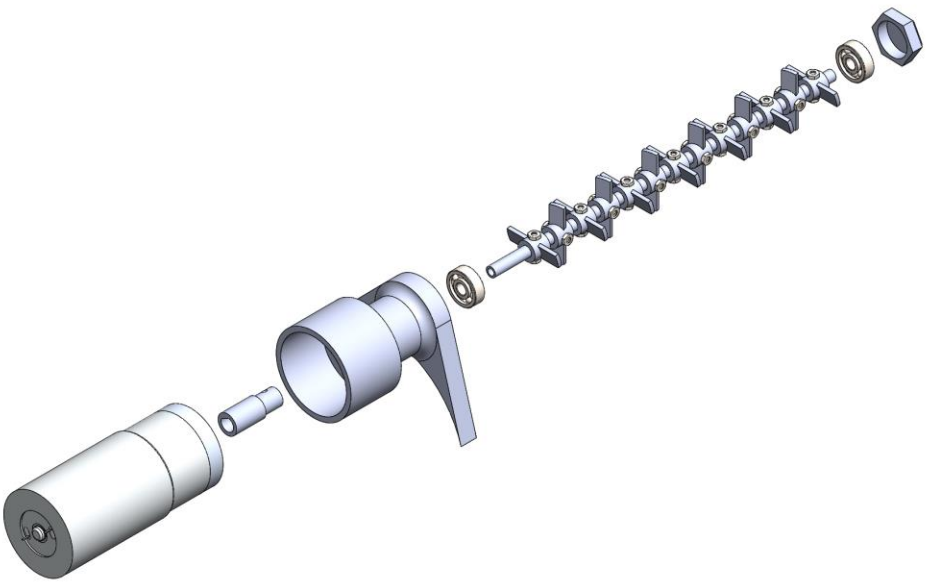


*Figure 2.44: Pin mill assembly exploded.*

#### 2.5.3.1 Motor for Pin Mill Axle

As opposed to the main motor, the requirement for the pin mill motor regarding torque is not as crucial for the functionality. The pin mill will only affect a fraction of the product inside the machine at a time, the powder thrown into it by the paddles. Its purpose is to hit the powder at high velocity to break lumps, and throw it out the other side. Hence, the main requirement for the functionality of the pin mill motor is to be able to rotate at high velocity. To be able to operate the RPM with a voltage regulator, another 12 V DC motor was chosen. A relatively affordable alternative from the producer Como Drills, a 975D series planetary-geared motor with a power output of 41,3 W and current rating of 5500 mA. Without the gear attached, the motor rotates at 5700 RPM at maximum efficiency, 7000 RPM under no load. The planetary gear included with the 975D41 motor has a reduction ratio of 4:1, which reduces the RPM under no load to 1750. The gearbox gives the motor a torque rating of 0,22 Nm, adequate in this application. Figure 2.45 shows the motor and gear combined, and more information can be found following the reference (RS-online, 2015). The motor axle seen to the left in Figure 2.45 has a flat section that lets it connect to an axle. A similar power supply as the one used for the main motor is used to control the velocity of the motor.


*Figure 2.45: Motor and gear unit for pin mill.*

#### 2.5.3.2 Motor Connector

A connector is used to join the pin mill motor with the pin mill axle. On one end, a cutout is made to fit tightly around the axle of the motor and to support the flat section on the axle as it rotates. At the opposite end of the connector a smaller hole allows the pin mill axle to be inserted and secured by a bolt.

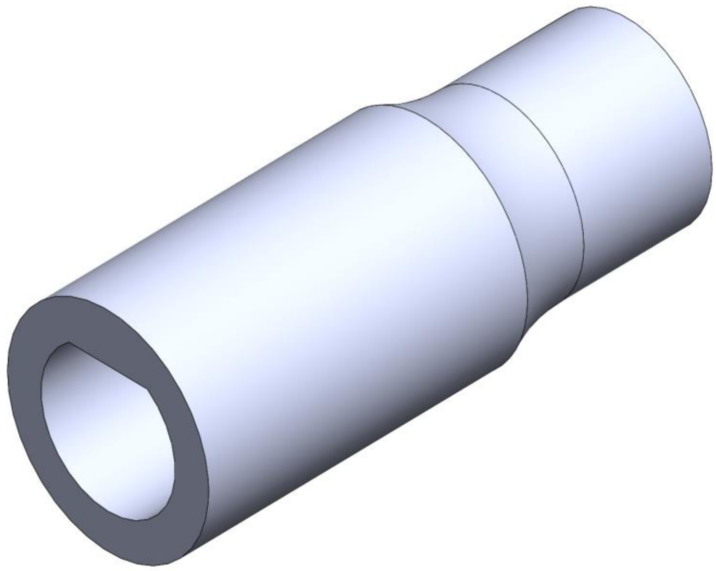


*Figure 2.46: Motor connector, showing the cutout for the motor axle.*

#### 2.5.3.3 Pin Mill Motor Housing

The motor for the pin mill is held in place by a similar housing as the main motor, with a tube extending from the wall that is sealing of the pin mill. Due to the size constraints, the tube varies in diameter and extends past the end of the cylinder of the main housing. The motor fits inside the widest part of the tube, and the motor will be attached to the axle inside the smaller cylinder. The wall of the housing has an edge that secures it inside the pin mill, and a hole that the axle can exit through and a bearing can be pressed into.

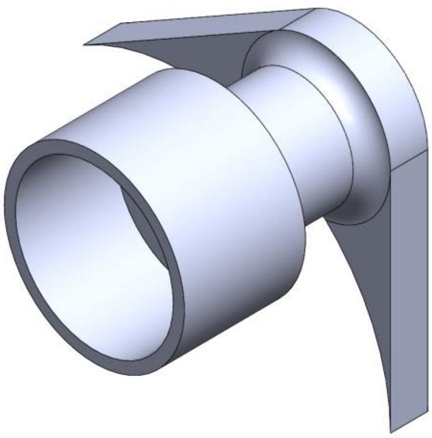


*Figure 2.47: Front view of the pin mill motor housing. The motor goes into the wide cylinder on the left.*

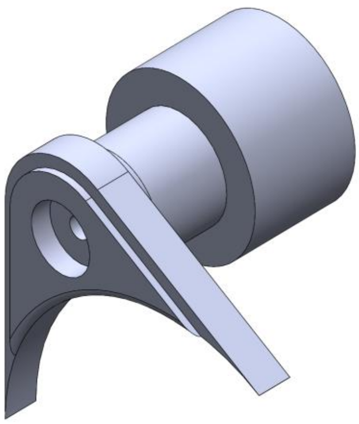


*Figure 2.48: Inside view of the pin mill motor housing. The circular cutout is for a bearing. An exit hole for the pin mill axle can be seen inside the cutout.*

#### 2.5.3.4 Pin Mill Axle

The pin mill is utilizing a stainless steel axle of a smaller diameter than the main axle, 6 mm in this case. To fasten the pins to the axle, thirteen 3 mm holes is drilled into the axle at equal distances, with every other hole at a 90° angle with the last. The axle is held to the motor connector by a screw through an additional hole at the end.

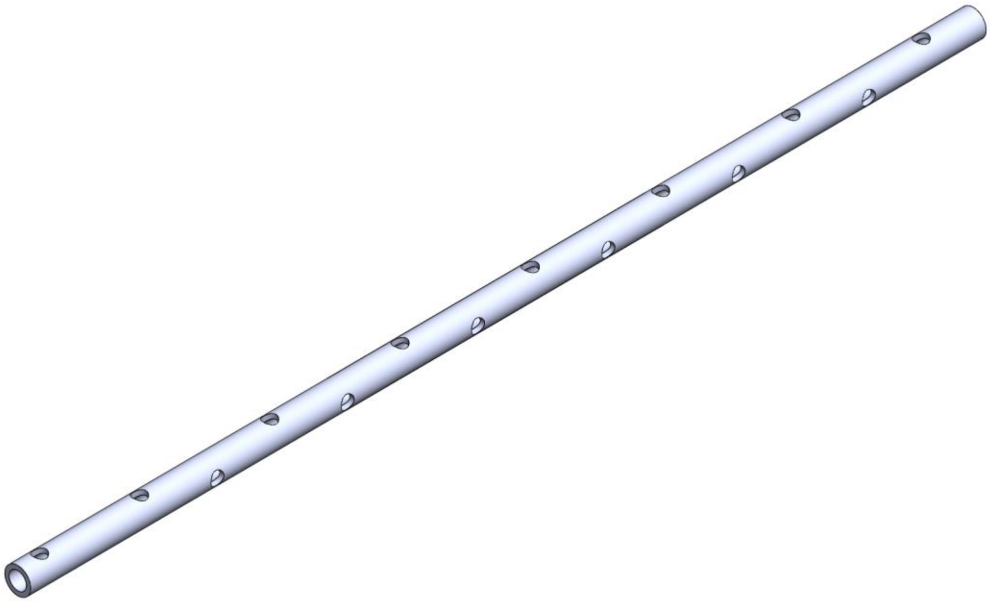


*Figure 2.49: Secondary axle. The hole for fastening to the motor is situated to the left.*

#### 2.5.3.5 Pin

Thirteen small pins are secured to the pin mill axle by bolts and nuts. Bolts are used for attachment to enable testing of different kinds of pins and servicing. The pins are almost like propellers, similar in construction to the paddle attachment points described in 2.5.2.5. Compared to the paddle mounts, instead of hollow cylinders extending radially, the pins have a rectangular blade extending radially at an angle. As these blades are angled in the same direction when viewed from the side, they will move the material hitting them in alternating directions as the axle rotates. A row of these pins along the axle will consequently throw the material in multiple directions at the same time and theoretically create a fine curtain of powder. Additionally, the sharp edge facing the powder will be able to break any lumps hitting them.

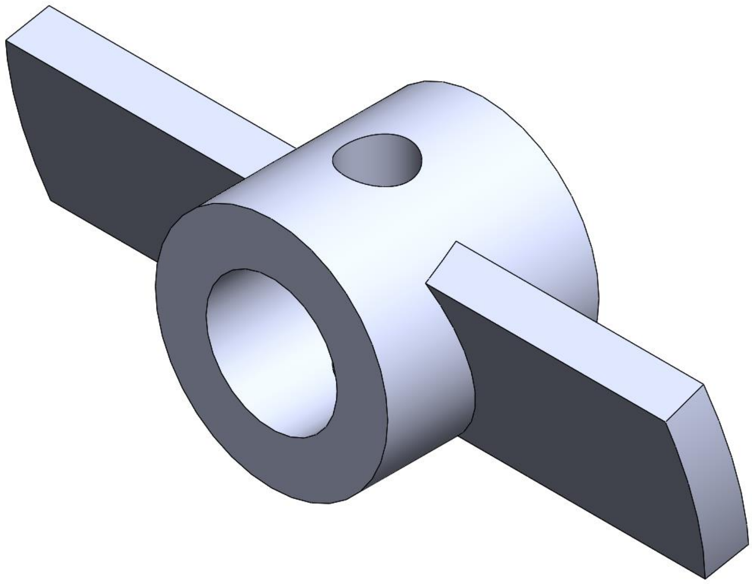


*Figure 2.50: Pin with small blades at an angle.*

### 2.5.4 Top Lid Assembly

The top lid assembly is made up of the top lid, a pneumatic fitting for the vacuum pump, a manometer, a nozzle holder, and the nozzle. Glue is used to attach the nozzle holder permanently, whilst the manometer and pneumatic fitting is screwed in place. The nozzle can be inserted and removed from the nozzle holder.

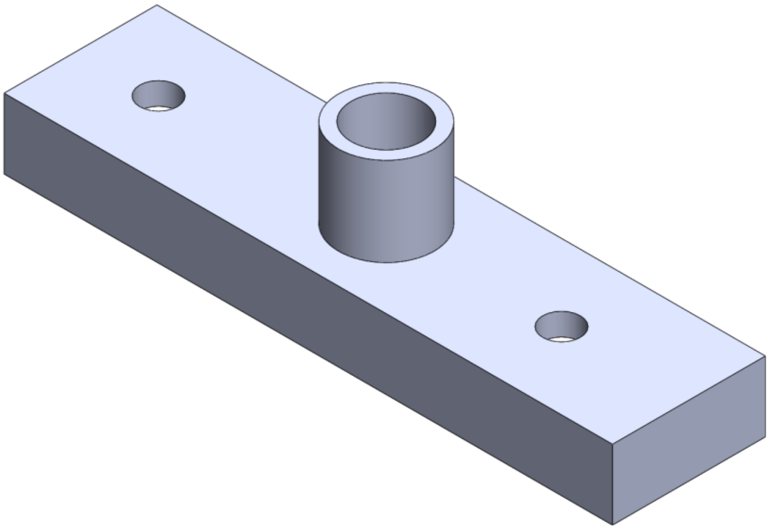


*Figure 2.51: Top lid assembly. The pneumatic fitting, nozzle and manometer are not shown.*

#### 2.5.4.1 Top Lid

A removable lid is sitting atop the inlet in the pin mill housing. Three holes in the lid will allow attachment of a manometer, a pneumatic fitting, and the nozzle for spraying liquid into the machine. The walls of the top lid will surround the inlet walls of the pin mill housing and create a tight seal.

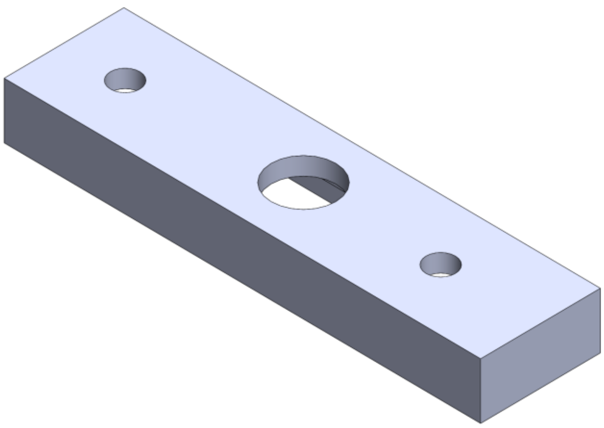


*Figure 2.52: Top lid with holes for attachment of, from left to right: pneumatic fitting, nozzle holder, and manometer.*

#### 2.5.4.2 Nozzle Holder

A nozzle holder is made to fit into the center hole of the top lid, so that a nozzle can be connected. The inside of the holder has been shaped to create a tight seal around the nozzle.

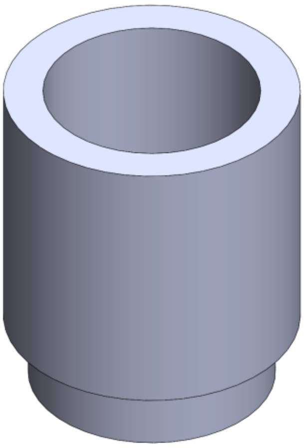


*Figure 2.53: Nozzle holder*

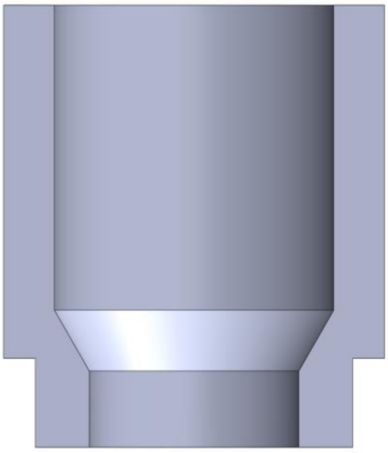


*Figure 2.54: Section view of the nozzle holder.*

#### 2.5.4.3 Nozzle

The nozzle for spraying liquid into the machine is a Schlick Mod. 970/0 S 117, which is connected to a compressor and uses pressurized air to create fine liquid particles. A gasket around the bottom part of the nozzle makes the interface between it and the nozzle holder airtight.

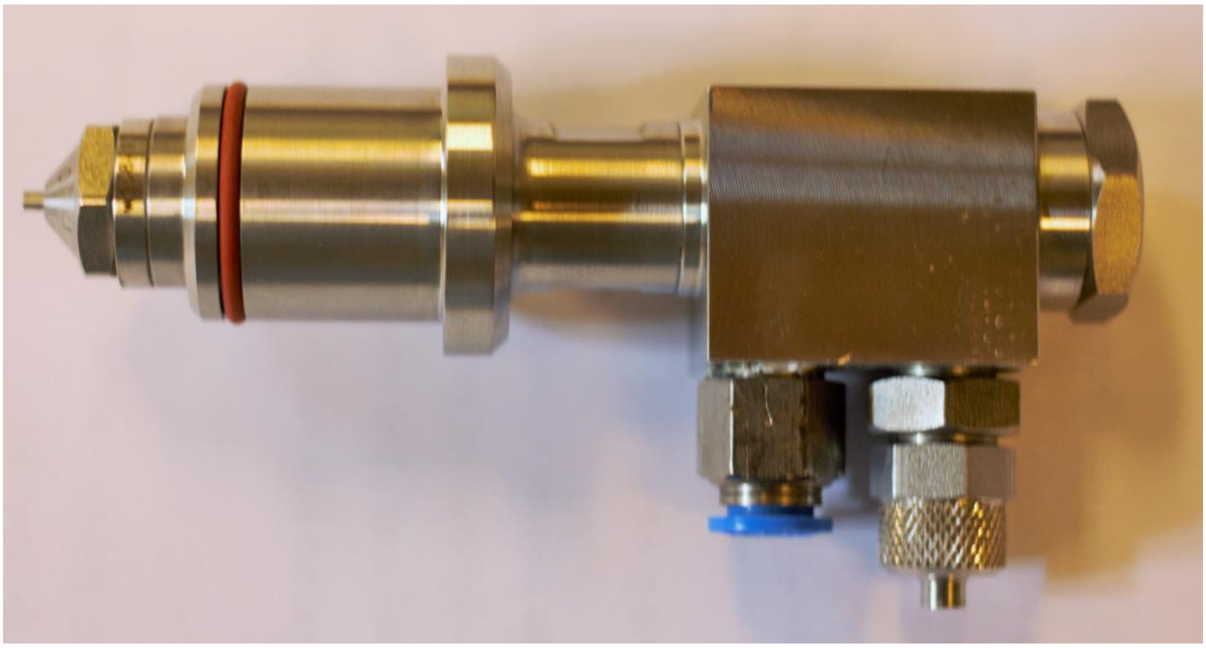


*Figure 2.55: The nozzle used to spray liquid into the machine.*

#### 2.5.4.4 Pressure Gauge

A manometer measuring from -1 to 1,5 bar has been fitted to the top lid. The threads has been covered in thread tape to make it airtight.

