**John von Neumann
Faculty for IT**

Thesis

OE-NIK	Student's name:	**Roland Richard Jakubik**
2022	Registration Number:	**T/005135/FI12904/N**

John von Neumann
Faculty for IT

THESIS
WORKSHEET

Student's name: **Roland Richard Jakubik**
Registration number: T/005135/FI12904/N
Neptun code: [redacted]

Thesis title:

Ipari dobhűtéses felsőtankos háromportú
Lágyfagylaltgép valósidejű vezérlése

Real-time Control of Industrial Scraped-surface
overheadtank triple port Soft-Ice machine

Supervisor: Kopják József
Consultant: -

Deadline: 2022. május 15.

Function

A fagylalt az egyik legősibb édessége az emberiségnek, olyannyira, hogy pontosan nem is tudni honnan ered, de már a Rómában is fogyasztották az előkelők. A fagylalt mára bárkinek elérhetővé vált, de előállításához speciális gépekre van szükség, amik fejlesztésével kizárólag az a maroknyi nagyvállalt foglalkozik, akik ezek árusításával foglalkoznak, mi több ezeket sokszor titok övezi. A dolgozatban bemutatásra kerül egy ilyen rendszer, annak működése és vezérlése részletes elemzésen esik át, melynek során az olvasó megismerkedhet a fagylalt készítés lépéseivel, és annak nehézségeivel. A dolgozat célja, hogy nem csak egy ilyen gép bemutatása, hanem fejlesztése is. Hardware, és software tervezése, úgy, hogy a rendszer képes legyen óránként akár 200 adag fagylaltot is kiadni, ipari körülmények között.

The thesis must contain the following:

- A lágyfagylatgépek működése, és a dobhűtés alkalmazása, források, és szakirodalom alapján
- A szakdolgozatban feldolgozott fagylaltgép alapvető mechanikai bemutatása.
- A gép elektronikai ismertetése, és az alkalmazott komponensek indoklása.
- Rendszerterv mint mechanika, elektronika, és vezérlés összhangja.
- Prototípus schematikus ábrájának elkészítése.
- Nyomtatott áramköri lap, vagy egyéb tesztelés tervezése
- A szoftver tesztelésének lehetségessé tétele
- Legyárthatóság vizsgálata, gyártási terv.
- A továbbfejlesztés során megcélzott részproblémák ismertetése.
- A szoftver feladatainak definiálása.
- A szoftver elkészítése, tesztelésé
- A tesztek értékelése
- Végleges verzió (1.0) elkészítése
- Érintésvédelmi, izolációs, és egyéb előírások átvizsgálása
- Nyomtatott áramköri terv
- Burkolat/szigetelés megtervezése
- Az eredmények értékelése.

Ph.

. . . .
Dr. Kozlovszky Miklós
head of faculty

limitation period: **2022. május 22.**
(by OE TVSz 55.§)

The thesis is approved for submittion:

. . . .
consultant

. . . .
supervisor

John von Neumann
Faculty for IT

STUDENT STATEMENT

Alulírott hallgató kijelentem, hogy a szakdolgozat/diplomunka saját munkám eredménye, a felhasznált szakirodalmat és eszközöket azonosíthatóan közöltem. Az elkészült szakdolgozatomban / diplomamunkámban található eredményeket az egyetem és a feladat kiíró intézmény saját céljára térítés nélkül felhasználhatja.

Helsinki, 2021.05.14. . . . .

. . . .
Jakubik Roland
student signature

Contents

Chapter 1

Introduction

1.1 Foreword

I was always close to ice-cream as my parents own a confectionery. My childhood was indeed full of joy and I am forever in their dept, yet I would try to give back a bit by an ice cream machine that has functions tailored to their needs, and full of extra function, customizable, and lets full control to the operator without constantly having to reach out to the manufacturer for costly consultations, hidden machine settings, and tricky *cheat* codes.
Currently development is still in progress and done according to schedule. The hardware is almost ready and software development can begin.
Accomplishments: The first prototype has been designed and on it's way to manufacturing. The final version's design have been started though adjustments may be necessary based on the observation from the testing.
Problems: The task remains is to create a control system for this hardware, by developing both hardware, and software to achieve high performance. The challenge in this project is that it is rarely researched, and only few aspects are covered by individual articles that are missing a kind of connecting tissue. My task was to understand the working principle of such machines and to come up with my own solution to the problems of the task. I don't expect everything to work on the first try so a careful testing have to be planned in order not to damage the hardware. The system of an ice-cream machine is built up from several subsystems, and control loops in control loops. The system have to be understood, individual solution have to be developed and composed together as a system.
I have previously worked on control systems such as diesel generator control, thermostat, and a portable air conditioner, which in system is a bit similar to an ice cream machine, but

only built of much less subsystems. By goal is to live up to this task and create something new using my previous experience, and conducting research. As my previous projects were successful my attitude is positive in relation to the outcome of this work.
Difficulties: The difficulties are more like personal than technical. I moved to Finland, and as all the developed hardware was left half manufactured in Hungary it really makes it hard to continue development.

Chapter 2

Methods

2.1 Overview

The following sections contain the hardware description that should be manufactured and assembled, and the software uploaded in order to fully test the concept.

2.2 Hardware

2.2.1 Overview

In the following chapters the build, and most important parts of the ice-cream machine will be discussed in detail, with drawings attached.

2.2.2 Research

Overview

The following section collects the different articles, and researches that are close to this topic and can be interesting to anyone planning to design, or simply understand such a machine.

Note that Research was a hard part of this thesis, as this topic is rarely explored, so I had to stray away from the original idea, but in such cases the conclusions seemed to be less reliable as well.

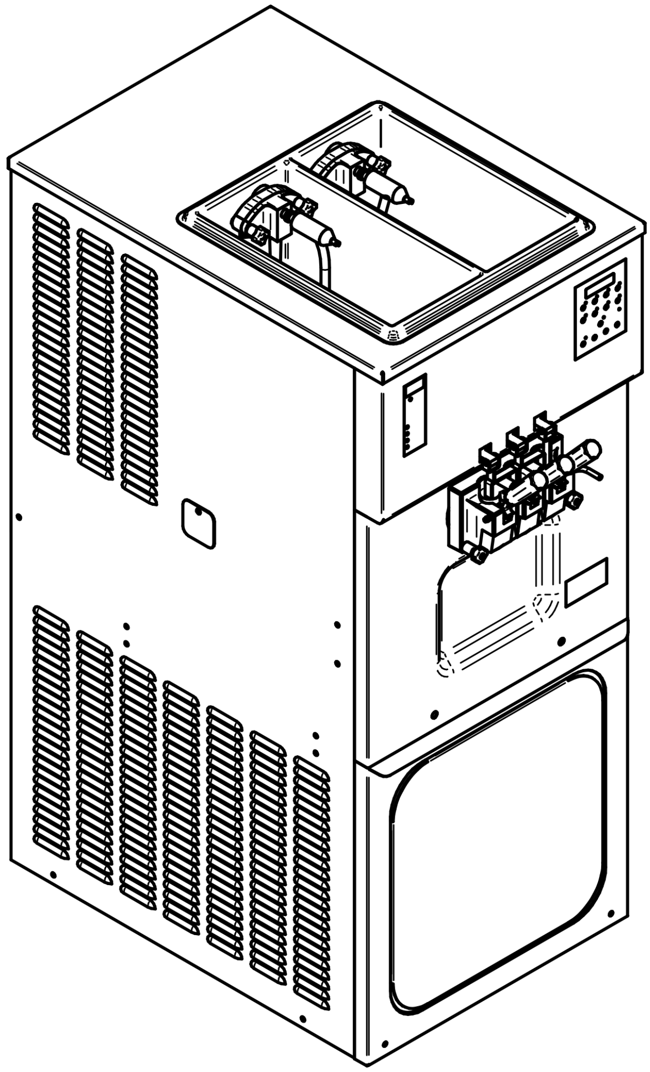

Figure 1-1: Ice-cream machine fully assembled

Refridgerant

This machine has been designed with a refrigerant in mind that was found to contribute to global warming. As so a new alternative had to be found that would ideally not require significant modifications in the design, or their effect would be minimal.
Nae-Hyun Kim's article titled "Application of the Natural Refrigerant Mixture R-290/ DME to a Soft Ice Cream Refrigerator" describes the effect of of replacing R-404A[11] with other candidates, such as R-290, and or DME. This mixture was optimized for best the Coefficient of Performance, although with this replacement a flammability issue arisen.
The machine further described in this document uses this same mixture, although the flammability may be a serous problem, as most of the cooling components, such as the TEV and evaporator are all enclosed under the heat insulating foam that only contains a minimal amount of fire retardant.