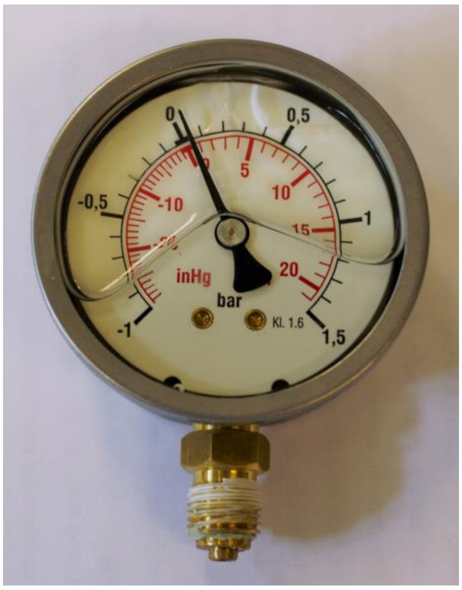



*Figure 2.56: Manometer.*

#### 2.5.4.5 Pneumatic Fitting

To connect the hose of the vacuum pump, a pneumatic fitting has been attached to the top lid. The threads has been covered in thread tape to make it airtight. The fitting has a release that enables removal of a pneumatic hose.

*Figure 2.57: Pneumatic fitting.*

#### 2.5.4.6 Vacuum Pump

To create the necessary vacuum inside the machine while vacuum coating, a vacuum pump is connected to the top lid via a hose to the pneumatic fitting described in the previous section.

*Figure 2.58: Vacuum Pump.*

# 3 Prototyping

Prototyping presents the work done to physically build the prototype described in the previous chapter. The chapter contains pictures of the physical model of each of the four subassemblies making up the machine, with a description of the construction methods used in the process of building them.

## 3.1 Main Housing

*Figure 3.1: Main housing.*

*Figure 3.2: Front of the main housing.*

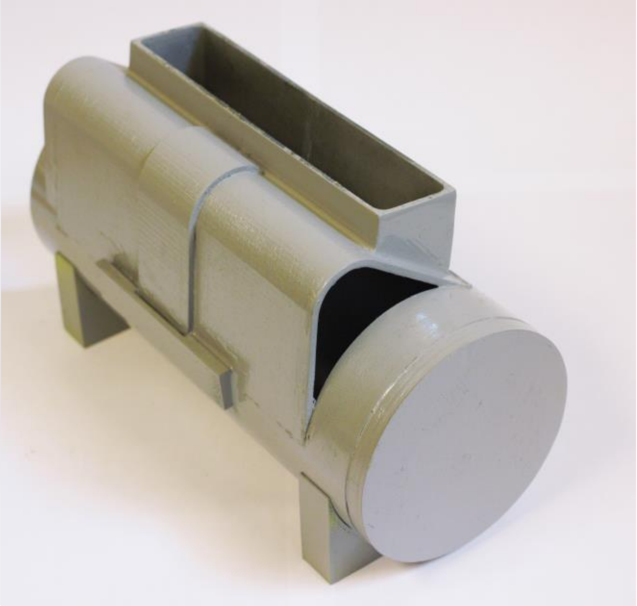


*Figure 3.3: Rear of the main housing.*

Assembly of the main housing started with cutting the PVC tube to the correct length. Next, the rectangular cutout was made in the cylinder wall. The cutout was made with a milling machine, to ensure that the two edges were perfectly straight and on the correct angle in relation to each other. This was of the utmost importance, as the geometry of the pin mill housing necessitated a very precise cutout to be able to fit. To fine-tune the fit between the cylinder and the pin mill housing, the edges were sanded. The two halves of the pin mill housing had already been glued together, and could in turn be glued into the cylinder cutout. To reinforce the interface between the pin mill housing and the cylinder, the support plates were glued along the edges. The cylinder and the pin mill housing was sealed of at one end by gluing the endcaps in place. All surfaces were sanded and cleaned to maximize the adhesion of the glue. Upon the completion of the assembly, the entire outer surface of the machine was spray painted to seal of any pores in the printed parts.

## 3.2 Main Axle Assembly

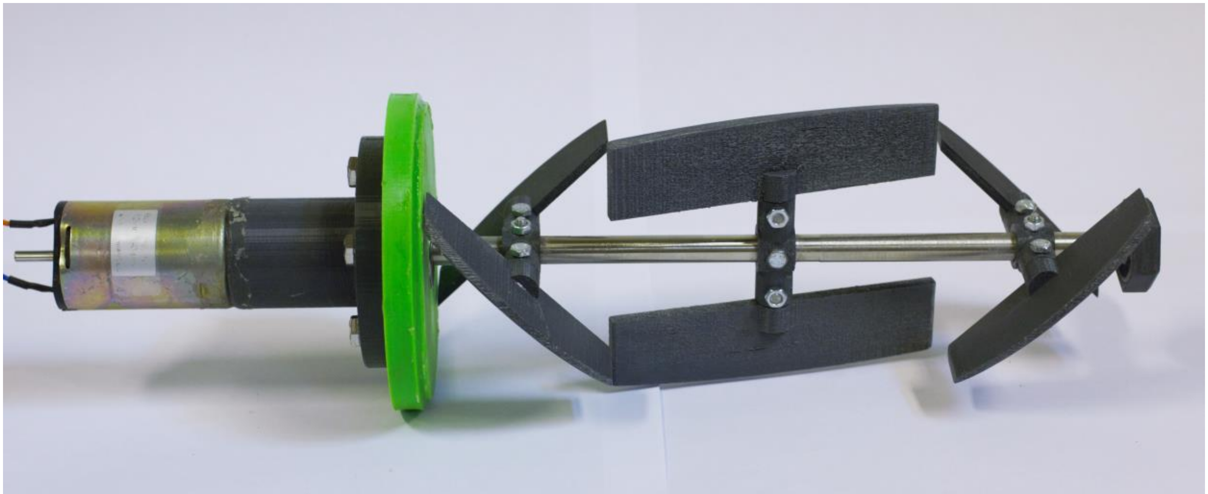


*Figure 3.4: Main axle assembly.*

This assembly is built up around the main axle, which was cut to the specified length out of stainless steel. The three holes for the paddle attachments were drilled through the axle using the milling machine, so that they would sit at the correct distances and angles. A fourth, smaller hole was drilled at one end, so that it could be fastened to the motor. Next, the axle had to be lathed so that the bearings would fit around the axle. A bushing was inserted into the end of the main axle with the smaller hole to remove the gap between it and the axle of the motor. The axle could then be tightened to the motor by a small bolt. The motor now blocked off one end of the axle, so every other component had to be introduced at the opposite end. The motor housing was glued to the lid to ensure air tightness, and tightened with six bolts. It was then led along the main axle and put in place over the motor. A bearing was pressed into the lid, the green part in Figure 3.4. An indentation made in the axle made the bearing rotate with the axle. Three paddle attachments were fastened with bolts through the holes drilled in the axle. In turn, the paddles could then be fastened to the paddle attachments. Finally, the second bearing, pressed into the bearing capsule, was introduced at the end of the axle, held in place by another indentation in the axle. Elastic glue was used around the edge of the green lid, to create a tight seal with the cylinder of the main housing.

## 3.3 Pin Mill Assembly

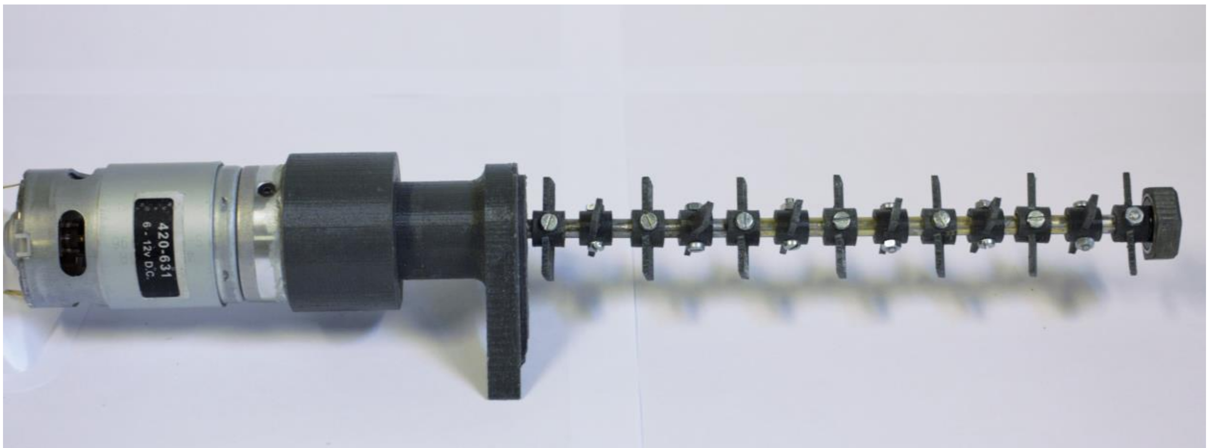



*Figure 3.5: Pin mill assembly.*

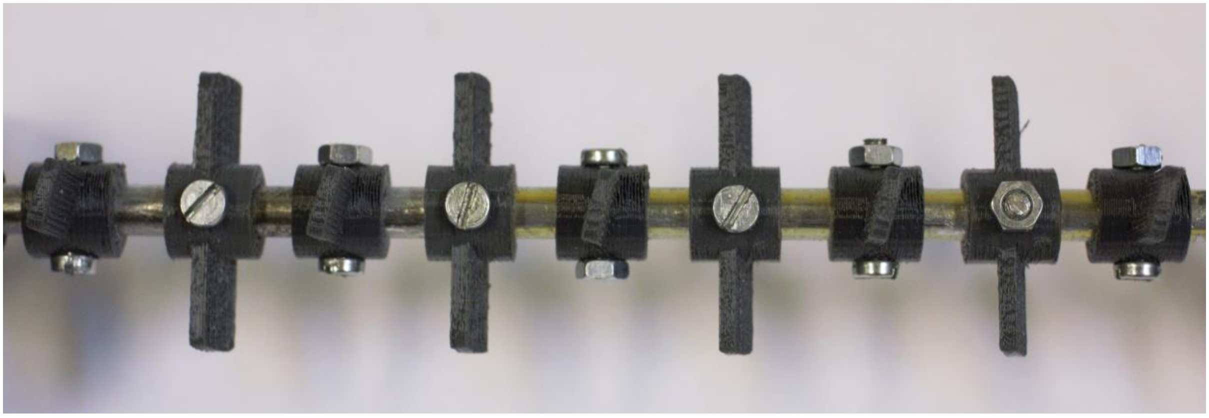


*Figure 3.6: Close-up of the pins.*

Assembly of the pin mill was done on the same principles as the main axle assembly. The axle was cut from a stainless steel tube with an outer diameter of 6 mm. Drilling the thirteen holes for the pins along the axle was a time-consuming process done in the milling machine. As can be seen in Figure 3.6, holes had to be drilled at equal distances, before rotating the axle 90° and drilling the rest of the holes at half of the distance between the holes already drilled. Another hole was drilled close to the edge of the axle so that the connector for the pin mill motor could be attached. The motor axle was pressed into the motor connector, which in turn was fastened to the axle by a bolt. As was the case with the main axle assembly, the rest of the components had to be introduced at the opposite end of the axle. First, the motor housing was put in place over the motor and a bearing was pressed into the wall facing away from the motor. An indentation made in the axle ensured that the bearing rotated with the axle. Thirteen pins were fastened to the holes by bolts and nuts, forming an alternating pattern. Lastly, the second bearing was pressed into the smaller bearing capsule and put in place over an indentation at the end of the axle. The edge of the motor housing to be inserted into the pin mill housing was given a layer of elastic glue acting as a gasket.

## 3.4 Top Lid Assembly

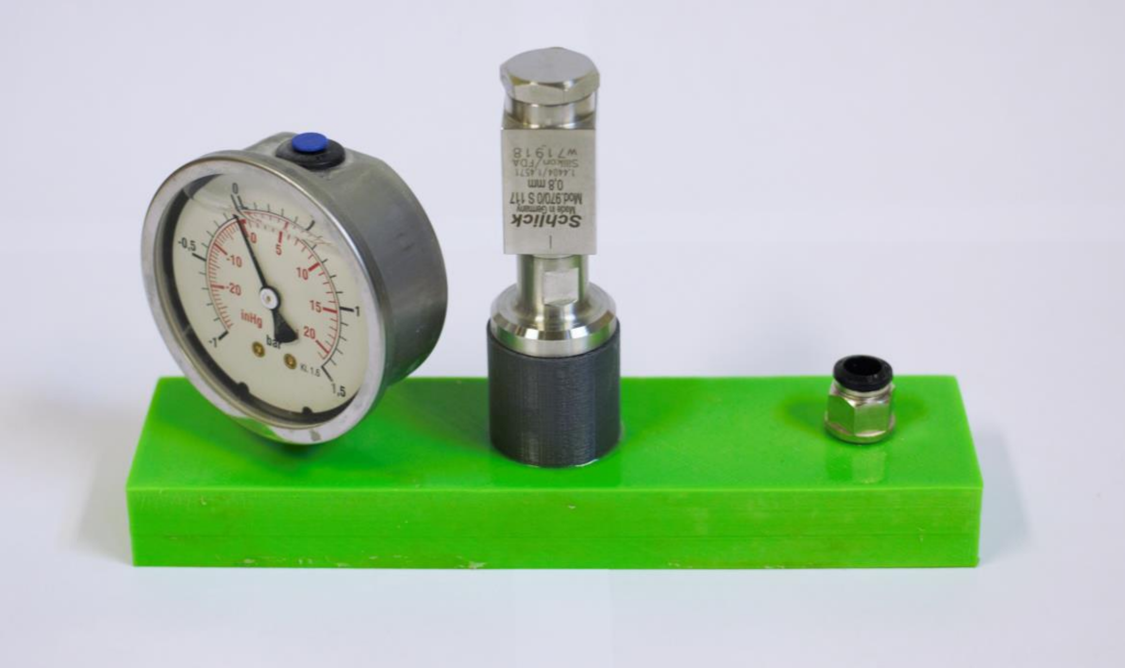



*Figure 3.7: Top lid with manometer, nozzle and pneumatic fitting.*

The top lid was printed as a solid part, to ensure air tightness. It was also printed with three holes on the top, one for the nozzle holder, and two holes that could be threaded. The two smaller holes were threaded internally to the specified thread of the manometer and pneumatic fitting. By covering the threads of both with thread tape, air tightness was ensured. Both the nozzle holder and the center hole had to be sanded down so that they would fit together. The nozzle holder could then be glued in place. It also had to be sanded on the inside, to create a smooth surface for the nozzle. A gasket around the nozzle created a seal inside the nozzle holder. Elastic glue was used along the inside edge of the lid to create a tight interface between the top lid and the inlet of the main housing.

## 3.5 Complete Assembly

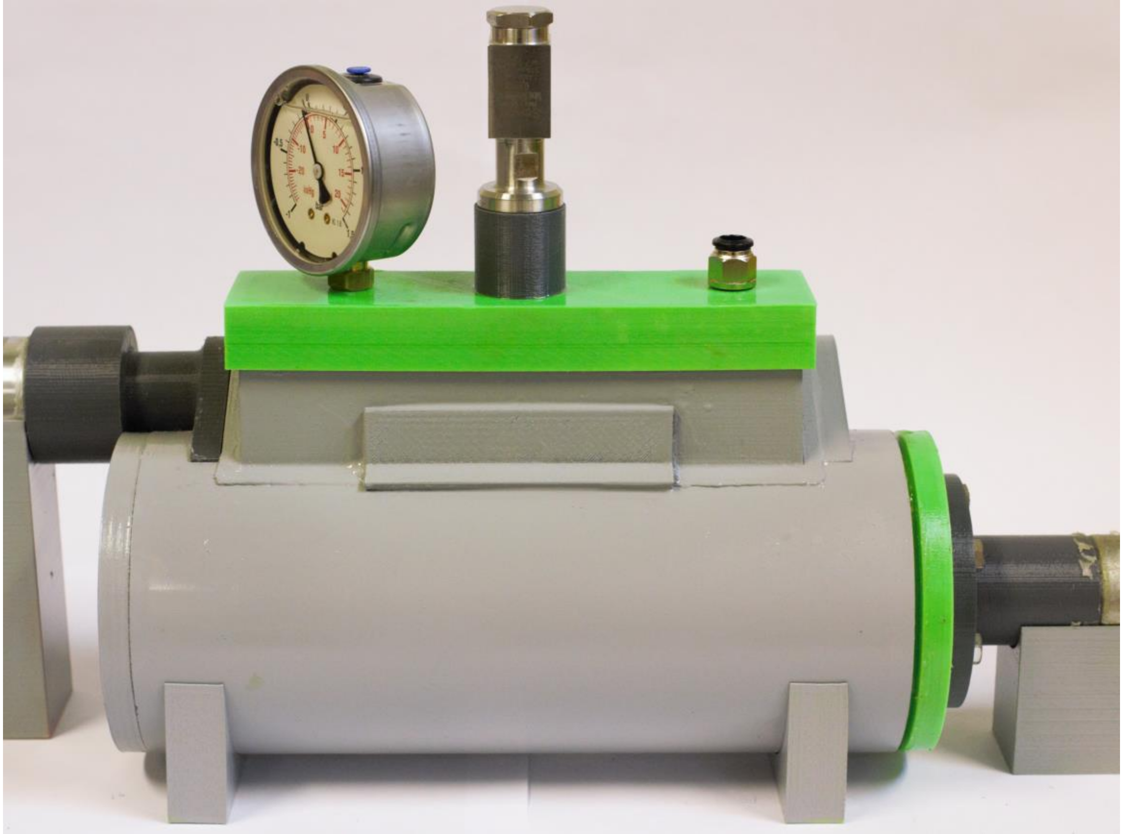


*Figure 3.8: Complete assembly.*

*Figure 3.9: Pin mill inserted into the pin mill housing.*

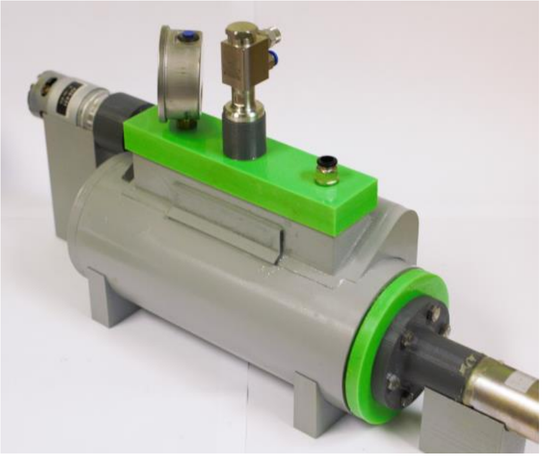


*Figure 3.10: Main axle inserted into the cylinder.*

Putting the top lid in place and inserting the pin mill and the main axle into the main housing completes the assembly. At this stage of the prototype, tape was used to hold the axles in place. The hose for the vacuum pump can be connected to the pneumatic fitting, whilst hoses for air pressure and fluid can be connected at the rear of the nozzle. Each motor is connected to its power supply by two wires.

# 4 Testing

This chapter explains and shows the results from the tests that have been conducted on the prototype. The tests were done to check if the required specifications have been achieved. The tests will also help identify potential improvements for future prototypes and development. Tests has been conducted to measure:

1. Mixing properties.
2. Dispersion of fluid in mixing process.
3. Vacuum coating.

## 4.1 Mixing

### 4.1.1 Methodology for Mixing Test

This experiment was conducted to determine how well particles of different sizes mix inside the machine. A given amount of particles of a predetermined particle size distribution were put into the machine in an unmixed state, and mixed for a set duration. The products used are regularly used in the feed industry.

To measure the degree of mixing, the weight fraction of the different particle sizes was measured before being put into the machine. After the mixing process, samples were taken from three different locations inside the machine (Figure 4.1). A sieving machine was used to separate the different particle sizes in each sample, so that the proportion of fractions could be determined post mixing.

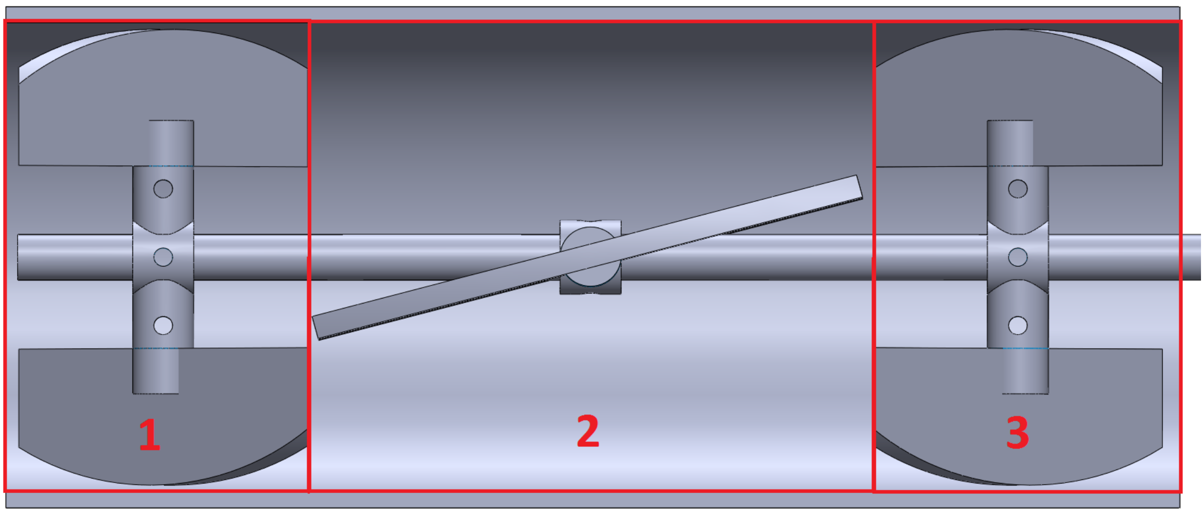



*Figure 4.1: Section view of the machine when viewed from above showing the sampled areas for the mixing test.*

Three different mixes were tested, with two, three, and four different fractions respectively. Each mix were repeated four times. The different particles sizes used and their respective designations as fractions are shown in Figure 4.2.

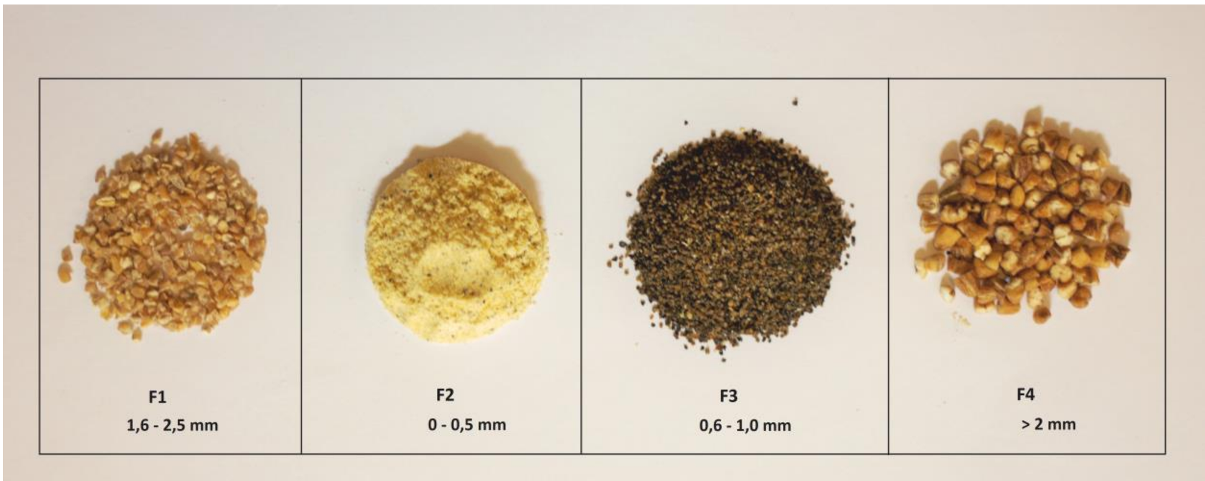



*Figure 4.2: The fractions used in the mixing test with particle size distributions.*

Step by step:

1. For repetition 1 – 4 an amount of F1 and F2 was weighed. For repetition 5 – 8 an amount of F1, F2 and F3 was weighed. For repetition 9 – 12 an amount of F1, F2, F3 and F4 was weighed.
2. The proportion of the fractions in each mix was calculated.
3. Each fraction was added at opposite ends of the inlet while the main axle was running at an estimated velocity of 85 RPM (3 V).
4. The mixing process was run at this velocity for two minutes.
5. Three samples were taken from the locations described above, and put into small ceramic vessels.
6. The vessels were sieved one by one, at an amplitude of 3 mm for 30 seconds.
7. The fraction remaining in each sieve was weighed and compared to its initial value.

### 4.1.2 Results for Mixing Test

Repetition 1 – 4 contained two fractions, F1 and F2. The averages of these initial fractions over the four repetitions are shown as bars in Figure 4.3. For each repetition, the fractions in each of the three sampled areas are expected to be the same as the initial fractions. The standard deviations calculated from the difference between the initial fractions and what was found in each sample are shown at the top of each bar. With only two fractions, the standard deviations within each sampled area are the same for both F1 and F2. The raw data for this test can be found in Appendix 1A.

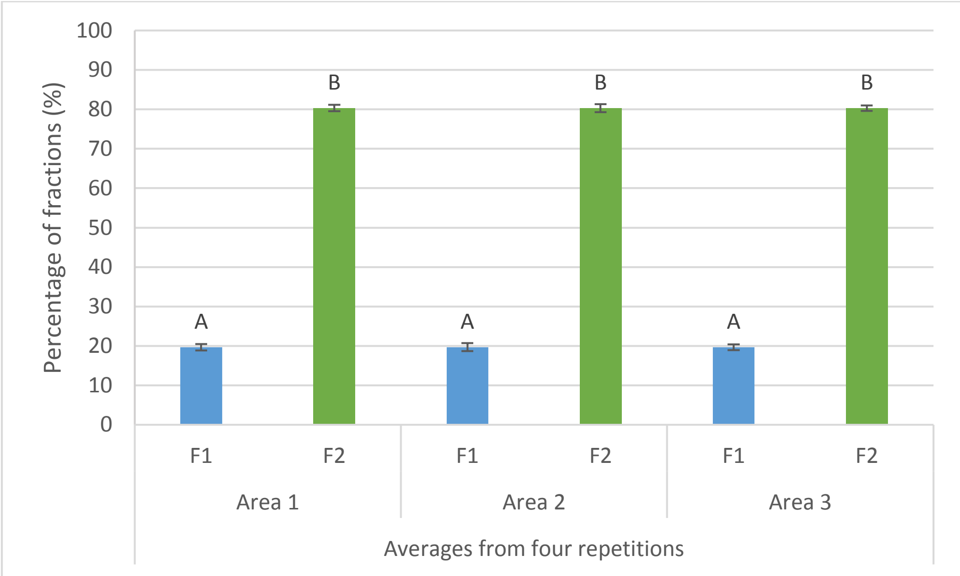



*Figure 4.3: Results from four repetitions. The bars are depicting the averages of the initial fractions over the four repetitions. Fractions are grouped by sampled areas (Area 1, 2, 3). Error bars represent the standard deviation. Different letters indicate significant differences (P < 0,05), according to the ANOVA test.*

Repetitions 5 – 8 contained three different fractions, F1, F2, and F3. The results are presented in a similar fashion to the first group of repetitions in Figure 4.4.

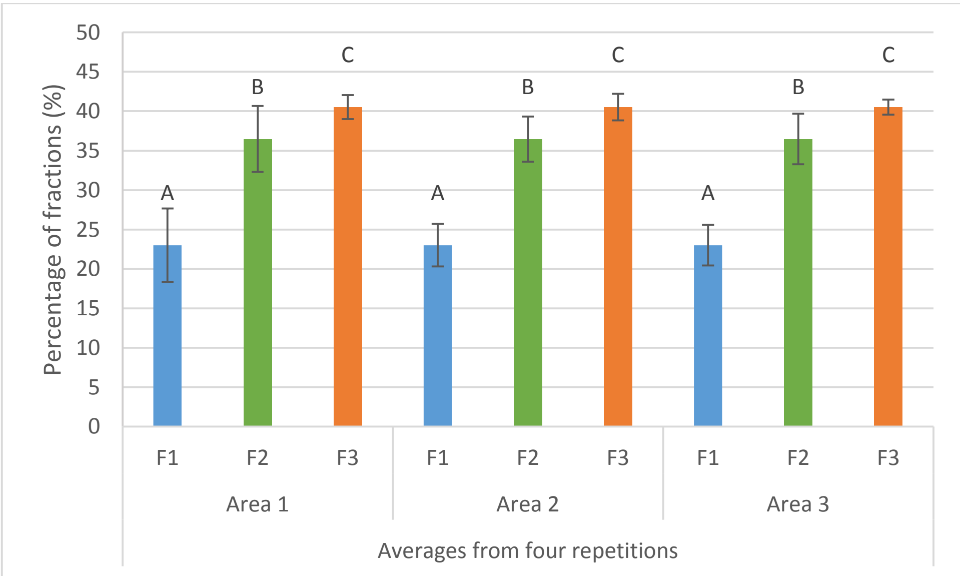



*Figure 4.4: Results from four repetitions. The bars are depicting the averages of the initial fractions over the four repetitions. Fractions are grouped by sampled areas (Area 1, 2, 3). Error bars represent the standard deviation. Different letters indicate significant differences (P < 0,05), according to the ANOVA test.*

Repetitions 9 – 12 contained all four fractions, the results of which are shown in Figure 4.5.

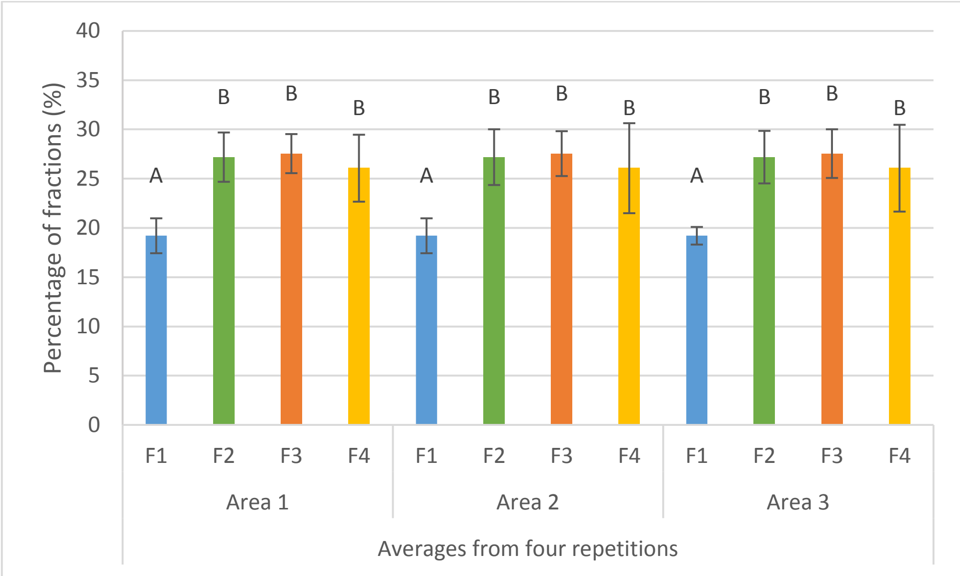



*Figure 4.5: Results from four repetitions. The bars are depicting the averages of the initial fractions over the four repetitions. Fractions are grouped by sampled areas (Area 1, 2, 3). Error bars represent the standard deviation. Different letters indicate significant differences (P < 0,05), according the ANOVA test.*

### 4.1.3 Discussion for Mixing Test

The purpose of the mixing test was to determine if the different fractions mix evenly throughout the machine. To determine if the fractions from the sampled areas were statistically the same, an analysis of variances, often called ANOVA (Løvås, 2010), were used. This analysis compares the variance within each group to the variance between the groups, and is based on the F-statistic defined as:

$$F = \frac{Variation\ between\ groups}{Variation\ within\ groups}$$

Assumptions for the analysis is that the observations in each group are independent of each other, normally distributed, and have the same standard deviation. The null hypothesis is that the groups are the same, with the expectation of $\mu_i$.

$$H_0: \mu_1 = \mu_2 = \mu_3$$

$$H_1: Not\ all\ expectations\ are\ the\ same$$

Within the same group of repetitions, the variation between the fractions was compared across sampled areas. This gave us an F-value and a corresponding P-value. Comparing the P-value to the chosen confidence level of $\alpha = 0{,}05$ did not lead to the rejection of the null hypothesis for any of the fractions or tests. On the basis of this, the fractions are shown to be statistically the same in every part of the machine for all repetitions. This is depicted in the graphs above by letters over each bar. Bars with the same letter above them are statistically similar.