Scraped surface heat exchanger

Most of the ice cream machines in the market use an Annular scraped surface heat exchanger to produce soft-ice cream, but even the more traditional machines use a similar technique, generally with a greater annular diameter.
In the 30th volume of Applied Thermal Engineering there was an interesting article about scraped surface heat exchangers (SSHE) where the authors tried to determine the heat transfer coefficients for different types of soft-ice machines. The tested the machines with a homogeneous test fluid composed of water and [4].
The article was interesting and helped me to better understand, but more likely to have a feeling of how such a heat exchanger responds to changes in viscosity.

Scraper design

One of the most interesting articles I fond was a design review in the Journal of Food Engineering of "A new arrangement of blades in scraped surface heat exchangers for food pastes" Personally I found this article to be different than what I am used to maybe because it was so much on this rare topic that I already liked it before reading trough it. But more likely as this was in such detail and more like a practical thesis. Although the article was about food pastes[5] not ice-cream, but it is not surprising. As I mentioned in the beginning of the section I had to explore other areas as well to find interesting articles.

Nevertheless this article helped with all the data that was collected, to better understand the temperature profiles, and how thick liquids agitate in a a closed cylinder.

Gear pump

The last article I would not miss to mention is the "Experimental analysis of the flow dynamics in the suction chamber of an external gear pump". I found interesting articles in the International Journal of Mechanical Sciences before but this article used a different approach to analyze flow in this kind of a pump.

Not just analyzed, but visualized by Time-Resolved Particle Image Velocimetry, which is a perfect way in my opinion and helps the reader better understand the flow in such devices. It helped me a lot to understand how the shapes of the gear enclosure contributes to the flow of the fluid and can help to increase performance.

2.2.3 Mechanics

Overwiew

The physical parts of the machine as a system consist of the components that provide the necessary resources ,and environment to create the ice cream. Furthermore it contains other assemblies, for supplying the above mentioned components with their needs to continuously be able to work in an industrial setting. The ice cream is created in the "Cylinder Assembly" also referred to as "Freezing assembly" cooling the liquid mix pumped with the air from the overhead "Tank Assembly" to be dispensed from the header. The hand operated lever-valve controls the flow. While the cylinder pressure is automatically controlled.

Usability

Note that most of the below discussed parts had to be designed with food safety requirements in mind, and have to be cleaned and maintained in a frequent manner. Also they need to be disassemblable to a level where every section can be cleaned. This may or may not involve special tools. Also the mechanism must sustain frequent disassemblies, and such operations have to be easily carried out by the operator.

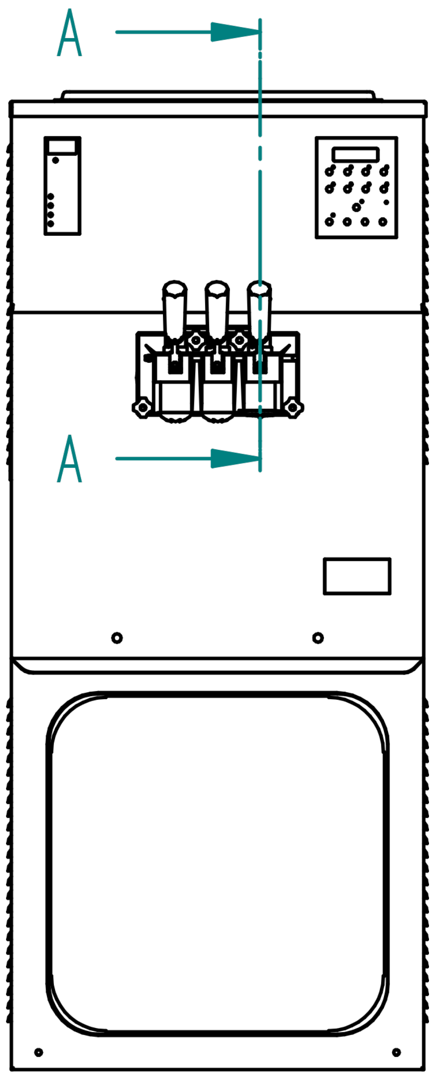

Figure 2-2: Assembled Machine front view

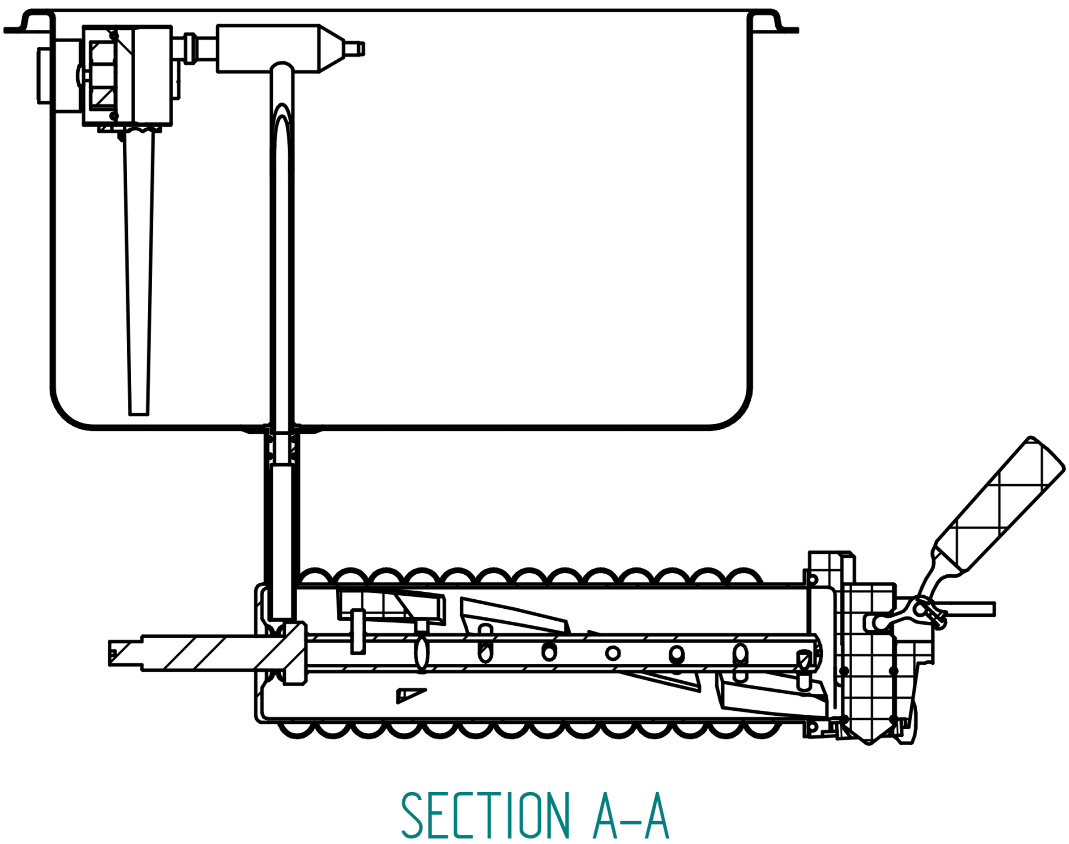

Figure 2-3: The “Wetted area”

Cylinder Assembly

Purpose The Cylinder Assembly is the most interesting part of the machine, as this is where the mix turns into edible ice cream, more importantly this is where most of the controlling takes place, so it is the main focus of this thesis. There are two identical assemblies in a machine, one on the left side(sometimes referred to as chocolate side), and the other on the right hand side (vanilla side). This is as in most configurations these are the mixes it holds, but the machine can be filled with other variants without a problem as long as they comply to specifications.