Mixing only two fractions, F1 with large particles and F2 with very fine particles, was expected to be the least demanding test. This is reflected in the results, which shows a very small standard deviation for every fraction. Although the standard deviation is small, some of it can be explained by human error in the sample taking. Utilizing a spoon to extract the sample from the machine meant that a small amount of the sample could fall off and contaminate the other areas when lifted out of the machine. Compounding the effect on the standard deviation was the tendency of the finest particles of F2 to stick to the sieves after being processed. This meant that the entire amount of F2 could not be perfectly weighed, shifting the fraction towards F1.

Three fractions proved to be more challenging, but the standard deviations were still within control. The same fine powder from F2 got stuck in the sieves, affecting the results.

All four fractions was the most demanding test, a fact that is echoed by the results. F4 was the particle size that deviated the most, especially in sample area 2, the middle section of the machine. Larger particles fell of the sample-taking spoon more easily, and this could mean that the middle section of the machine got contaminated. Because of the relatively large weight per particle of F4, a few stray particles would greatly affect the results. On the other hand, a controlled weighing of F4 was much easier than for the smaller particle sizes. This would in consequence skew the results toward F4 if all of it got weighed from each sample, and not all of the other fractions.

Another point is that the average weight of the mix was 150 grams, a relatively small amount given the size of the machine. The weight was limited by the amount of each fraction prepared for testing.

### 4.1.4 Conclusion for Mixing Test

No significant differences ($P < 0,05$) between the sampled areas were found. The conclusion is that the machine is able to mix particles of different size distributions in an appropriate matter to a confidence interval of 95%.

## 4.2 Dispersion of Fluid in Mixing Process

### 4.2.1 Methodology for Dispersion Test

The purpose of this test is to discover how well liquid sprayed into the machine disperses throughout the product inside. A relevant way to test this is to use regular wheat flour as the powder inside the machine, and water as a liquid. The material properties of these ingredients approximate what would be used in the feed industry.

Dispersion of two levels of water content has been measured, 1% and 5% of water content as a percentage of the weight of the flour. As the flour bought in a convenience store contains water, it is dried at 105 ºC to evaporate the water and make the flour completely dry before mixing.

A Schlick Mod. 970/0 S 117 nozzle was used to spray the water into the machine. By manually controlling the flow of water into the nozzle, the addition of 1% of water was conducted in approximately 30 seconds. To increase the water content to 5%, additional water was added over a period of approximately 80 seconds.

Six locations inside the machine were examined, before and after each paddle, as shown in Figure 4.6. Samples were taken from all of the location both at 1% and 5% of water content, for a total of twelve samples.

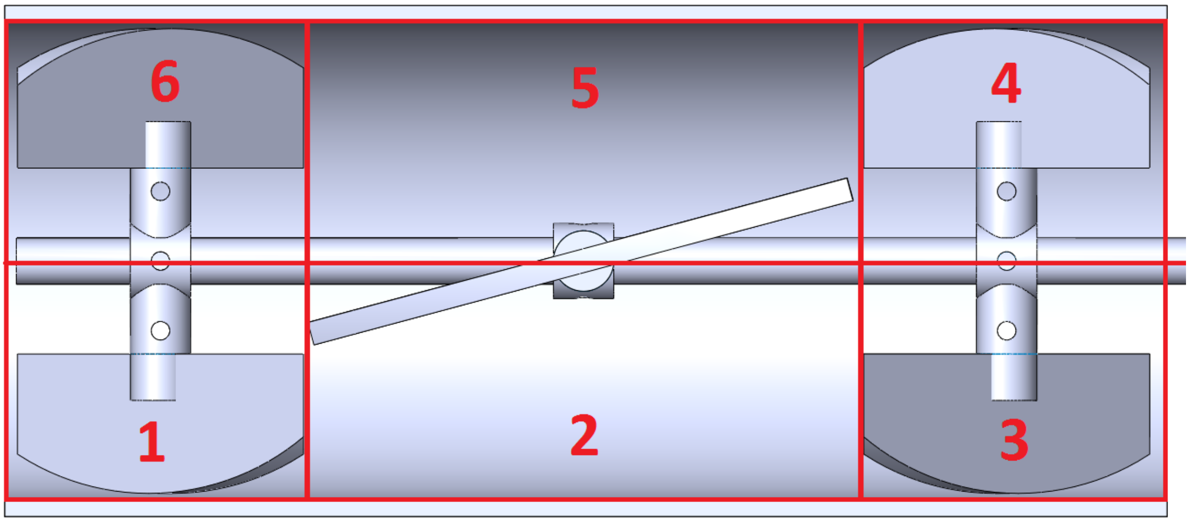



*Figure 4.6: Sampled areas for fluid dispersion test.*

Step by step:

1. An amount of flour was measured and put into the machine whilst the main axle is rotating at a velocity of 140 RPM (voltage regulator at 5 V).
2. The lid was put in place.
3. The velocity of the main axle was increased to 200 RPM (at 7 V) to throw the flour into the pin mill. This velocity was the best setting for creating a curtain of powder out of the pin mill.
4. The pin mill was set to rotate at maximum velocity of 1750 RPM (at 12 V), creating a curtain of powder directly below the nozzle.
5. Air pressure in the nozzle was set to 0,125 bars.
6. 1% of the weight of flour was added in water.
7. After the addition of water, the mixing process was ran for one minute.
8. Both the rotating axles were stopped, and the lid removed.
9. Six samples were taken from the locations described above by means of a teaspoon, and put into small ceramic vessels. Every vessel was weighed beforehand and given a number.
10. Each vessel with powder was weighed and dried in a heater, where the water content of the sample was evaporated at 105 ºC for 15 minutes. The weight after drying was registered, so that the percentage of water content could be calculated in each of the six areas.
11. To determine the weight of the remaining flour in the machine, the weight of each of the six samples was subtracted from the initial weight of the flour.
12. In turn, an additional 4% of water could be added as a percentage of the remaining flour weight. This way, the remaining flour inside the machine would ultimately contain a total of 5% of water.
13. Steps two to ten was repeated for the five-percentage test.

### 4.2.2 Results for Dispersion Test

The test described in section 4.2.1 was repeated seven times. A1-A6 represents the samples from the area they were taken after respectively 1% water and 5% water was added. The results of the 1% water content test are shown in Figure 4.7. The numbers are based on an average of the water content level in test vessels 1-6 after mixing, and the standard deviation shows the spread of each repetition. The raw data for this test can be found in Appendix 1B.

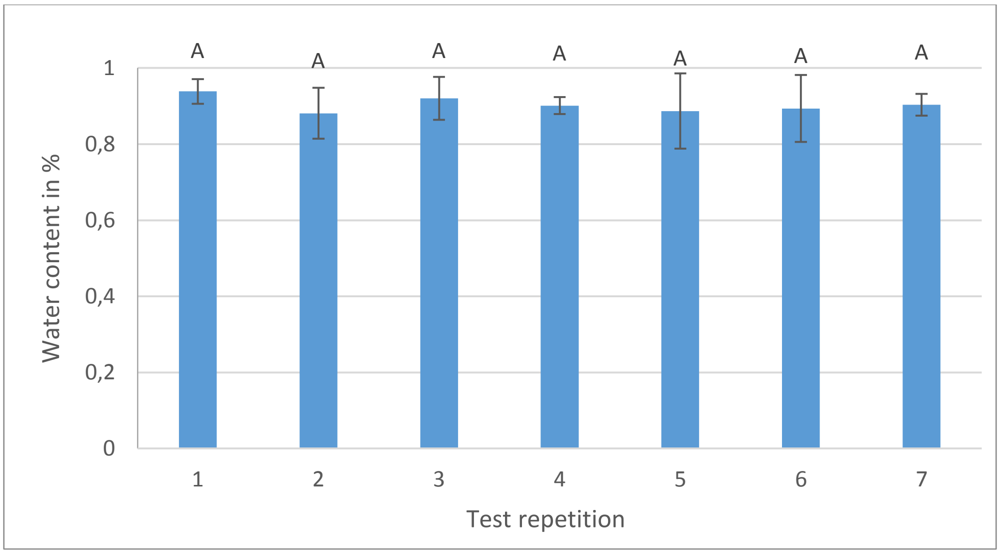



*Figure 4.7: Average water content in the six test samples taken from area 1-6 after 1% water addition, showed in seven test repetitions. Standard deviations are shown at the top of each bar. Different letters indicate significant differences (P < 0,05), according to the ANOVA test.*

The results of the 5% water content test are shown in Figure 4.8. The numbers are based on an average of the water content level in test vessels 1-6 after mixing, and the standard deviation shows the spread of each repetition.

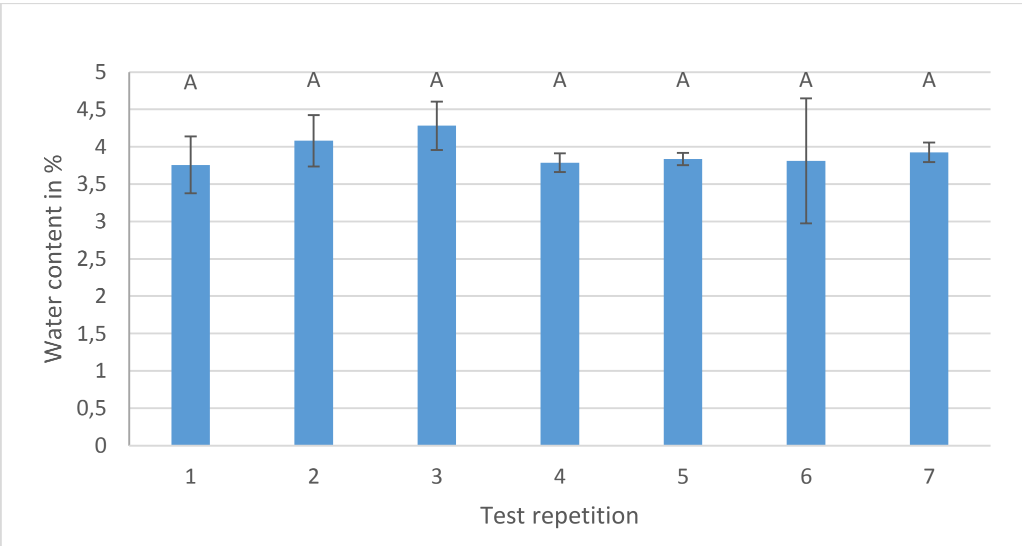



*Figure 4.8: Average water content in the six test samples taken from sample 1-6 after 5% water addition, showed in seven test repetitions. Standard deviations are shown at the top of each bar. Different letters indicate significant differences (P < 0,05), according to the ANOVA test.*

Figure 4.9 shows the average of fluid content in percentage in each area, A1 through A6, after 1% water is added. The average is calculated from the seven repetitions.

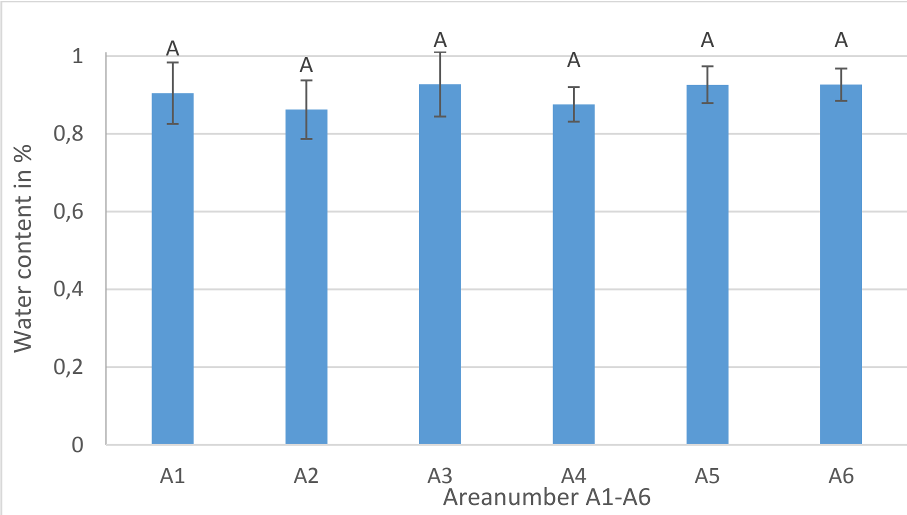



*Figure 4.9: Average water content in each area, A1 through A6, after 1% water addition. The average is calculated from seven test repetitions. Standard deviations are shown at the top of each bar. Different letters indicate significant differences (P < 0,05), according to the ANOVA test.*

Figure 4.10 shows the average of fluid content in percentage in each area, A1 through A6, after 5% water is added. The average is calculated from the seven repetitions.

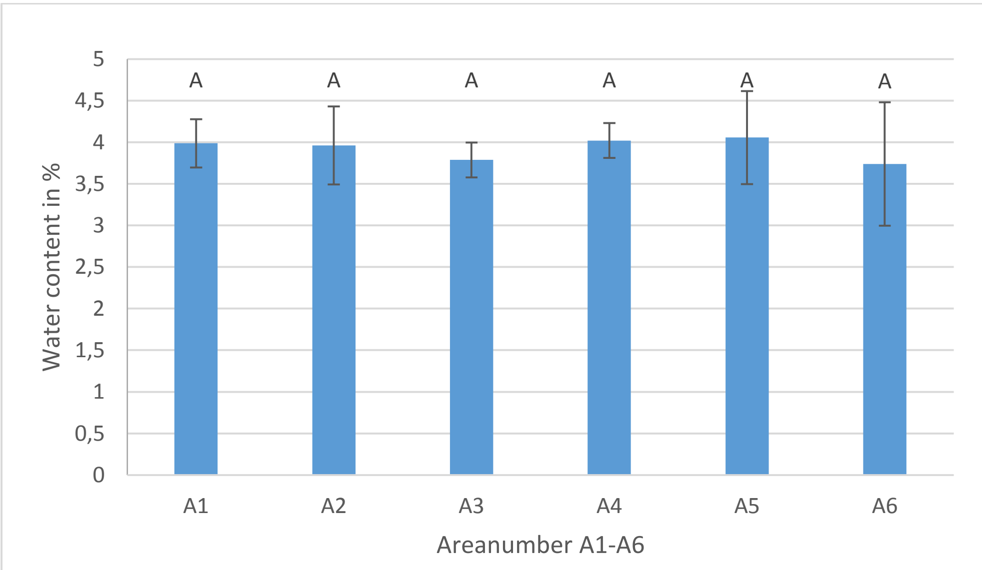



*Figure 4.10: Average water content in each area, A1 through A6, after 5% water addition. The average is calculated from seven test repetitions. Standard deviations are shown at the top of each bar. Different letters indicate significant differences (P < 0,05), according to the ANOVA test.*

### 4.2.3 Discussion for Dispersion Test

In the fluid dispersion test, the functionality of the prototype regarding the design of both the main cylinder and the pin mill was evaluated. Both axles have to work in unison so that all the flour in the machine will be exposed to the water injected at the top. However, an important factor is also that the water injected doesn't create lumps that stick to the walls of the cylinder and pin mill. The latter is shown in the two first figures in the results part, as they show the average water content in the prototype after injection. In Figure 4.7 the average water content in the flour is measured after 1% water, calculated from the flours weight, is injected. The seven repetitions show an average below 1%, which tells us that some of the water doesn't get mixed into the flour. This can be explained by looking at the area where the water is injected, the top inlet part of the pin mill housing.