Operation The cylinder cools the liquid mix below it's freezing point, while the beater agitates the freezing ice cream. By the time it reaches the end of the cylinder it freezes to the correct temperature and consistency. Also, the beater, and the pressure helps to dispense the ice cream. The operation is simplified to the following steps:

- The aerated ice-cream mix is pumped into the cylinder from the top back entry port.
  - Pressure is being built up inside the compartment.
- The solenoid valve opens. Pressurized gas is pressed trough the evaporator to the outside sleeve of the cylinder cooling it.
- The mix is frozen to the wall of the cylinder.
- The beater scrapes off the wall with its blades in a spiral motion.
- The mix thickens until the set consistency is reached
  - The thickness is measured by the beater motor itself.

Also note that the ice forming on the wall of the cylinder heat exchanger, it creates a heat insulating layer[3], therefore constant scraping is necessary, and heat transfer in this way is a pulsating exchange.

Build

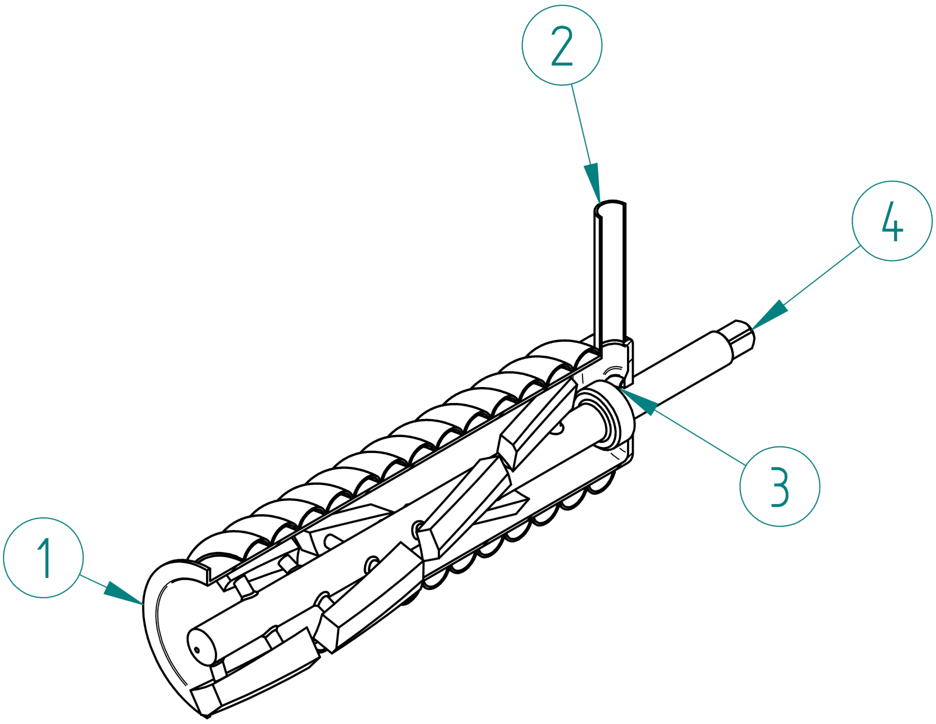

Figure 2-4: Breakout of the freezing assembly

Item Number	Name
1	Cylinder
2	CylinderTankBridge
3	BeaterGasket
4	BeaterAssembly

Figure 2-5: Names of subcomponents

Cylinder inner wall Cylinder inner wall: The inner wall is made of 2.5mm thick stainless steel. It is both a structural part of the machine, and as being in direct contact with the food product it has to be compliant with FDA/EFSA regulations, considering ease of regular cleaning, and intoxication hazards. The center back is raised to an astonishing 7mm thickness, so the raised rim would give counter pressure against the shaft sealing gasket ring.

The rim of the inner wall is flanged out wards, and flush with the outside of the machine so that it would cover, and insulate the assembly.

There are two holes on the piece. One opening on the center back to give way to the beaters shaft to enter and connect with the motor coupling. The other is on the top back. It has the mix feed line seamlessly welded to it, and is directly connected to the opening on the bottom of the tank.

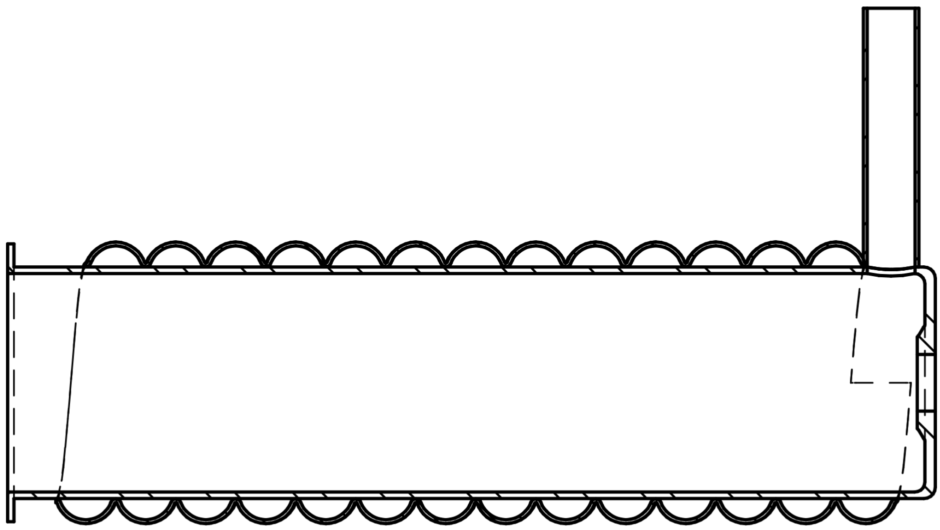

Figure 2-6: Side section of the evaporator construction

Cylinder outer sleeve Cylinder outer sleeve: The Outer Sleeve is formed around the inner wall from a single piece of metal sheet. It has a ribbed structure that creates a helical interconnected compartment around the inner wall. The structure is airtight with only a few notable openings. The evaporator port, where the gas enters, and starts to expand in between the two sheets of metal, starting it’s cooling journey across the helix. The output port for the gas to exit the channel where it is sucked trough by the compressor’s low pressure side. Finally the sensor opening for the cylinder temperature thermistors. These sensors have a crucial role in the control of the machine.

Beater blade Assembly Beater blade Assembly: The beater is made up from a solid metal coupler, and pre-shaft welded to a hollow main shaft that contains the blades. It is capped with a stainless slightly conical end piece. The blades are configured in a double helix configuration. There are 7 blades around the two edges of the scraper, each blade rests between two pins trough the shaft. Pins are 22.5° apart dividing the full circle with their positions. The blades themselves are designed to have a vedged trailing edge, so ice build up cannot clog between the wall and the blades. Also the blades have an opening between them to give a free flow to the iced shavings into the center of the chamber further increasing efficiency[12]. One of the helix blade configurations are shifted so that a full scarping can be achieved even with the openings, as creating a redundant configuration around the perimeter of the cylinder.
The shape of the helix greatly contributes to the consistency of the product. The shape also creates a back mixing effect that further contributes to higher heat transfer efficiency[5].