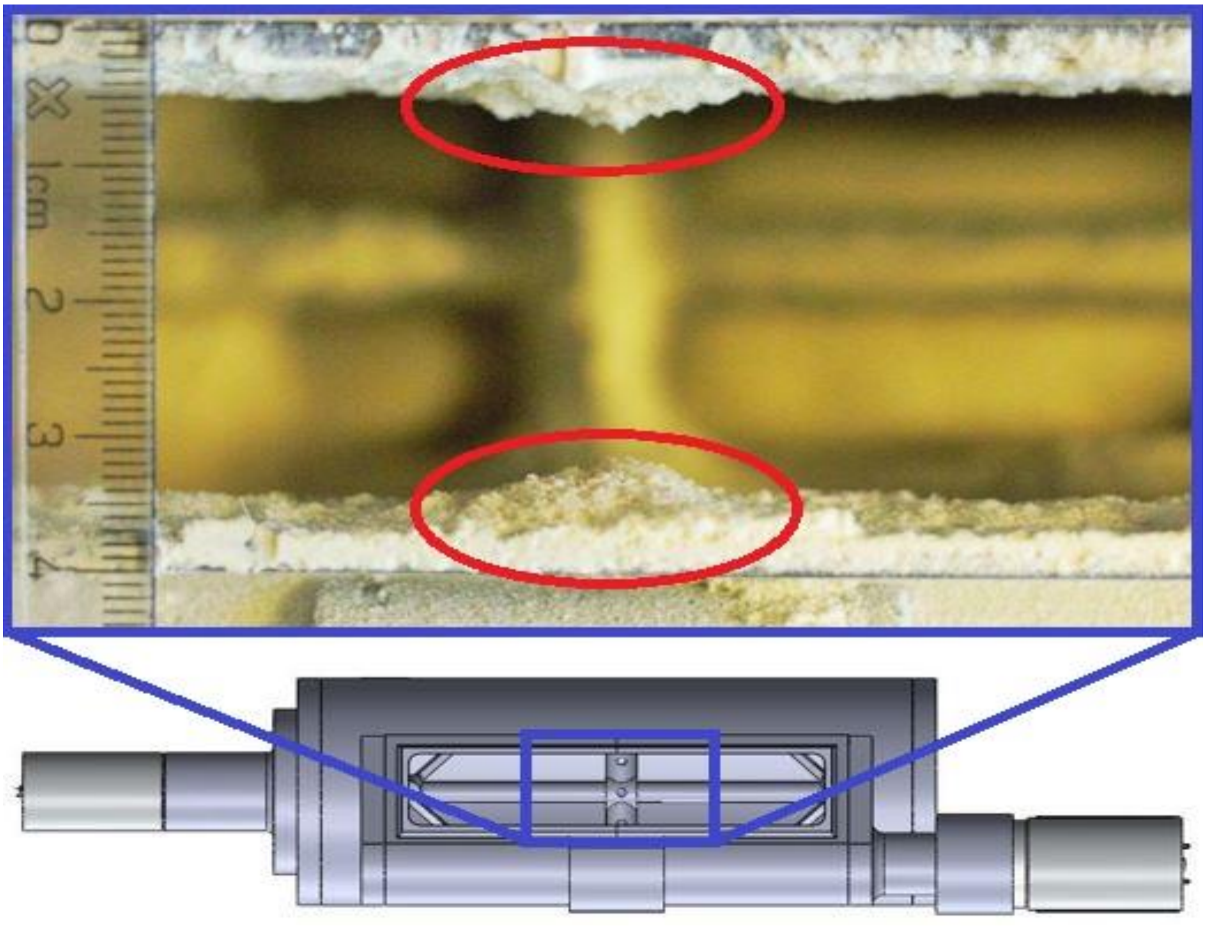


*Figure 4.11: Picture taken from the top inlet of the mixer after 5% water addition. Red circles marks areas where the water hits the wall, and the flour tends to agglomerate.*

As Figure 4.11 shows, some of the water injected is hitting the inlet wall instead of the flour, creating lumps and denying the water from reaching the flour passing below. Even though it is only a small amount of water that is sticking to the wall, the total amount of water injected when testing for 1 % rarely exceeded 4,1 mL, thus literally making every drop count. The same phenomenon is discovered when the test for 5% water injection is executed. From Figure 4.8 in the results part, one can see that the average water content that should have been 5%, is between 3.5% and 4.5%. The differences here are bigger than for the 1% test, and Figure 4.12 shows why.

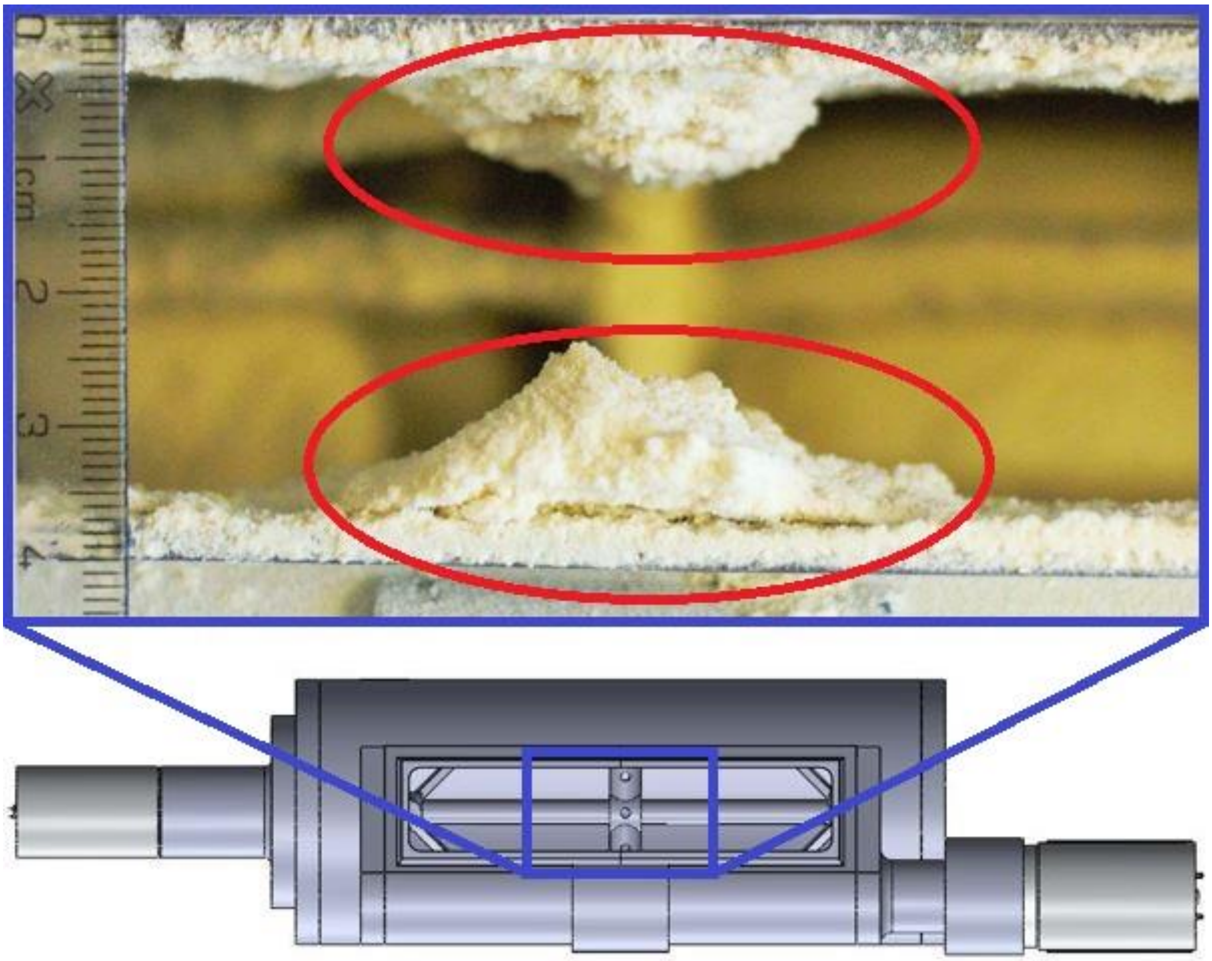


*Figure 4.12: Picture taken from the top inlet of the mixer after 5% water addition. Red circles marks areas where the water hits the wall, and the flour tends to agglomerate.*

When injecting 5% water the flow rate and the time of water injection is increased, which leads to more water hitting the inlet wall. In turn, there is more agglomeration on the wall and less water is distributed among the flour.

It is believed that there are two main reasons that create the situation discussed in the paragraph above. The first one can be seen as an external case, and applies to the nozzle used when injecting water. As the nozzle sprays liquid in a circular configuration, it is not possible to spray perfectly onto all of the powder from the pin mill. The second reason is that the inlet opening is not wide enough, which denies some of the flour the path that would be optimal for mixing. As some of the flour hits the moist wall, it starts agglomerating and binding more water to the wall. However, the pin mill fulfilled its purpose and was able to break lumps in the powder and create a wide stream of fine powder underneath the inlet.

Back to the results part, Figure 4.9 and Figure 4.10 shows the spread of water regardless of the amount. These figures show how the water is distributed among the six areas of the mixer. At 1% water injection, Figure 4.9 shows that the water is evenly spread around in most cases, although the standard deviation shows some variation from test to test. At 5% water injection, the deviation is somewhat bigger than for 1%.

### 4.2.4 Conclusion for Dispersion Test

Figure 4.9 and Figure 4.10 indicates that the mixer is spreading fluid evenly among the flour. A variance analysis taken with a confidence level of 95% shows that there is no significant difference between the samples taken from test to test, and area to area. It can be concluded that the mixer distributes fluid evenly, but some features regarding the mixer inlet must be changed to make sure that the water doesn’t hit the walls whilst injected.

## 4.3 Vacuum Coating

### 4.3.1 Methodology for Vacuum Coating Test

The vacuum coating test was conducted to determine how well the machine is able to mix oil and pellets in a low-pressure environment. Factors affecting the performance of the vacuum coating process are how well the paddles are able to mix the pellets without destroying them, and how the oil is sticking to the different surfaces inside the machine. Additionally, the minimum achievable pressure and the release of the low pressure have a huge influence on the ability to vacuum coat pellets.

The materials used in the test are extruded feed pellets with a diameter of 2 mm and regular rapeseed oil. Using the expertise of the principals as guidance, the ratio of pellets to oil was set to 70% pellets and 30% oil. The whole batch of pellets where weighed before and after vacuum coating, to determine how much oil the pellets had absorbed.

Step by step:

1. An amount of dry pellets was weighed. This amount corresponded to 70% of the total weight added to the machine.

2. The amount of oil necessary to achieve a 70/30 ratio between pellets and oil was calculated and weighed.
3. Pellets and oil were added to the machine through the inlet.
4. The main axle was set to rotate at 85 RPM (at 3 V). Pellets and oil were mixed for one minute at this velocity, before the axle was stopped (more on this in the following discussion section).
5. The lid was put in place and the vacuum pump was started.
6. After achieving the minimum pressure inside the machine, the vacuum coating process was run for one minute.
7. The air was slowly let into the machine, over the course of a minute. This corresponded to about 0,1 bar per 10 seconds.
8. All the pellets were extracted from the machine and weighed.

### 4.3.2 Results for Vacuum Coating Test

The result from the vacuum coating test is shown in Figure 4.13. The test was executed three times, and each test respectively labeled T1, T2 and T3. The bars shows percent ratio of oil in the pellets after vacuum coating. The raw data for this test can be found in Appendix 1C.

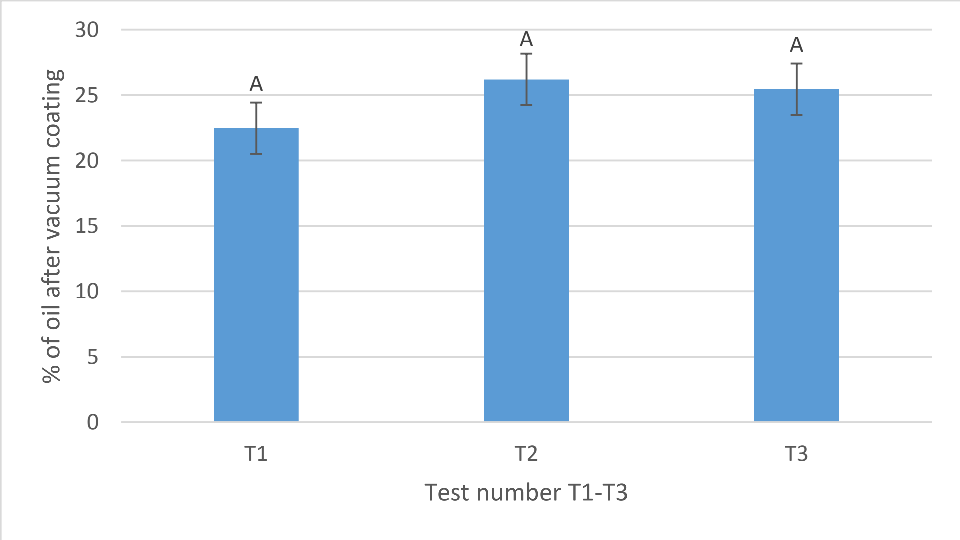



*Figure 4.13: Shows the ratio of oil in percent after vacuum coating. Standard deviations are shown at the top of each bar. Letters above each chart marks which of the tests who are statistical similar, were the same letter indicates similarity (P < 0,05), according to the ANOVA test.*

### 4.3.3 Discussion for Vacuum Coating Test

As Figure 4.13 shows, there were some variation in the results from test to test. Flaws regarding both the prototype and the method used for measuring can explain this. As the prototype is made of plastic, it was not possible to seal it sufficiently enough to achieve the goal of a low pressure equal to 0,2 bar. Furthermore, perfect vacuum coating relies on the pressure to equalize slowly with a steady pace when released (Li, Li, Liu, Ruan, & Mao, 2003). This requires a discharge valve. With this part missing, the pressure was released more or less manually by opening gaps as slowly as possible. The manual procedure was not sufficient for a perfect vacuum coating process to be conducted. When the pressure is released to fast, the oil which have been absorbed during the vacuum period seeps out again.

The method of measuring the weight of the pellets before and after coating would be a good way to examine the effect, had it not been for the fact that the oil sticks to the outside of the pellets. This resulted in a large amount of the pellets being more top coated than vacuum coated, see Figure 4.14. However, this doesn't show in the results section as the weight of each pellet still increases when top coated in oil, and indicates a better result than it actually was.

*Figure 4.14: From left to right: dry pellets, vacuum coated pellets, and top coated pellets.*

Figure 4.13 shows that between 70 % and 90 % of the oil that was added before the vacuum coating still was in contact with the pellets after coating, either as a result of vacuum coating or top coating. The rest of the oil was either stuck to the wall, or just wasn't absorbed by the pellets due to a faulty vacuum coating procedure.

The reason the axle was stopped before starting the vacuum pump was due to the pellets creating a jam between the paddles and the inlet. This is described in detail in section 5.1.

### 4.3.4 Conclusion for Vacuum Coating Test

As this test had a lot of uncertainties related to it, it is not possible to draw any hard conclusions. The two recent tests have shown promise both for mixing solids and fluids, so it should be possible to achieve vacuum coating. However, material and method must be changed to achieve a result that is statistically correct.

# 5 Recommendations for Future Prototypes

This chapter has been provided as guidance for further work on the prototype developed in this thesis. Through the tests conducted on the machine, some areas of improvement have been identified. These are elaborated in the following sections.

## 5.1 Shape of Inlet

### 5.1.1 Issue with Inlet

A challenge with the shape of the inlet was found when testing the mixing properties. Large, hard particles had a tendency to jam the main axle if they got stuck between the inner edge of the inlet and the center paddles. The red circle in Figure 5.1 marks the area in question.

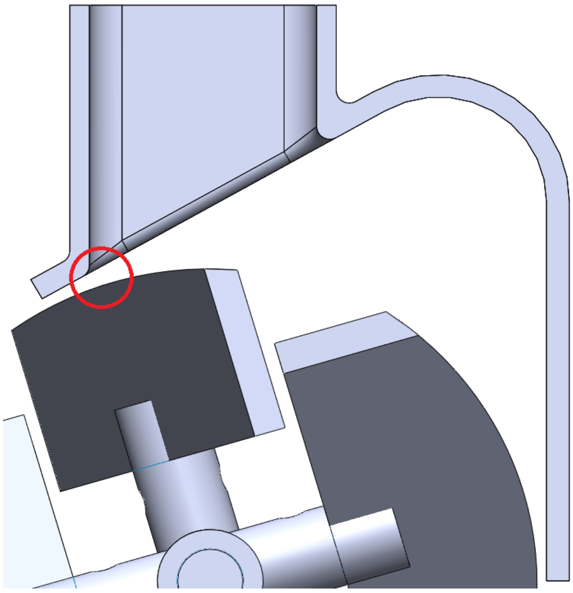


*Figure 5.1: The red circle marks the spot where particles can be caught between the leading edge of the middle paddle and the edge of the inlet.*

The very same edge also disrupted the flow out of the pin mill, and made the stream out of the pin mill less than perfect. Figure 5.2 is showing the inlet viewed from directly above. The pin mill is located over the picture, sending powder downwards when viewed from this angle. As can be seen, the upper part of the stream is hitting the wall on the opposite side of the pin mill. Moments later, the bunched up powder falls into the machine.

*Figure 5.2: Suspended flour particle stream traveling out of the pin mill located above the picture hitting the opposite wall.*

The test described in section 4.2 uncovered another problem with the inlet. Mixing fluid with a fine powder created agglomerations along the inner wall of the inlet in close proximity to the nozzle. Figure 4.12 illustrating how the mix of flour and water is sticking to the wall can be found in section 4.2.3. The nozzle that were used, which has a circular spraying pattern, compounds this issue.

### 5.1.2 Recommendation for Inlet

Increasing the opening of the inlet could be a possible solution to all of these issues. Lengthening the distance between the pin mill and the opposite wall would stop the disruption of the stream. In addition, moving the wall further away from the pin mill could potentially decrease the likelihood of particles getting stuck between the paddles and the edge.

Regarding the nozzle, a wider opening for the inlet would mean that it could be located further away from the wall on both sides, thus preventing the nozzle from spraying directly onto the walls. This issue could also be resolved by using a nozzle with a more linear spraying pattern, so that it would spray in parallel to the length of the inlet.