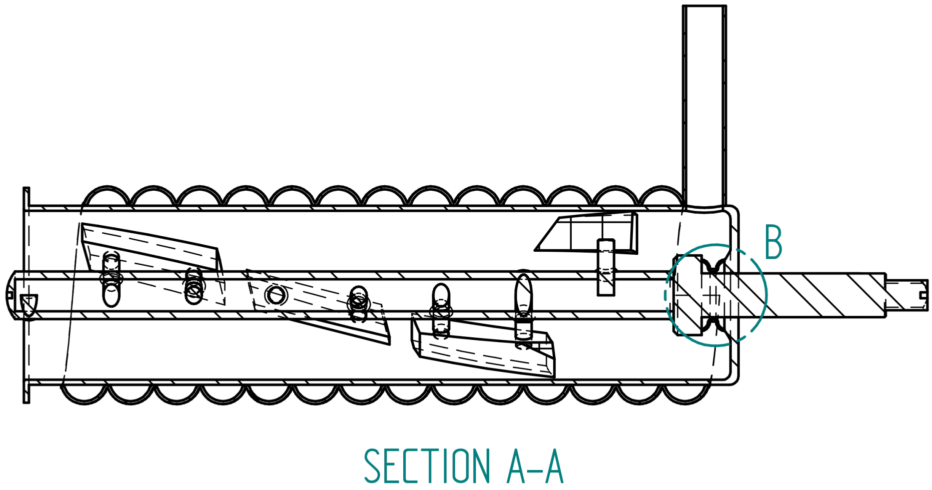

Figure 2-7: Scraper position in freezing cylinder

Shaft Gasket Shaft Gasket: The shaft gasket is crucial for the watertight operation of the machine. It ensures that no mix would seep trough the opening into the heat insulated compartment. This part is at most importance when operating the machine and the technician should care to add it in the assembly process as there are no fail safes for detecting the correct assembly of this part. The detail draw below (Detail B) show the gasket in it's uncompressed state. When compressed it deforms around the protrusion of the back wall.

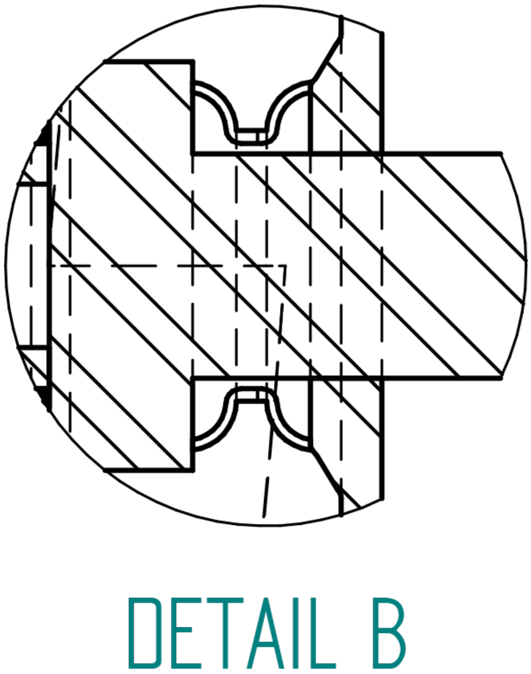

Figure 2-8: Detail of the gasket sealing the coupler

Misc Sensors: There are two temperature sensors in the assembly. One in the cylinder, and one in the evaporator. They are needed for precise control of the cylinder tempeature. Measurement is done by NTC thermistors.
Thermal Expansion Valve: The gas flow is controlled by the solenoid valves, but those only have two states. A fully open and a Fully closed state. The local control is done by a mechanical gas pressure regulator that cares for the safety of the cylinder, and protects the machine even in case of an electrical failure or any faulty control from the solenoid valves.
The pump transmission: power is transmitted from the motor shaft to the pump coupler shaft in the overhead tank. This is done by a belt, and pulley pair that ensures constant connection. Note that it also means when the beater is under operation it operates the gear pump, and vice versa. This is constantly trying to push mixture into the cylinder. It is not a problem because the pump has a pressure valve that would not let too much pressure to be built up in the cylinder chamber.

Notes The inner cylinder due to it’s design will not cool on the first half, and the last half part as the outer sleeve as the gas compartment would not reach there.
The beater assembly is held in place by the counterforce against the header’s flat inner surface, and kept in center by the blades themselves.

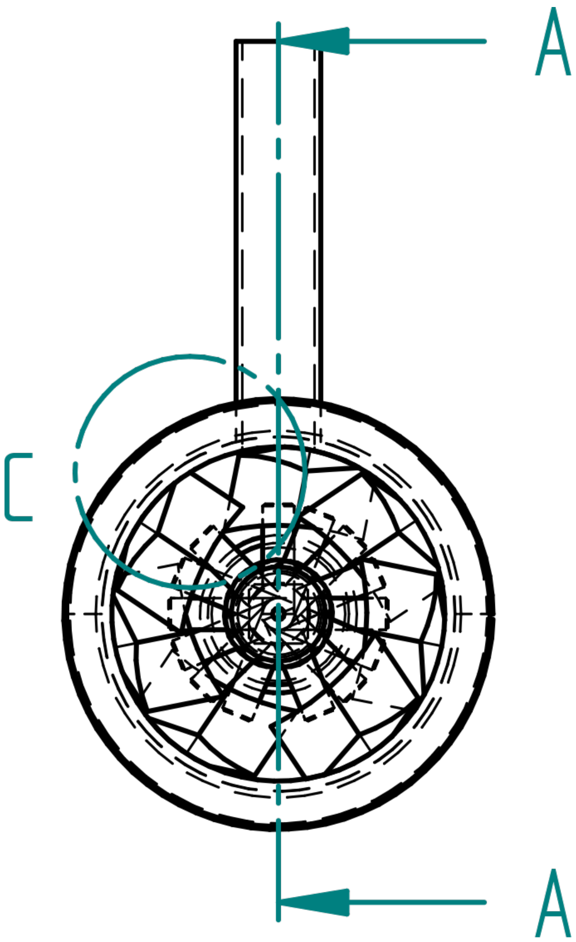

Figure 2-9: Detail of the gasket sealing the coupler

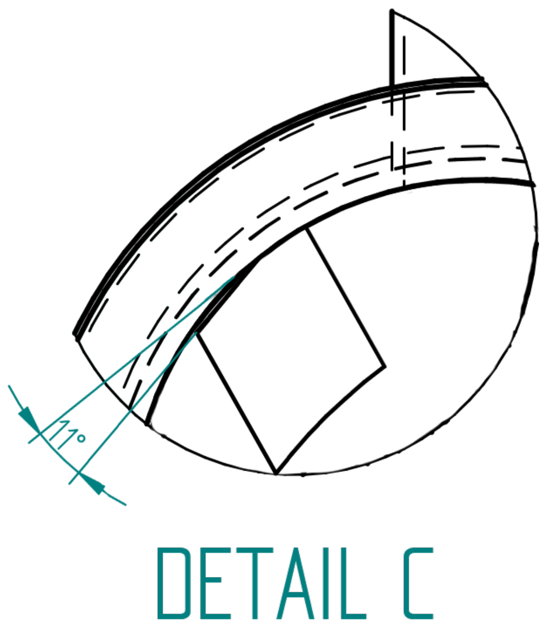

Figure 2-10: Vedged scraper blades

The two cylinders are welded to a metal sheet, which have four screws pointing out wards. They are secured to the front plate of the through the internal framing, hence steadily holding the assembly in place. I did not draft these parts for better visibility of the mechanism.

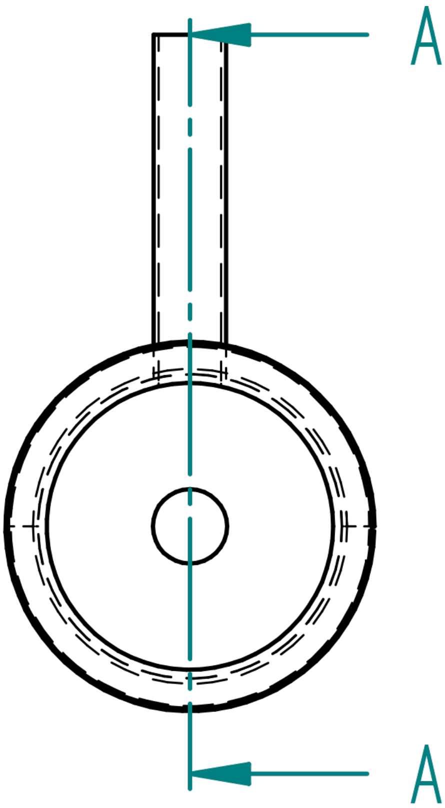

Figure 2-11: Shape of the cylinder

Tank Assembly

Purpose The Tank Assembly is the other main component in the machine that is in direct contact with the mix. It was designed to hold the two kinds of mixes, and to keep them at storage temperature until they are pumped into the cylinder assembly. The pumps are also part of this assembly, with all the necessary valves, and mechanism for operation.