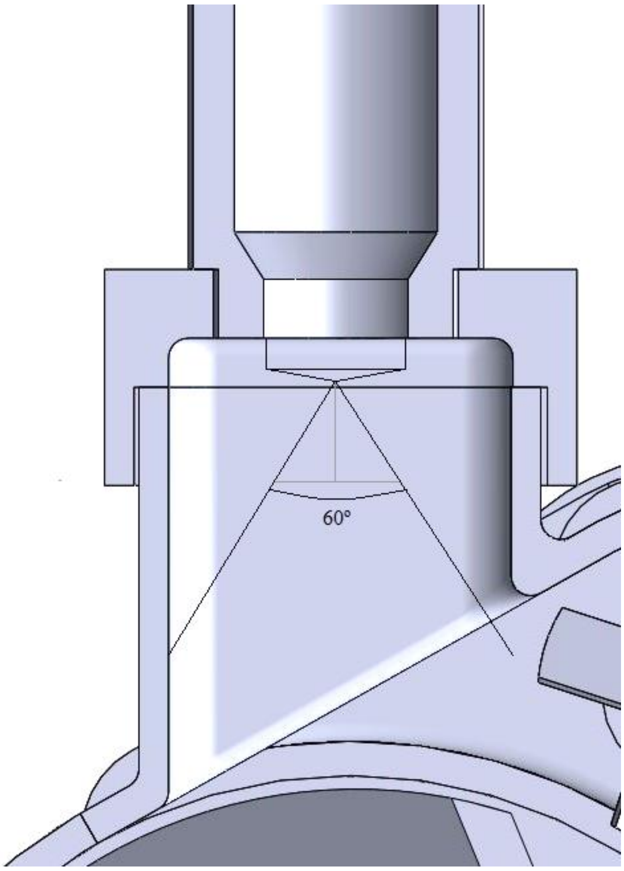



*Figure 5.3: Illustrating the angle of the spray from the nozzle. Some drops will still hit the wall above the lines and contribute to agglomeration.*

## 5.2 Sharp Angles

### 5.2.1 Issue with Sharp Angles

When mixing fine powder, such as flour, there is the risk of the miniscule particles sticking to and agglomerating at any sharp edges inside the machine. Such sharp angles can be found on some of the parts that were designed early on, namely the paddles. The edge where the blade of the paddle meets the part that connects to the paddle attachment is one such area, shown in Figure 5.4.

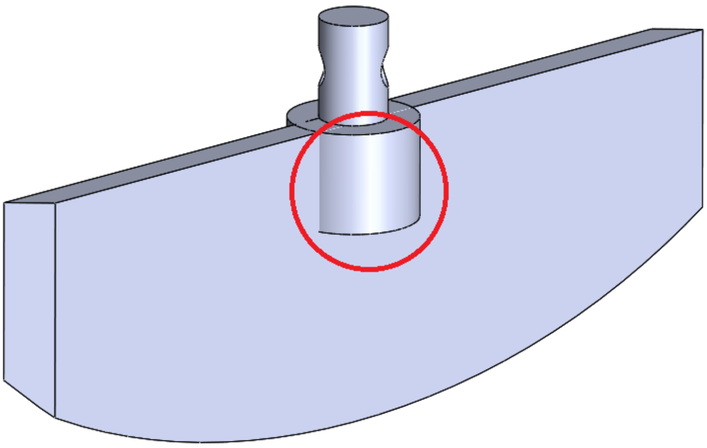


*Figure 5.4: Area of paddle where small particles can get stuck in sharp angles.*

Sharp edges can also be found where the paddle attachment meets the main axle. On this prototype level, these parts were designed to be easily exchangeable to test different solutions. The paddle attachment had to be rugged enough to withstand the forces at play, and this meant that the cylindrical part that goes around the axle had to be fairly thick. This created a 90° angle between the axle and paddle attachment, which is shown in Figure 5.5. The same problem also applies to the pins in the pin mill, which are attached the same way.

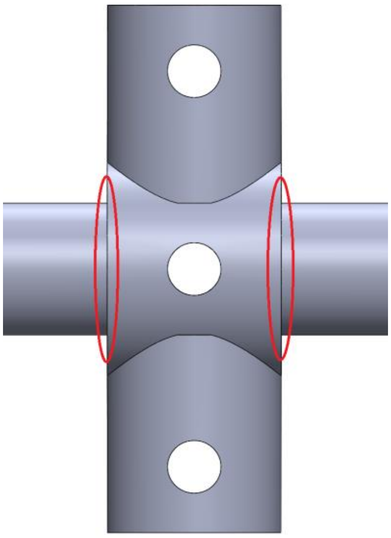


*Figure 5.5: Red ellipsis marks the sharp angle between main axle and the paddle attachment point.*

### 5.2.2 Recommendation for Sharp Angles

A redesign of these parts could focus on smoothening these sharp angles, thus fixing the problem.

## 5.3 Nuts and Bolts

### 5.3.1 Issue with Nuts and Bolts

Because of the modular nature of the paddles, a quick and easy way to attach and detach them was needed. By utilizing nuts and bolt, this goal was achieved but also created the unfortunate side effect of more sharp angles where fine particles can get stuck.

### 5.3.2 Recommendation for Nuts and Bolts

Either making the paddles permanently attached to the axle, or coming up with a more integrated solution for attaching/detaching the paddles could be possible solutions.

## 5.4 Fastening of Lids and Sealing

### 5.4.1 Issue with Lids and Sealing

Making a container airtight places strict requirements on the precision of the different interacting components. Using 3D printed parts, with an inherent amount of imprecision, makes complete air tightness difficult to achieve. This is especially true around parts that are made to be removable. The removable axles and the top lid created challenges in this case. A dried layer of elastic glue was used to create a sealing around the contact points between the removable parts and the body of the machine. Other than being prone to wear and tear, the elastic glue did not get a perfectly smooth surface after application, thus increasing the possibility of small leaks.

During vacuum coating, the low pressure alone should, in principle, be sufficient to pull the lids in and create a tight sealing. After inducing low pressure, this feature seemed to work. However, the machine is lacking some means of holding the lids in place when not using the vacuum pump. A simple, but far from ideal, solution was to use tape around the creases to hold the lids in place.

### 5.4.2 Recommendation for Lids and Sealing

Further development of the machine could use some custom gaskets around each lid to create a better sealing. The development of some sort of clamping system was envisioned as a more permanent solution to holding the lids in place.

## 5.5 Air Vent

### 5.5.1 Issue with Air Vent

When utilizing the nozzle to spray liquid into the machine, one has to take into consideration that the nozzle is using air pressure to create the fine particles. This leads to over pressure inside the machine when spraying, and this air has to escape somewhere. A temporary solution was to use the pneumatic fitting for the vacuum pump hose as an opening when spraying, as the vacuum pump is not used during the mixing process. The opening also let some of the powder being mixed to escape together with the air.

An additional issue was discovered during the vacuum coating test. A system to release the air pressure was needed to control the depressurization, so that the vacuum coating process could be conducted.

### 5.5.2 Recommendation for Air Vent

A more advanced vent with a filtration system could be developed to let the air escape without the powder.

To be able to control the flow rate when releasing the lowered pressure, a discharge valve could be attached to the machine, possibly as a secondary function of the air vent.

## 5.6 Motor Housing

### 5.6.1 Issue with Motor Housing

Upon activating the vacuum pump it became clear that a small amount of air was able to travel through the rear of the pin mill motor and into the machine. This was only a problem with the pin mill motor, as it has an open back design. The air hindered the machine in achieving the required internal pressure. A temporary solution was to cover the motor in plastic foil.

### 5.6.2 Recommendation for Motor Housing

A permanent solution would be to create a housing that fully encapsulates the motor. The housing needs to have sealed exits for the wires necessary for operating the motor.

## 5.7 Door

### 5.7.1 Issue with Door

Emptying the machine would be considerably simplified if the machine had a door as part of the cylinder. This theoretical door would when opened let the paddles transport the product inside towards the middle of the machine and out the door.

### 5.7.2 Recommendation for Door

If the door was to be an integrated part of the cylinder, the precision between the interface of the cylinder and the door would have to be very tight. Any gaps or creases along the walls where the paddles are rotating could possibly lead to crushed pellets, and this is in part why the door was scrapped as a feature of this first prototype.

## 5.8 3D-printing

Early on, most of the parts were printed with the "sparse" setting on the 3D printer. This means that instead of making the part solid throughout, the 3D printer will create the outer surfaces of the part and fill the inside with a lattice of plastic strings. In turn, the sparse parts does not have the same strength as solid parts, which led to some parts failing when put under load. It was also observed that lids created with sparse material are not airtight. Although 3D-printing is a great method for evaluation different concepts, the plastic parts have limited durability when put under mechanical load. The paddles and the paddle attachments were the parts under the most stress and should ideally have been made in metal.

# 6 Evaluation of Economics and Markets

This chapter provides an estimation of the costs for both the plastic prototype, and if it were to be made in metal. It also provides an evaluation of the market, with emphasis on competition and customers.

## 6.1 Economics

This section present the cost of building the prototype and the cost if were to be built using steel parts. It also provides an economics of scale for comparison against other players on the market.

### 6.1.1 Cost of Prototype

A spreadsheet with all costs connected to build the prototype is found in Table 6. The components that aren't listed with a price has been borrowed or donated by the university, and is not possible to acquire a price on. The spreadsheet is mostly meant as guidance for further development of the prototype, and does not take into account the time spent on designing, developing and assembly.

*Table 6: Cost of prototype.*

| Item | No. of units | Cost per unit (incl. taxes) | Cost per item |
|---|---|---|---|
| **Motors** | | | |
| DC Geared Motor, 12V, 13.9 W | 1 | NOK 2 018 | NOK 2 018 |
| DC Geared Motor, 12V, 41,3 W | 1 | NOK 512 | NOK 512 |
| **Assembly components** | | | |
| Bearings (main axle) | 2 | NOK 82 | NOK 164 |
| Bearings (pin mill) | 2 | NOK 76 | NOK 152 |
| Screw, M4 | 15 | NOK 1 | NOK 17 |
| Nut, M4 | 15 | NOK 1 | NOK 8 |
| Primer, Loctite 7063, 150 ml | 1 | NOK 159 | NOK 159 |
| Glue, Loctite 3090, 10 g | 1 | NOK 244 | NOK 244 |
| Glue, Loctite 3430, 24 ml | 1 | NOK 119 | NOK 119 |
| **Others** | | | |
| Manometer | 1 | NOK 626 | NOK 626 |
| Varnish, spray | 1 | NOK 128 | NOK 128 |
| **3D printing** | | | |
| Material, Mojo | 1207 g | NOK 1 207 | NOK 1 207 |
| Printer plate | 10 | NOK 20 | NOK 200 |
| **Total cost** | | | NOK 5 554 |

### 6.1.2 Cost of Prototype Built in Metal

To make it possible to compare the machine against other competing products on the market, the cost of building it using metal parts is calculated. Some of the parts are the same as in the plastic prototype, and some are scaled up to match the increased weight of components, e.g. both motors. The largest differences are the parts that have been 3D-printed, which would be machined in a computer numerical control (CNC) machine. The cost of producing these parts are based on assumptions which are made in cooperation with Bjørn Brenna, the technical manager at NMBUs workshop. Costs of labor are taking into consideration the man-hours spent on design, production and assembly. Further details regarding the costs of these parts can be found in Appendix 2.

*Table 7: Cost of metal prototype.*

| Item | No. of units | Cost per unit (inlcuding taxes) | Cost per item |
|---|---|---|---|
| **Motors** | | | |
| DC Geared Motor, 12V, 13.9 W (main axle) | 1 | NOK 5 000 | NOK 5 000 |
| DC Geared Motor, 12V, 41,3 W (pin mill) | 1 | NOK 2 000 | NOK 2 000 |
| **Assembly components** | | | |
| Bearings (main axle) | 2 | NOK 82 | NOK 164 |
| Bearings (pin mill) | 2 | NOK 76 | NOK 152 |
| Screw, M4 | 15 | NOK 1 | NOK 17 |
| Nut, M4 | 15 | NOK 1 | NOK 8 |
| **Others** | | | |
| Manometer | 1 | NOK 626 | NOK 626 |
| **Metal components** | | | |
| Cost of material | 15,64 kg | NOK 160 | NOK 3 460 |
| Cost of machining | 2280 | NOK 20 | NOK 45 600 |
| **Labor** | | | |
| Man-hours | 480 | NOK 500 | NOK 240 000 |
| **Total cost** | | | NOK 297 026 |

As can be seen in Table 7, a substantial part of the total cost stems from the man-hours used on designing and building the prototype. To estimate the cost of the machine if it were to be put into serial production, the cost of development would be allocated on a per unit basis. This is a rough estimation of the decreasing costs with increased units. Serial production would also be able to reduce the cost of machining, as the setup cost of the CNC machining is reduced when producing the same component. Other economies of scale, like better operating efficiency and bulk buying of materials, would further help reduce the costs (Economies of scale, Investopedia, 2015), as would production in lower cost countries.

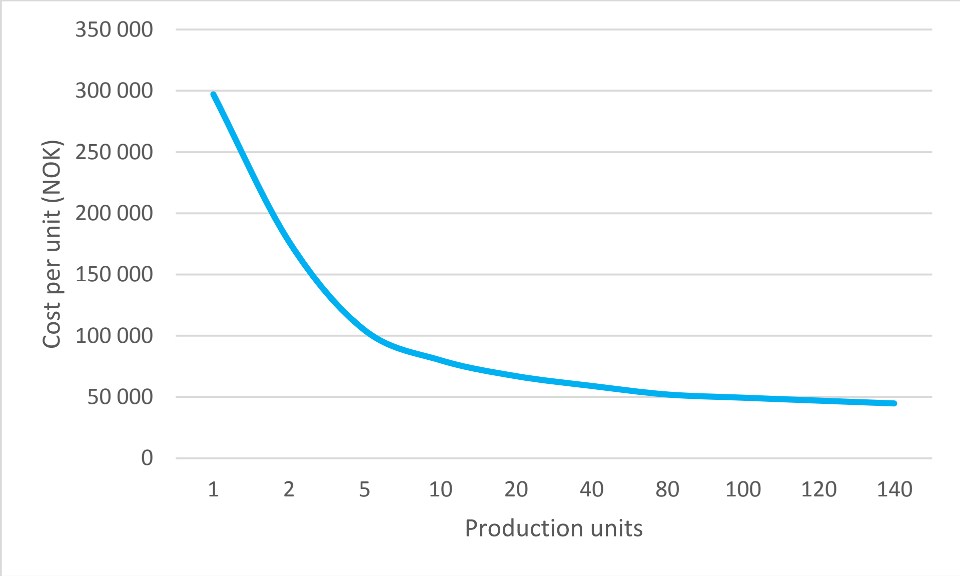



*Figure 6.1: Economies of scale, showing the decreasing cost with increasing units.*

These estimations are shown in Figure 6.1, where the unit cost decreases and stabilizes around NOK 50.000 with production units over 80. This number was used when comparing the machine to the competition.

## 6.2 Market situation

The purpose of this section is to give a brief overview of what kind of competition one can expect, and the status of a possible customer base. As both subjects are equally extensive and important, a more detailed analysis is required before an actual launch of the product. However, these chapters should be able to create a foundation for further analysis at a later stage of development.

### 6.2.1 Competition

Mixing can be found as part of the production process in many different industries, where a number of companies produce mixers catering to the specific needs of a given industry. As the majority of the existing mixers operate on an industrial scale, they are made for mixing large volumes. This is especially true in the feed industry, where large quantities of ingredients are processed at a time. Large-scale mixers are often customized to suit the specifications of the buyer; essentially making them build to order. As a consequence, some of the producers are reluctant to give a quote for the price unless you are a serious buyer.

Vacuum coating is a process somewhat specific to the feed, food and pharmaceutical industry. Similarly to mixing, the vacuum coaters delivered to production companies are made to operate on a large scale.

Direct comparison to a lab-sized machine is somewhat difficult, as few mixers or vacuum coaters exist in the same size category. Some of the ones that do are often highly complicated machines. One such category is machines manufactured to the precise requirements of the pharmaceutical industry. The precision of these machines put them in a price bracket way above the machine developed in this thesis, which has been constructed with simplicity and low cost in mind.

Forberg International AS, a part of the Skala Group (About us: The Skala Group, 2015), is one company providing mixing and vacuum coating solutions to the food industry. Their product portfolio contains mixers and vacuum coaters ranging from about 2 liters up to 8000 liters for mixing and 5000 liters for vacuum coating. (Brochures, Forberg International, 2015). However, the products in sizes below 200 liters are not part of the standard delivery program. Smaller machines are often built to order, increasing the cost because of the low production volume.

A relevant comparison would be that of a smaller mixer or vacuum coater. The quoted price of a 6-liter mixer from Forberg International is NOK 160.000. (Miladinovic, 2015). Comparing that price to the estimated cost of a serial produced machine built in stainless steel (NOK 50.000) gives a price delta of about NOK 110.000. Taking further refinement of the prototype into consideration, there is the potential of a significantly lower price for the machine. Another producer, Dinnissen from the Netherlands, is one of the larger players with years of experience within the feed industry (Dinnissen, 2015). Their price for a Pegasus® vacuum lab mixer which takes up to 10 liters in volume with or without vacuum is about NOK 165.400 (EUR 19.860) (Michels, 2015). This gives a price delta of about NOK 115.400.

Other players in the market include Wynveen, Anritz and Diosna. Most of these companies produce a lab sized vacuum coater. Diosna is offering one such small volume pharmaceutical mixer for mixing, granulation and vacuum drying, the P1-6 Laboratory Mixer. The Diosna mixer can’t be compared feature for feature, but its application as a mixer for pellet ingredients makes the comparison valid. The machine is highly advanced, something that is reflected in the price of about NOK 500.000. In other words, a lot more than the machine evaluated in this thesis.

### 6.2.2 SWOT Analysis

A SWOT analysis is helpful when evaluating a business, a strategy plan or in this case a product. SWOT is an acronym that stands for *Strengths*, *Weaknesses*, *Opportunities* and *Threats*. It consists of both an internal analysis for finding out the products strengths and weaknesses, and an external analysis that evaluates the products opportunities and threats (Fine, 2009).

A SWOT analysis for the product can be seen in Table 8. It has been performed to identify possible outcomes if the product is to ever hit the market of mixers and vacuum coaters. It clarifies what further developers on the product should be aware of, when it comes to both internal threats connected to research and development and external threats connected to the market. A further explanation for each headline can be found below.

*Table 8: SWOT analysis*

| **Strengths** | **Weaknesses** |
|---|---|
| - Combines two important functions within the pet-food and feed making process: mixing and vacuum coating.<br>- Provides a low-cost option in a relatively expensive industry.<br>- Non-complicated, considering the usability and maintenance. | - Designers' lack of experience in the pet-food industry.<br>- No customer base.<br>- Limited timeframe on R&D. |
| **Opportunities** | **Threats** |
| - Further development into a full-scale machine.<br>- Possibility to add other functions to make it suitable for more applications. | - Other, more experienced, competitors in the same market.<br>- Financial backing. |

**Strengths**

The main focus in this part is on the three features that is considered most important regarding the product: dual functionality of both mixing and coating, simplified design and usability. The strength regarding dual functionality is almost self-explanatory, as it combines two parts of process technology into one machine. In industries were saving time and space are important factors this could be an advantage. The simplified design is also an important attribute, as many of the machines on the market today are considered somewhat overcomplicated and expensive. The product described in this thesis is designed to reduce material and assembly costs, in addition to being simple in operation.

**Weaknesses**

The weaknesses of the product are linked to the developers' lack of experience, and their limited period of time to do the necessary background analysis for a perfect result. The lack of experience have somewhat been compensated with regular meetings with the principals, which have years of experience within the process technology and feed technology. However, as most parts are designed without supervision, it can be argued that the lack of experience can lead to flaws with some parts that would have been obvious to experienced designers. Regarding time usage, as this is a first prototype, one can say that a perfect result is neither required nor expected. Product development takes time, and this thesis merely lays out the groundwork for the final product.

**Opportunities**

The opportunities of the product are basically possibilities with further development and are also connected with the development of the market of mixers and coaters. Here, the possibility of adding more functions to the machine means that at this development stage it is possible to change the products design so it can be adapted to other purposes. Development of a machine with the same basic design, only larger volume, is also a possibility depending on what the market requires.

**Threats**

The main point of this headline is to emphasize that there are other large companies that produces mixer and coaters, while the product described in this thesis lacks the financial backing of other development projects in the business.

### 6.2.3 Porter's Five Forces

Porter's five forces is a framework used to analyze the competitive forces of an industry (Hill & Jones, 2009). The model is based upon five forces shaping the competitive landscape: (1) threat of new entrants, (2) competitive rivalry, (3) bargaining power of buyers, (4) bargaining power of suppliers, and (5) threat of substitute products. These forces are illustrated in Figure 6.2.

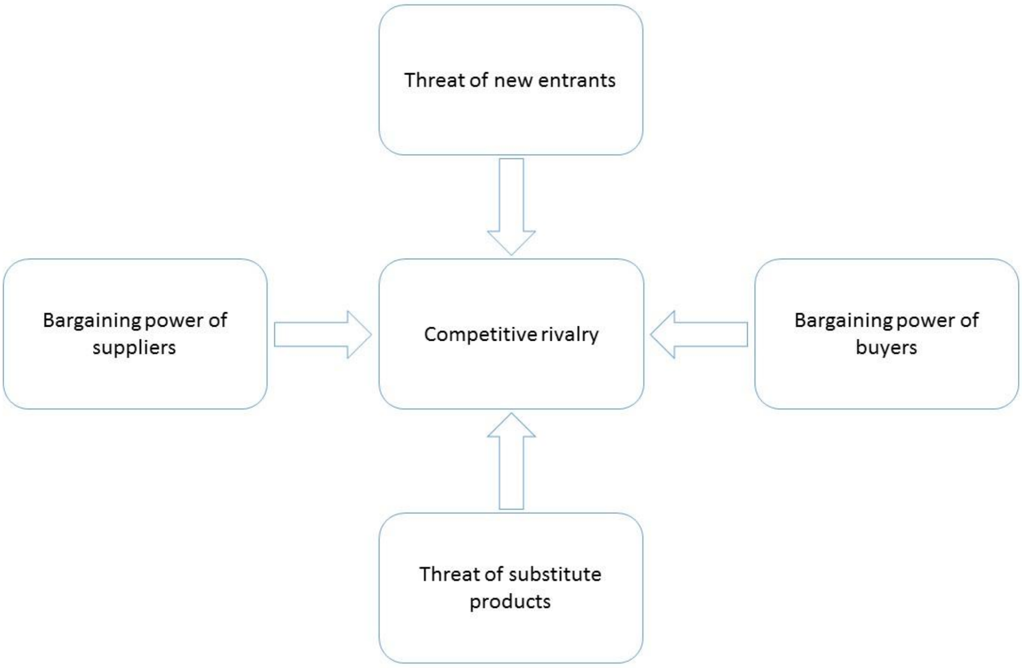



*Figure 6.2: Illustration of Porter's Five Forces*

**Threat of new entrants**

The threat of new entrants builds mostly on few main factors: the price connected to starting up the business, how well developed the market is today and what kind of technology that is required, and how easy it is to enter the market with regards to brands and differentiation. The market of coaters and mixers are a bit different from each other. The market for coaters consists of a few big players, while the market for mixers is larger and consists of both big and small players. As both require high technology, and the startup price for a new business is relatively large, the risk connected with starting up a new business is considered quite big. In addition, as many of the players are well established and recognized as trustworthy brands, the threat of new entrants are considered to be relatively small. However, some of the offerings in the market are quite expensive, which means that a low cost solution could be able to disrupt the market of the higher end products, as long as the required features are in place.

**Competitive rivalry**

As mentioned above, the market for mixers and coaters already consist of many well-established players, and entering the market with a new product could prove difficult.

From a customer's point of view, the costs connected with switching supplier can be relatively large, as the machines are different from producer to producers. This strengthens the theory of new entrants having trouble to conquer market shares, as customers tends to stick with their supplier if they don't have a substantial reason to change.

**Bargaining power of buyers**

The bargaining power of buyers relies mostly on two factors: the price sensitivity and the relative bargaining power. The price sensitivity addresses the possibility that the customers want to negotiate the price, and the relative bargaining power if they will succeed in reducing the price (Healy & Palepu, 2012).

As there are no known substitutes for coaters or mixers, the price sensitivity will have little impact on customers as they will still need the products if the price goes up evenly amongst the suppliers. It is nonetheless possible that some companies might try to differentiate their product with some special applications to defend an increase in price. The buyer will however have the possibility to decide which product is most suitable for their needs.

The relative bargaining power relies on the number of buyers compared to number of suppliers, alternative products and exchange cost. Since the market of mixers is a vast market, which includes more than just the feed industry, there are many suppliers relative to buyers. This strengthens the buyer's position. Still, in some cases a buyer will need a special kind of equipment only available from a few suppliers. In those cases the customer will have low bargaining power. The exchange costs, which represent the cost of switching supplier, can be large if the company has designed other processes to work in unison with a certain company's machines. This also weakens the buyers bargaining power.

With the large number of suppliers within the market for mixers, the buyer has relatively large bargaining power unless they are in the need of some special type of mixer, which is not one of the typical mixers sold.

**Bargaining power of suppliers**

Vacuum coaters and mixer are, in addition to the parts made by the company itself, comprised of fairly standard parts as electrical motors, pumps and hydraulic solutions. Suppliers of the mentioned standard parts are fairly common, as there are a lot of other industries that uses the same components in their production. The bargaining power goes down as the market consists of more suppliers than buyers. With standard parts one can also say that the exchange cost, the cost related to switching supplier, are lower than if the parts had to be bought as a special order. The conclusion is that the bargaining power of suppliers is fairly low, as there are many suppliers in the market and the exchange cost are considered to be low.

**Threat of substitute products**

Further research into the dietary needs of feed eating animals could possibly reveal that pellets are not the optimal solution. This could have severe implications for the producers of vacuum coaters, as the main application is the coating of pellets. The same could happen if other ways of adding fatty content to the pellets were to be discovered. These deliberations are highly hypothetical, and not very likely in the near future. Mixers are not as dependent on one particular industry, and are not in the same danger of disruption. The conclusion is that the threat of substitute products is considered to be low.

### 6.2.4 Customers

There are a great number of usage areas for coaters and especially mixers in general. As this thesis is made in cooperation with FôrTek, which main focus is on the pet food and fish feed industry, the most obvious potential customer for the machine is a producer of pet food and fish feed. In addition, it is most likely customers within those industries that will have best use of the dual functionality with both coating and mixing. With Norway as one of the biggest export countries of salmon, numerous producers of fish feed that use both coaters and mixers in their industry can be found on a national level. Biomar, Skretting and Ewos, all Norwegian companies that uses coaters and mixers on a daily basis, can be mentioned as some of the potential customers within fish feed. Within the pet food industry, one should probably look at the larger companies abroad, such as Mars Petcare Inc., Nestlè Petcare and many more.

In addition to these markets, one can find a large number of producers within other areas, such as food producers and producers within the medical and health treatment industry. Both industries are often dependent on special and accurate mixing equipment that can handle exact portions of one or more substances. As the machine is currently meant as a laboratory product, it might suit such producers and research facilities that could make use of a smaller mixer and coater for testing purposes.

# 7 Discussion

The first part of the MSc. thesis contains the development and design sections. Here, different designs were evaluated and calculations were made to ensure that the printed parts would be sufficiently dimensioned for the testing part. Together with the principals, a design based on Mr. Nikqi's idea for a machine was developed, with a main axle consisting of a set of pedals and a separate pin mill axle. As the printer equipment limited the size in some cases, some parts had to be redesigned to fit and depended on some creative solutions. Several meetings with the principals both from NMBU and FôrTek were held to discuss the design, and to optimize each part for testing. It was also decided which parts that should be bought or made in stainless steel to ensure that the prototype would hold. Buying the right components with the right dimensions was important, as they had to fit the specifications for the design but also not be too costly. The motors especially required the assessment of various types. The rotating speed and torque needed was calculated on assumptions, and since DC-motors are expensive it was not an alternative to outsize the specifications due to budget limitations. Two motors whose speed and torque met the calculated criteria was obtained, whilst not being too expensive.

Looking back at the 3D-printed parts, it is discussable whether plastic is a good option for making solutions that should withstand low pressure and repeated stress cycles. Especially when it comes to parts that were printed sparse (for further reference, see section 5.8), as they rely on additional processing, like varnish or paint, to fill small air gaps. They also show less strength and deform more quickly under pressurized conditions.

The second part of the thesis entailed 3D-printing and assembly of the prototype. Here, it was experienced that the accuracy of the 3D printer was a bit off on some of the smaller parts, which led to some manual processing after printing. However, the rapid prototyping proved to be a great method for evaluating ideas and designs. As the parts were printed they were assembled together either with glue or screws, and mounted together with the other bought or machined components. Help from NMBUs workshop crew simplified the assembly process.

After the prototype was assembled, it was transported to a testing facility. Three tests were executed. These are elaborated in chapter 0. Dejan Miladionvic, the principal from FôrTek, provided us with samples for testing and information about how the tests usually were executed in the feed and food industry. As discussed in their respective sections, the tests showed good promise for mixing. However, the results were somewhat inconclusive for vacuum coating. The testing did however uncover some important areas of improvement, which is essential for further development into a perfectly functional machine.

In the part regarding economics and market analysis, some assumptions were made regarding the analyses as obtaining enough information on the market was challenging. The economic estimation of the prototype, if built in metal, showed that the product evaluated in this thesis would most likely be cheaper than other similar products in the market. As few of the existing producers would give a quote for their product, the potential cost had to be compared to a few known prices. However, the principals agreed with the theory that other laboratory sized machines were in the same price range of those that were known. The brief evaluation of markets was also showing promise in both the competition and customer section. The competition is recognized to be a few big players. As many of them are producing complicated and expensive machines, there is potential for a low-priced, simplified solution, as the product developed in this thesis, to enter the market. Regarding customers, many different industries could make use of a relatively inexpensive way to perform vacuum coating and mixing processes on different materials. As mentioned, there are numerous different possible market areas, which should be further investigated at a later stage of development.

In chapter 5, features that were either missing or didn’t work are discussed. These features were discovered during the testing part, and since this thesis has a limited timeframe, there were restriction on how late new designs could be created and tested. Some of the improvements are fairly simple to make, as they only need minor adjustments. Other imperfections however, might warrant a more extensive study as they may affect other areas of the prototype.

# 8 Conclusion

The main objective of this thesis was to design and construct a new type of equipment to be used as a mixer and a vacuum coater. With a basis in Ismet Nikqi's ideas, a laboratory-sized prototype was designed, built, and evaluated regarding performance and economics.

Performance-wise, the machine satisfied the requirements in two of the three tests, and showed potential as a future product. When mixing differently sized particles, the six paddles worked as planned and distributed the particles evenly throughout the machine. The addition of a small amount of water into the mix was dispersed evenly, although some factors of the design affected the efficiency of the machine. The tests also uncovered areas where further development of the prototype is needed to achieve optimal functionality, especially regarding the vacuum coating procedure.

The economic evaluation uncovered some of the potential for the machine in the marketplace. As more development and refinements are needed to finalize the product, the complete picture will be more relevant to obtain at later stages.

# 9 References


*About us: The Skala Group*. (2015, April 28th). Retrieved from Skala web page: http://www.skala.no/process_eng/About-us/The-Skala-group

Andritz. (n.d.). http://www.andritz.com/index/gr-about-us.htm.

Batchcrete. (2015). *http://www.batchcrete.net.au*. Retrieved from http://www.batchcrete.net.au/productlisting/cement-mixers-for-sale-and-hire/cement-drum-mixer/

Bright Hub Eningeering. (2015). Retrieved from http://www.brighthubengineering.com/manufacturing-technology/57380-twin-shaft-paddle-mixer/

*Brochures, Forberg International*. (2015, April 30). Retrieved from Forberg International: http://www.forberg-international.com/brochures/cms/21

Dinnissen. (2015). *http://www.dinnissen.nl*. Retrieved from http://www.dinnissen.nl/about-us/s/3081

*Economies of scale, Investopedia*. (2015, May 6). Retrieved from Investopedia: http://www.investopedia.com/terms/e/economiesofscale.asp

Erhard, G. (2006). *Designing with Plastics.* Carl Hanser Verlag GmbH & CO. KG.

Fairchild, F. (2013, 9 12). Choosing a batch mixer.

Fine, L. G. (2009). The SWOT Analysis: Using your Strenght to over come Weaknesses, Using opportunities to overcome Threats. Kick It, LLC.

Healy, P. M., & Palepu, K. G. (2012). Business Analysis Valuation: Using Financial Statements 5th Edition. Cengage.

Hill, C., & Jones, G. (2009). Strategic Management Theory: An Integrated Approach. Cengage Learning.

Li, Y., Li, J., Liu, Z., Ruan, R., & Mao, Z. (2003, March). Vacuum coating of heat-sensitive liquid ingredients onto feed pellets. *Transactions of the American Society of Agricultural Engineers*, pp. 383-387.

Løvås, G. G. (2010). *Statistikk for universiteter og høgskoler.* Universitetsforlaget.

Michels, R. (2015, May 7). E-mail.

Miladinovic, D. D. (2015, April 30).

*Mixing (process engineering), Wikipedia*. (2015, May 5). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Mixing_%28process_engineering%29

nationalvetcontent.edu.au. (2015). Retrieved from https://goo.gl/LNLBur

Patrick, S. (2005). *Practical Guide to Polyvinyl Chloride.* Creve: Rapra Technology Limited.

PEW. (2015). Retrieved from http://www.pewindia.net/ribbon-blender-mixer-676586.html

Prism Pharma Machinery. (2015). *www.liquidsyrupmanufacturingplant.com*. Retrieved from http://www.liquidsyrupmanufacturingplant.com/agitator-stirrer.html

RS-online. (2015). *rs-online.com*. Retrieved from Main Axle motor: http://no.rs-online.com/web/p/dc-geared-motors/3989710/

Sinnot, R. K. (2005). *Chemical Engineering Design, Volume 6.* Oxford: Coulson & Richardson's .

StaMixCo. (2015). *www.stamixco-usa.com*. Retrieved from http://www.stamixco-usa.com/principles-of-operation

Stratasys. (2015). *stratasys.com.* Retrieved 2 6, 2015, from http://goo.gl/9MZe4y

Stratasys. (2015). *stratasys.com.* Retrieved 2 6, 2015, from http://goo.gl/T4Z6bu

Terjesen, G. (2014). Spenningsanalyse og trykkbeholdere. Norge.