Operation The tanks are surrounded by a cooling coil spiraled around the outer edge of the joint tanks assembly. It is controlled in a similar manner than the cylinder evaporator. Meaning a solenoid valve opens up controlled by the main board, and a mechanic pressure controller supervises the gas flow.
The pump assembly is placed to the top of the tank, and is driven by the beater motors. The pump has a snorkel reaching to the bottom of the tank as an input, and a feed-line

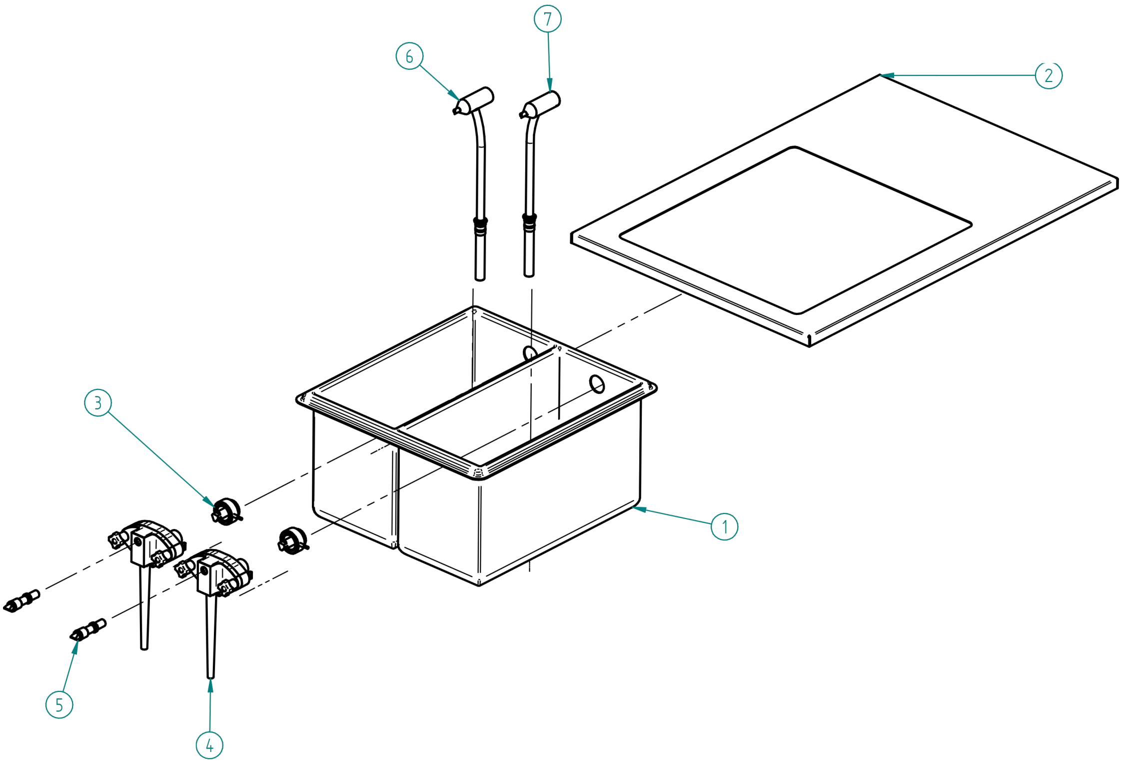

Figure 2-12: Exploded view of the tank assembly

Item Number	File Name (no extension)
1	Tank
2	PlateTank
3	ConnectroPumpShaft
4	PumpAssembly
5	ValveAssembly
6	Injectorassembly
7	InjectorMirrorassembly

Figure 2-13: The list of tank components

reaching down to the middle of the cylinder assembly as an output. It is also equipped with a mechanical pressure release. Combined with the valve at the output feed-line, they keep the cylinder under pressure. The main part of the mechanism is the gear-pump itself. It circulates the mix, and also enriches it with air according to the setting on the feed-snorkel.
The feed snorkel reaches to a few millimeters above the floor of the tank, and sucks up the mix to be transported into the pump. It has a notched side that crates a ratchet like mechanism to set the aeration in the transported mix.
The tank is also equipped with thermal sensors, and a contact level sensor that senses if the level of the mix is below a certain threshold.

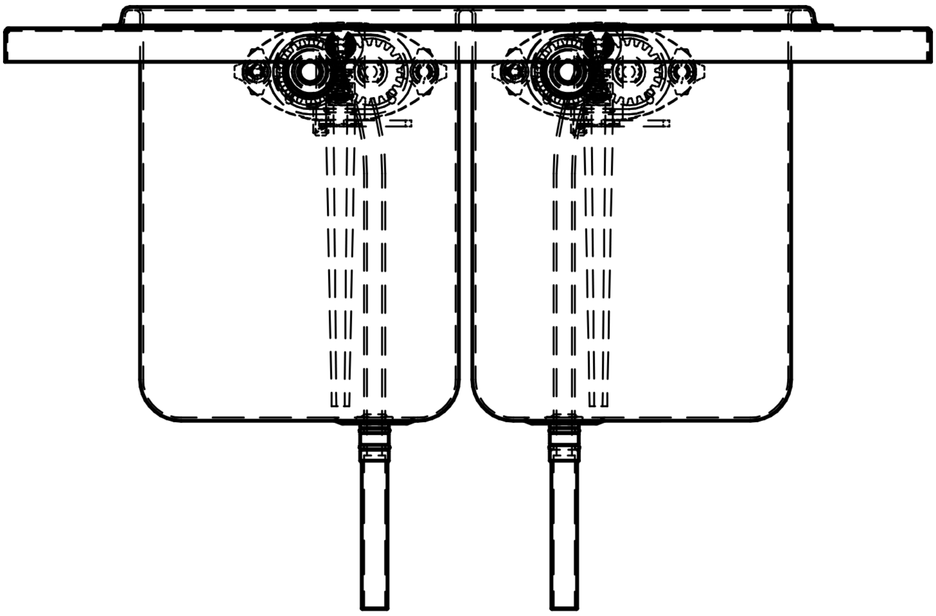

Figure 2-14: Frontal view of the tank

Build

Tank The tank is made of a thick 2mm stainless steel sheet.It is drawn to two contain two sections one for each mix to be stored. An upper rim is pressed right before the flange. It is purposed to hold the lid of the tank in place under normal operation. There are two openings on the back, one on each side for the pump drive coupler. There is one opening with a dimple sunk around it. It leads to the cylinder, referred to as the “Cylinder Tank bridge”. The level sensors also take place on the bottom of the tanks, and as so two ports are cut for those. On the contrary, thermistors are glued to the outside of the tank covered by the insulation.

The tank is glued to the top late of the machine, so by norms they together form the tank plate assembly, but as this separation has no effect on operation, and are even visually not so distinct, I did not dedicate a section to describe this.

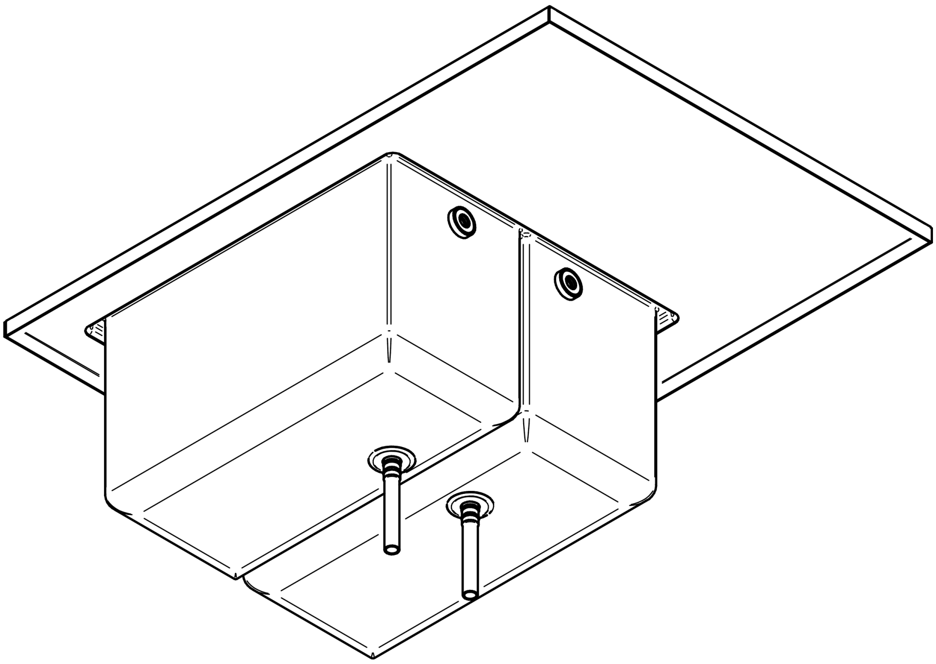

Figure 2-15: Bottom view of the tank

Pump Assembly

Purpose The pump assembly is the heart of the machine. It circulates the mix to be injected into the cylinder. Also it aerates the mix to the required level that can be set on the snorkel by adjusting the setting lever.

Operation The pump operates only when the beater is activated. Than it would pump the mix from the tank to the cylinder, operation as follows.

- The beater motor starts, turning the drive shaft, which is turning the upper drive shaft trough a drive belt. It is connected to the driving gear of the pump, which rotates the driven gear, and as so creating the suction.
- The snorkel is filling with mix and to be filled until the tank runs out, or the pump is disassembled.

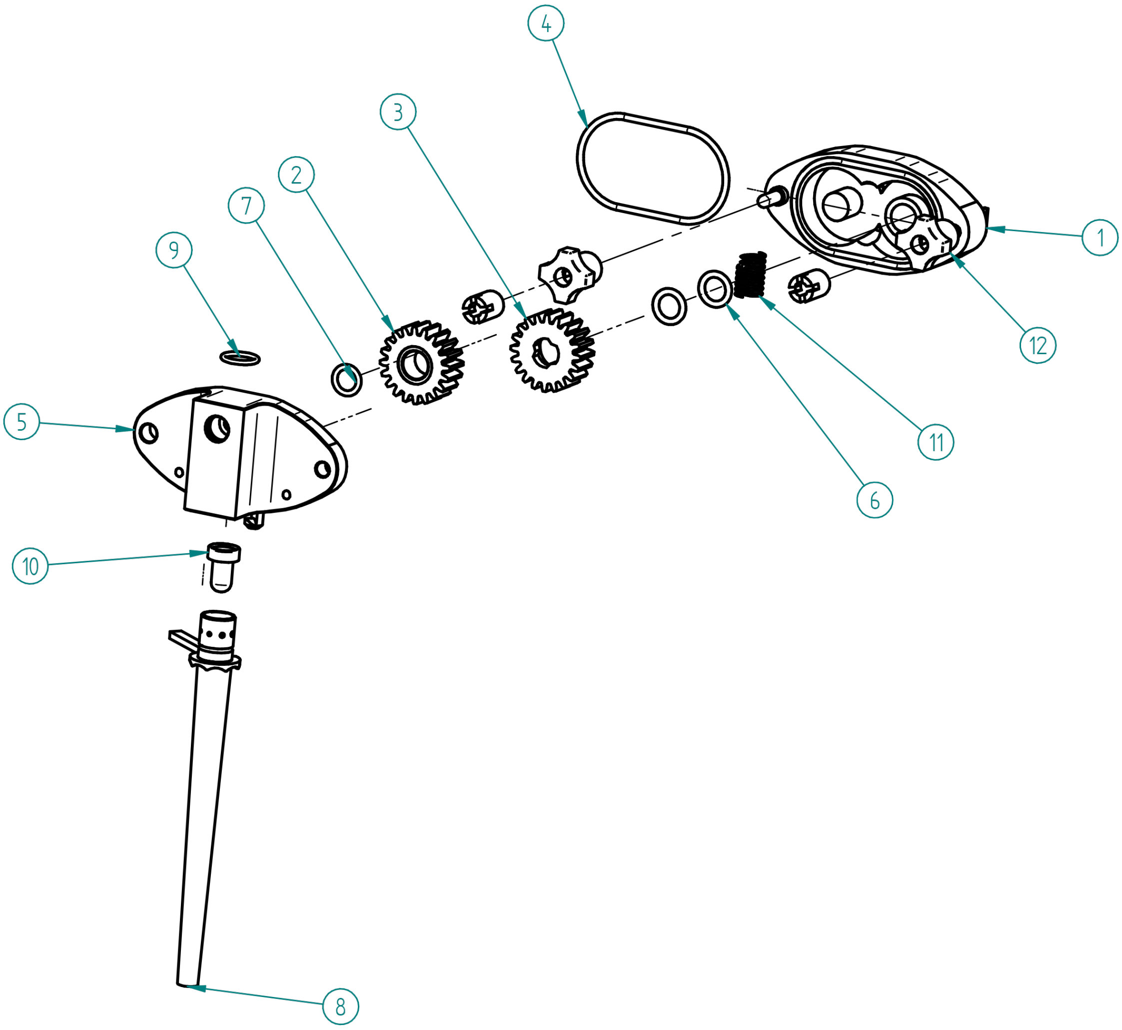

Figure 2-16: Exploded view of the Pump assembly

Item Number	File Name (no extension)
1	PumpBase
2	Spur2
3	Spur1
4	GasketPumpOv
5	PumpHead
6	GasketPumpShaft
7	GasketPumpSnork
8	Snorkel
9	GasketSnorkel
10	ValvePumpReverse
11	SpringValve
12	PumpScrewAssembly.par

Figure 2-17: List of pump components

- Mix is squeezed trough the flow limiter hole(set by the lever on the snorkel) to the pump.

- The pump is sucking up as much mix as it can. It still has a small amount of vacuum between it's teeth.

- The pressure equalizes in the chambers between the teeth as they reach the air opening. It creates a partially air mixture.

- The mixture is pushed out trough the high pressure opening of the pump to the pressure control chamber.

- The chamber has a piston suspended by a spring. If the pressure is lower than the spring force, all of the mix is pushed on to the valve. Otherwise, if the pressure is greater than the spring force, it opens the piston, and the excess mix is blown back to the snorkel. If the snorkel has air bubbles inside it would also help to push them out of the pipe.

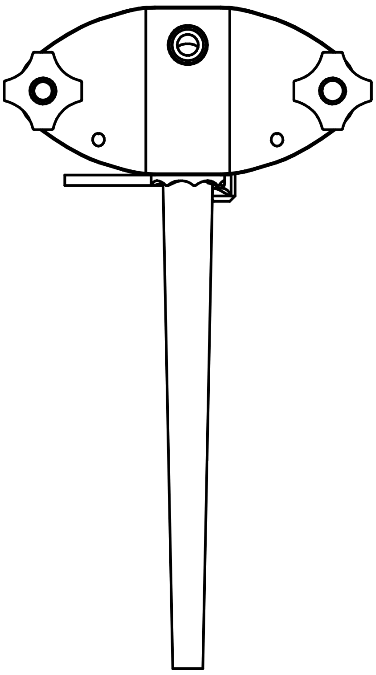

Figure 2-18: Pump viewed from the front

Build

Housing The housing consists of two parts. Th backplate (block), and the front plate (head). They are thick stainless blocks with considerable weight, machined to absolute precision.