Young, G., Forte, D., & van Doore, F. (2007). *Food & Feed Extrusion Technology*.

# Appendix 1A – Mixing test data

| | Input 1 | | | Input 2 | | | Input 3 | | | Input 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | d (mm) | m (g) | % | d (mm) | m (g) | % | d (mm) | m (g) | % | d (mm) | m (g) | % | Total m (g) |
| 1 | 1,6 - 2,5 | 32,12 | 19,35 % | 0 - 0,5 | 133,88 | 80,65 % | - | 0 | 0,00 % | - | 0,00 | 0,00 % | 165,99 |
| 2 | 1,6 - 2,5 | 32,72 | 19,17 % | 0 - 0,5 | 137,96 | 80,83 % | - | 0 | 0,00 % | - | 0,00 | 0,00 % | 170,69 |
| 3 | 1,6 - 2,5 | 32,33 | 20,11 % | 0 - 0,5 | 128,39 | 79,89 % | - | 0 | 0,00 % | - | 0,00 | 0,00 % | 160,71 |
| 4 | 1,6 - 2,5 | 32,20 | 20,03 % | 0 - 0,5 | 128,58 | 79,97 % | - | 0 | 0,00 % | - | 0,00 | 0,00 % | 160,78 |
| 5 | 1,6 - 2,5 | 32,11 | 22,35 % | 0 - 0,5 | 50,78 | 35,35 % | 0,6 - 1,0 | 60,76 | 42,30 % | - | 0,00 | 0,00 % | 143,65 |
| 6 | 1,6 - 2,5 | 31,70 | 27,99 % | 0 - 0,5 | 35,43 | 31,28 % | 0,6 - 1,0 | 46,13 | 40,73 % | - | 0,00 | 0,00 % | 113,26 |
| 7 | 1,6 - 2,5 | 29,99 | 21,37 % | 0 - 0,5 | 55,33 | 39,43 % | 0,6 - 1,0 | 55,02 | 39,20 % | - | 0,00 | 0,00 % | 140,34 |
| 8 | 1,6 - 2,5 | 30,64 | 20,32 % | 0 - 0,5 | 60,06 | 39,82 % | 0,6 - 1,0 | 60,11 | 39,86 % | - | 0,00 | 0,00 % | 150,81 |
| 9 | 1,6 - 2,5 | 30,75 | 20,02 % | 0 - 0,5 | 42,30 | 27,54 % | 0,6 - 1,0 | 40,06 | 26,08 % | > 2 | 40,50 | 26,37 % | 153,61 |
| 10 | 1,6 - 2,5 | 27,28 | 19,64 % | 0 - 0,5 | 35,66 | 25,67 % | 0,6 - 1,0 | 35,79 | 25,76 % | > 2 | 40,19 | 28,93 % | 138,92 |
| 11 | 1,6 - 2,5 | 26,57 | 19,31 % | 0 - 0,5 | 40,74 | 29,61 % | 0,6 - 1,0 | 40,08 | 29,13 % | > 2 | 30,19 | 21,94 % | 137,58 |
| 12 | 1,6 - 2,5 | 27,81 | 17,86 % | 0 - 0,5 | 40,37 | 25,93 % | 0,6 - 1,0 | 45,43 | 29,18 % | > 2 | 42,06 | 27,02 % | 155,67 |

| Area 1 | Output 1 | | | Output 2 | | | Output 3 | | | Output 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | m (g) | % | Δ | m (g) | % | Δ | m (g) | % | Δ | m (g) | % | Δ | Sample m (g |
| 1 | 1,19 | 19,91 % | 0,57 % | 4,77 | 80,09 % | -0,57 % | 0 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 5,96 |
| 2 | 1,35 | 21,67 % | 2,50 % | 4,87 | 78,33 % | -2,50 % | 0 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 6,22 |
| 3 | 2,39 | 20,04 % | -0,07 % | 9,55 | 79,96 % | 0,07 % | 0 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 11,94 |
| 4 | 2,42 | 20,53 % | 0,50 % | 9,37 | 79,47 % | -0,50 % | 0 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 11,79 |
| 5 | 2,19 | 23,20 % | 0,85 % | 3,44 | 36,44 % | 1,09 % | 3,81 | 40,36 % | -1,94 % | 0 | 0,00 % | 0,00 % | 9,44 |
| 6 | 3,28 | 29,34 % | 1,35 % | 3,77 | 33,72 % | 2,44 % | 4,13 | 36,94 % | -3,79 % | 0 | 0,00 % | 0,00 % | 11,18 |
| 7 | 2,70 | 22,88 % | 1,51 % | 4,41 | 37,37 % | -2,05 % | 4,69 | 39,75 % | 0,54 % | 0 | 0,00 % | 0,00 % | 11,80 |
| 8 | 2,18 | 17,97 % | -2,34 % | 5,29 | 43,61 % | 3,79 % | 4,66 | 38,42 % | -1,44 % | 0 | 0,00 % | 0,00 % | 12,13 |
| 9 | 1,81 | 15,99 % | -4,03 % | 3,50 | 30,92 % | 3,38 % | 3,24 | 28,62 % | 2,54 % | 2,77 | 24,47 % | -1,90 % | 11,32 |
| 10 | 1,95 | 18,16 % | -1,48 % | 2,70 | 25,14 % | -0,53 % | 2,69 | 25,05 % | -0,72 % | 3,4 | 31,66 % | 2,73 % | 10,74 |
| 11 | 1,60 | 20,30 % | 0,99 % | 2,11 | 26,78 % | -2,84 % | 2,21 | 28,05 % | -1,09 % | 1,96 | 24,87 % | 2,93 % | 7,88 |
| 12 | 1,81 | 18,53 % | 0,66 % | 2,58 | 26,41 % | 0,47 % | 2,9 | 29,68 % | 0,50 % | 2,48 | 25,38 % | -1,63 % | 9,77 |

| Area 2 | Output 1 | | | Output 2 | | | Output 3 | | | Output 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | m (g) | % | Δ | m (g) | % | Δ | m (g) | % | Δ | m (g) | % | Δ | Sample m (g |
| 1 | 1,97 | 22,24 % | 2,89 % | 6,87 | 77,76 % | -2,89 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 8,84 |
| 2 | 1,90 | 19,89 % | 0,72 % | 7,64 | 80,11 % | -0,72 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 9,54 |
| 3 | 2,54 | 21,15 % | 1,04 % | 9,47 | 78,85 % | -1,04 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 12,01 |
| 4 | 2,91 | 20,42 % | 0,39 % | 11,34 | 79,58 % | -0,39 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 14,25 |
| 5 | 2,57 | 23,95 % | 1,60 % | 3,73 | 34,76 % | -0,59 % | 4,43 | 41,29 % | -1,01 % | 0 | 0,00 % | 0,00 % | 10,73 |
| 6 | 3,46 | 28,91 % | 0,92 % | 3,85 | 32,16 % | 0,88 % | 4,66 | 38,93 % | -1,80 % | 0 | 0,00 % | 0,00 % | 11,97 |
| 7 | 2,71 | 22,83 % | 1,46 % | 4,43 | 37,32 % | -2,10 % | 4,73 | 39,85 % | 0,64 % | 0 | 0,00 % | 0,00 % | 11,87 |
| 8 | 2,49 | 24,06 % | 3,74 % | 4,00 | 38,65 % | -1,18 % | 3,86 | 37,29 % | -2,56 % | 0 | 0,00 % | 0,00 % | 10,35 |
| 9 | 2,01 | 17,28 % | -2,74 % | 3,33 | 28,63 % | 1,10 % | 3,18 | 27,34 % | 1,26 % | 3,11 | 26,74 % | 0,38 % | 11,63 |
| 10 | 2,53 | 18,62 % | -1,02 % | 2,95 | 21,71 % | -3,96 % | 3,20 | 23,55 % | -2,22 % | 4,91 | 36,13 % | 7,20 % | 13,59 |
| 11 | 2,08 | 20,74 % | 1,43 % | 2,49 | 24,83 % | -4,79 % | 2,83 | 28,22 % | -0,92 % | 2,63 | 26,22 % | 4,28 % | 10,03 |
| 12 | 2,10 | 16,75 % | -1,12 % | 3,15 | 25,12 % | -0,81 % | 3,56 | 28,39 % | -0,79 % | 3,73 | 29,74 % | 2,73 % | 12,54 |

| Area 3 | Output 1 | | | Output 2 | | | Output 3 | | | Output 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | m (g) | % | Δ | m (g) | % | Δ | m (g) | % | Δ | m (g) | % | Δ | Sample m (g |
| 1 | 1,21 | 20,69 % | 1,35 % | 4,64 | 79,31 % | -1,35 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 5,85 |
| 2 | 1,30 | 19,37 % | 0,20 % | 5,40 | 80,63 % | -0,20 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 6,70 |
| 3 | 2,60 | 20,30 % | 0,18 % | 10,21 | 79,70 % | -0,18 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 12,82 |
| 4 | 2,13 | 21,01 % | 0,98 % | 8,01 | 78,99 % | -0,98 % | 0,00 | 0,00 % | 0,00 % | 0 | 0,00 % | 0,00 % | 10,14 |
| 5 | 2,07 | 21,34 % | -1,01 % | 3,70 | 38,14 % | 2,79 % | 3,93 | 40,52 % | -1,78 % | 0 | 0,00 % | 0,00 % | 9,70 |
| 6 | 2,40 | 25,42 % | -2,56 % | 3,23 | 34,22 % | 2,93 % | 3,81 | 40,36 % | -0,37 % | 0 | 0,00 % | 0,00 % | 9,44 |
| 7 | 2,25 | 20,38 % | -0,99 % | 4,35 | 39,40 % | -0,02 % | 4,44 | 40,22 % | 1,01 % | 0 | 0,00 % | 0,00 % | 11,04 |
| 8 | 2,27 | 19,65 % | -0,66 % | 4,84 | 41,90 % | 2,08 % | 4,44 | 38,44 % | -1,42 % | 0 | 0,00 % | 0,00 % | 11,55 |
| 9 | 2,20 | 18,23 % | -1,79 % | 3,24 | 26,84 % | -0,69 % | 3,05 | 25,27 % | -0,81 % | 3,58 | 29,66 % | 3,29 % | 12,07 |
| 10 | 2,26 | 19,43 % | -0,20 % | 2,83 | 24,33 % | -1,34 % | 3,05 | 26,23 % | 0,46 % | 3,49 | 30,01 % | 1,08 % | 11,63 |
| 11 | 1,55 | 18,17 % | -1,14 % | 2,63 | 30,83 % | 1,22 % | 2,60 | 30,48 % | 1,35 % | 1,75 | 20,52 % | -1,43 % | 8,53 |
| 12 | 1,38 | 17,27 % | -0,59 % | 2,19 | 27,41 % | 1,48 % | 2,34 | 29,29 % | 0,10 % | 2,08 | 26,03 % | -0,99 % | 7,99 |

## Appendix 1B – Fluid Dispersion test data

| Test/Sample number | Moisture content (1% water addition) 1 | 2 | 3 | 4 | 5 | 6 | Average | Std. Dev | Variance |
|---|---|---|---|---|---|---|---|---|---|
| T1 | 1,003 | 0,916 | 0,925 | 0,935 | 0,929 | 0,924 | 0,939 | 0,032 | 0,001 |
| T2 | 0,941 | 0,808 | 0,829 | 0,828 | 0,960 | 0,921 | 0,881 | 0,067 | 0,004 |
| T3 | 0,900 | 0,897 | 0,858 | 0,887 | 0,977 | 1,003 | 0,920 | 0,057 | 0,003 |
| T4 | 0,875 | 0,910 | 0,904 | 0,874 | 0,916 | 0,929 | 0,901 | 0,023 | 0,001 |
| T5 | 0,938 | 0,733 | 1,016 | 0,821 | 0,934 | 0,881 | 0,887 | 0,099 | 0,010 |
| T6 | 0,769 | 0,910 | 1,035 | 0,907 | 0,841 | 0,901 | 0,894 | 0,088 | 0,008 |
| Average | 0,904 | 0,862 | 0,928 | 0,875 | 0,926 | 0,926 | | | |
| Std. Dev | 0,079188407 | 0,075269812 | 0,0831304 | 0,0445038 | 0,047357 | 0,041472 | | | |

| Test/Sample number | Moisture content (5% water addition) 1 | 2 | 3 | 4 | 5 | 6 | Average | Std. Dev | Variance |
|---|---|---|---|---|---|---|---|---|---|
| T1 | 3,583 | 3,715 | 3,418 | 3,891 | 3,478 | 4,454 | 3,757 | 0,382 | 0,146 |
| T2 | 4,319 | 3,658 | 3,861 | 4,136 | 4,608 | 3,904 | 4,081 | 0,345 | 0,119 |
| T3 | 4,315 | 4,029 | 4,047 | 4,287 | 4,895 | 4,116 | 4,282 | 0,324 | 0,105 |
| T4 | 3,879 | 3,581 | 3,851 | 3,716 | 3,783 | 3,912 | 3,787 | 0,123 | 0,015 |
| T5 | 3,823 | 3,937 | 3,821 | 3,935 | 3,763 | 3,738 | 3,836 | 0,084 | 0,007 |
| T6 | 4,012 | 4,851 | 3,725 | 4,154 | 3,813 | 2,307 | 3,810 | 0,838 | 0,702 |
| Average | 3,988 | 3,962 | 3,787 | 4,020 | 4,057 | 3,739 | | | |
| Std. Dev | 0,290255 | 0,46781 | 0,208963 | 0,20944 | 0,55886 | 0,743201 | | | |

## Appendix 1C – Vacuum Coating test data

| | IN | | OUT | | | |
|---|---|---|---|---|---|---|
| | Pellets (g) (70% of tot) | Oil (g) (30% of tot) | Total weight combined (g) | % of in weight | Weight of oil (g) | % fraction of oil |
| T1 | 102,1 | 43,75714286 | 134,89 | 92,48 % | 32,79 | 22,48090108 |
| T2 | 100,33 | 42,99857143 | 137,88 | 96,20 % | 37,55 | 26,1985448 |
| T3 | 100,03 | 42,87 | 136,4 | 95,45 % | 36,37 | 25,45136459 |

# Appendix 2 – Cost of CNC Machining

| Component | No. of items | Setup (min) | Machining (min) | Total time (min) | Cost/min | Cost of Machining (NOK) | Weight (kg) | Cost/kg | Cost of Materials (NOK) | Total Cost (NOK) |
|---|---|---|---|---|---|---|---|---|---|---|
| Side Paddles | 4 | 60 | 30 | 180 | 20 | 3600 | 0,62904 | 160 | 402,59 | 4002,59 |
| Center Paddles | 2 | 60 | 30 | 120 | 20 | 2400 | 1,25496 | 160 | 401,59 | 2801,59 |
| Paddle Attacments | 3 | 30 | 20 | 90 | 20 | 1800 | 0,25392 | 160 | 121,88 | 1921,88 |
| Pins | 13 | 30 | 15 | 225 | 20 | 4500 | 0,0076 | 160 | 15,81 | 4515,81 |
| Sylinder lids | 2 | 30 | 30 | 90 | 20 | 1800 | 0,89624 | 160 | 286,80 | 2086,80 |
| Top lid | 1 | 60 | 90 | 150 | 20 | 3000 | 0,70448 | 160 | 112,72 | 3112,72 |
| Nozzle holder | 1 | 15 | 15 | 30 | 20 | 600 | 0,09016 | 160 | 14,43 | 614,43 |
| Bearing cup | 2 | 15 | 15 | 45 | 20 | 900 | 0,0268 | 160 | 8,58 | 908,58 |
| PM Motor Housing | 1 | 60 | 100 | 160 | 20 | 3200 | 0,39408 | 160 | 63,05 | 3263,05 |
| PM Housing | 1 | 200 | 400 | 600 | 20 | 12000 | 7,82624 | 160 | 1252,20 | 13252,20 |
| PM Endcap | 1 | 30 | 60 | 90 | 20 | 1800 | 0,13208 | 160 | 21,13 | 1821,13 |
| Main motor housing | 1 | 30 | 60 | 90 | 20 | 1800 | 0,44776 | 160 | 71,64 | 1871,64 |
| Cribs | 2 | 30 | 60 | 150 | 20 | 3000 | 0,83264 | 160 | 266,44 | 3266,44 |
| Cylinder Holder | 2 | 15 | 30 | 75 | 20 | 1500 | 0,29472 | 160 | 94,31 | 1594,31 |
| Motor connector | 1 | 5 | 5 | 10 | 20 | 200 | 0,01816 | 160 | 2,91 | 202,91 |
| Bushing | 1 | 5 | 5 | 10 | 20 | 200 | 0,00168 | 160 | 0,27 | 200,27 |
| Tube | 1 | 30 | 30 | 60 | 20 | 1200 | 1,73 | 160 | 276,80 | 1476,80 |
| Support Plates | 3 | 15 | 30 | 105 | 20 | 2100 | 0,09696 | 160 | 46,54 | 2146,54 |
| **SUM** | | **720,00** | **1025,00** | **2280,00** | | **45600,00** | **15,64** | | **3459,67** | **49059,67** |

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