The backplate houses the two gears. One has a shaft the other has a hole in the back side with a sealed shaft hood, to be fitted with the upper drive shaft. It has a specially machined connector that inserts into the drive gear. The drive shaft also acts as the turning axis of the drive gear. It also has the screws embedded inside that are used to secure the two plates together.

The front plate has numerous chambers and openings. The inflow chamber is where the snorkel is socketed. This is also the place for the overflow valve that connects the inflow, and the outflow chambers. Note that the shape of the chamber is important in directing the fluid. It has to be design in accordance to the gear rotational speed, and the thickness of the liquid[6]. The outflow chamber is where the valve is fitted. It also has an opening that connects it to the previously mentioned chamber. The main plate(chamber) This is the back side of the pump head. It directly covers the gears, and has 4 crucial openings.

The Inflow opening, it is connected to the inflow chamber. The outflow opening which is machined in a tapering manner. It was needed to let flow to the liquid squeezing out from the decreasing space between the meeting teeth of the gears. The other two openings are airways machined in a 23° angle sucking in air according to the Venturi effect[16].

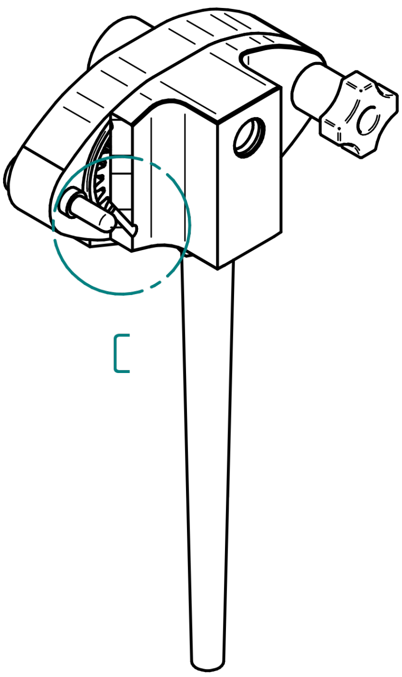

Figure 2-19: Breakout view of the pump gears

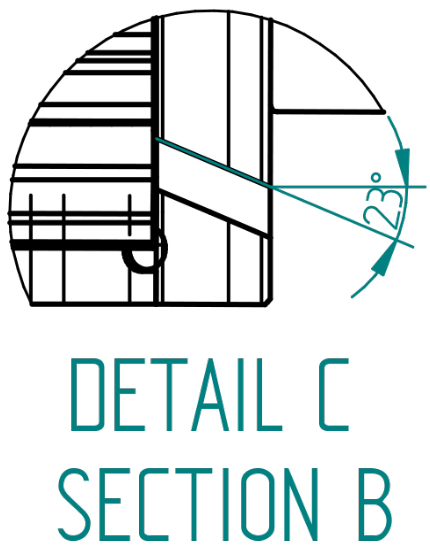

Figure 2-20: The breather hole of the gear pump

Gears The gears are the parts actually transporting the mix, and creating the pressure. They are machined to absolute precision. These spur gears divide the chamber to a high-pressure, and a low-pressure side[13]. The area in the teeth fill with mix, and it is transported to the high pressure chamber. When the teeth of the two gears interlock they squeeze out the liquid from between them, and close the middle section. To be able to do it the had to be designed so this part would always be sealed.(visible in section D)
The driving gear has a cutout in the middle to connect to the drive shaft, which would also act as the rotational axis of this gear. The driven gears shaft is a solid stainless cylinder secured from the back side of the pump block.

Snorkel The snorkel is a solid nylon tube for aid of suctioning mix. It is narrowing tube. The narrowest point is the bottom, and going up the diameter increases. It also has a skirt like stopper on the top. It has arches on the upper side that fit over the machined bottom of the stopper on the bottom of the pump block. They form a ratcheting mechanism. The skirt also has a lever used to set the correct mixture. The air ration is set by turning the lever it turns the tube inside the inflow chamber. The snorkel tube has holes around it's outside wall, each with a different diameter. Knowing that we can see that the "air adjustment lever" actually counter actively adjusts the mix-air ratio, by limiting the mix's flow.

Valve The valve is a small Polyvinyl-chloride piston pressed against the inflow outflow chamber bridge,it is held under constant tension by a tension spring. While this spring is

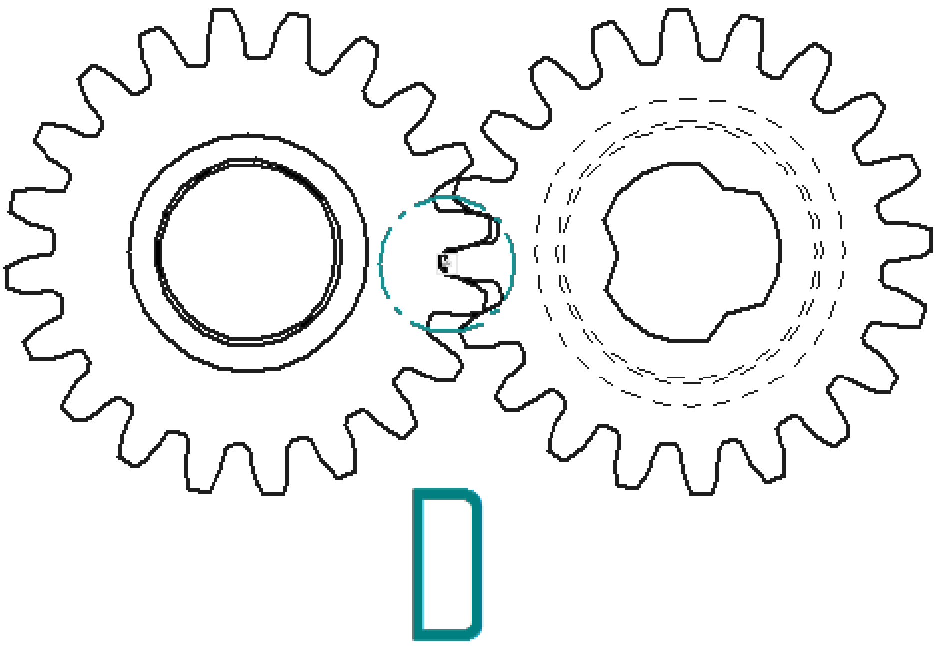

Figure 2-21: Interconnection of the gears

Figure 2-22: Sealing profile of the gears

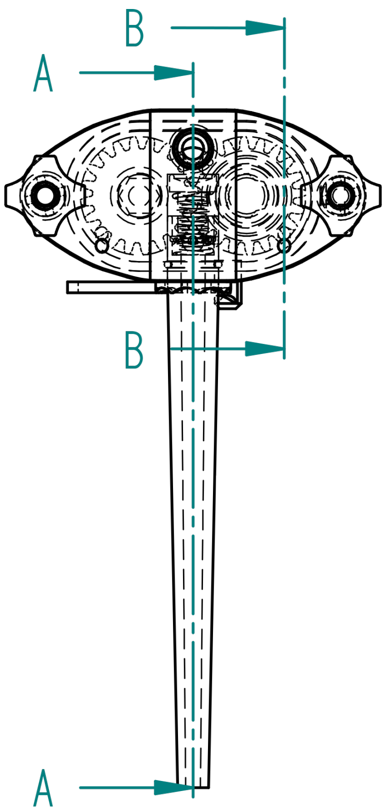

Figure 2-23: Pump internal structure

held in place by the snorkel. The valve has a basin formed on the top, the surrounding ring-like area acts as a gate for the mix. When the pressure reaches a high enough level, or it peaks suddenly, the spring is compressed, and the mix can breach above this wall. When the pressure drops the spring pushes the piston back, to normal operating position.

Misc There are five additional gaskets to the pump assembly listed below:

- The Main Gasket is the special elliptic rubber sealing between the pump block, and the pump head. It is held in a specially machined channel in the block. It surrounds the gears, and ensures an airtight seal
- The Pump Shaft Gaskets 1, and 2. There are two gaskets on the inside of the driving gear drive-shaft cover. They create a redundant sealing to make sure no mix, or condensate may flow into the belt chamber behind the tanks, as that section is partially surrounded by the molded heat insulation are, it can not be serviced non destructively. As so it is extremely important to protect that are during the lifetime of the machine.

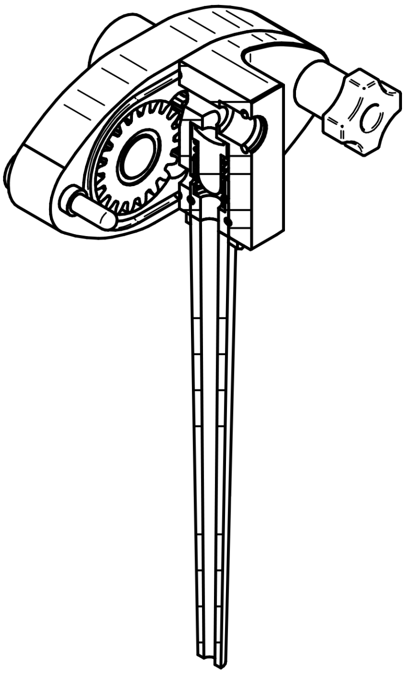

Figure 2-24: The valve of the pump

- The Valve Gasket, is the sealing ring around the exit of the outflow chamber. It is pressed against the outside of the valves shaft.
- The Snorkel Gasket is the rubber ring on the outside of the snorkels coupling, on the top. It seals the snorkels inside to the inflow chamber opening.

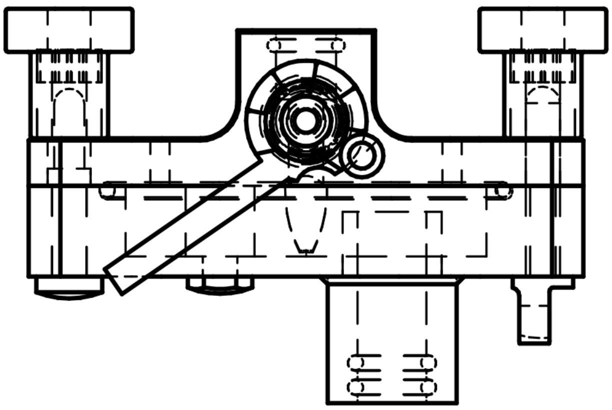

Figure 2-25: Bottom view of the pump

Notes The pump is a truly heavy part of the machine. The back side has the drive shaft cover welded to it. It also has a notch that connects to the securing rod on the pump

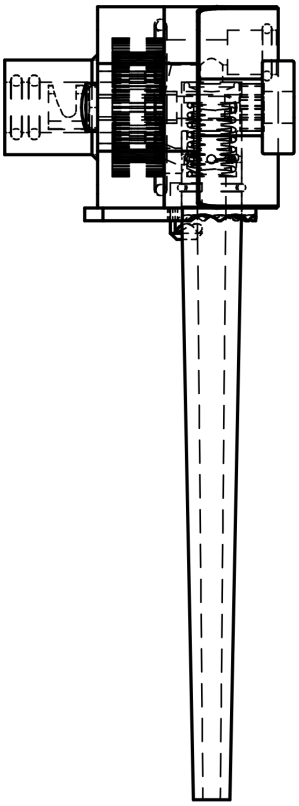

Figure 2-26: Internal components of the pump

coupler on the back side of the tank. It is so that the pump would not turn around in the machine. Also the pump is easy to remove, and can be removed to check the rotating direction of the pump drive shaft protruding from the coupler on the machine. It proves to be useful when the machine is connected to an electric source, and the phase sequence is unknown. An experienced operator should know the shaft should turn counter-clockwise observed from the front of the machine, so in any other case two terminals shall be changed over, before operation.

Injector The injector assembly consist of an injector feed rod, which has a port opening on the top, and a stopper ring at the bottom sealed with two gaskets.
The top port also has a manual pressure release valve for de-airing the line, and to release pressure in case of service. This is a simple plug held in place by the pressure, but when pushed the end is pressed deeper into the chamber where it is wider, so the pressure can creep around the perimeter of the plug.
The top port is made to house the valve. From here the rod goes trough the bottom of the tank, there straight to the cylinder. The bottom pipe extends down to the center of the cylinder as much as possible, so it would inject the mix into the center far from the

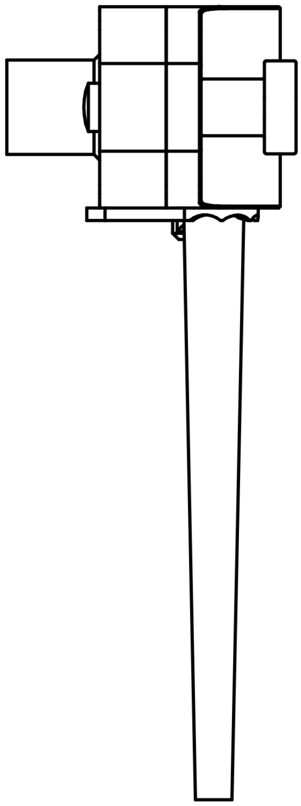

Figure 2-27: Side view of the pump

cooling walls, this way avoiding icing to collect on the opening.

Valve The valve is made of a single turned stainless steel piece, with a silicone insert, and a gasket on the outside.
The silicone insert is the duckbill valve itself that restricts reverse flow of the mixture. The check valve operates so it has a fluid in, and a fluid out side. This second one is the high pressure side in case the pump stops, and pressure is released.

Misc The tank is also fitted with a coupler that is used to mount the pump assembly, but as the snorkel, and the Injector is hold on the pump, this coupler is to bear the weight of all the detachable components from the tank. Also it has a drive shaft in the middle that provides the necessary power for the pump's operation.

Notes As the mix level sensor measures the fill level of the tank by conductivity between it's terminal it can only tell if the level is above the upper terminal, or not. After the "circuit" is open there is still a liter or more mix inside the tank. As so the proper amount of ice cream can only be estimated. It has to be made in software. Also being careful to

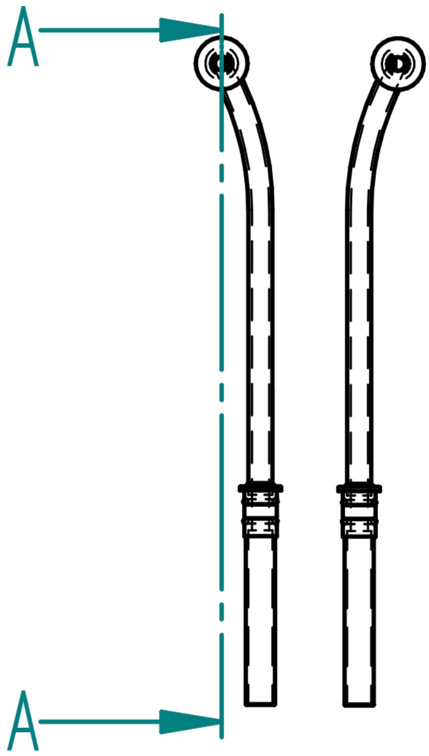

Figure 2-28: Symmetry section of injectors

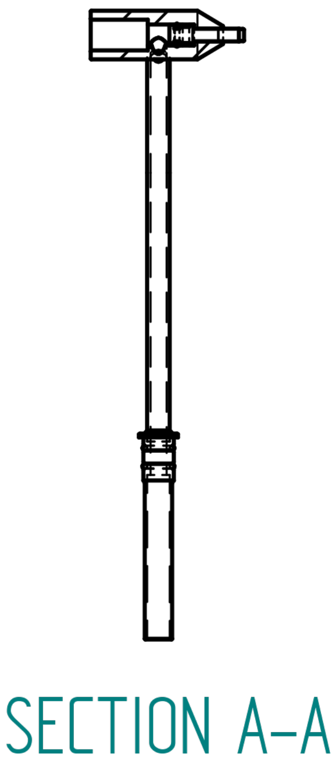

Figure 2-29: Injector Section

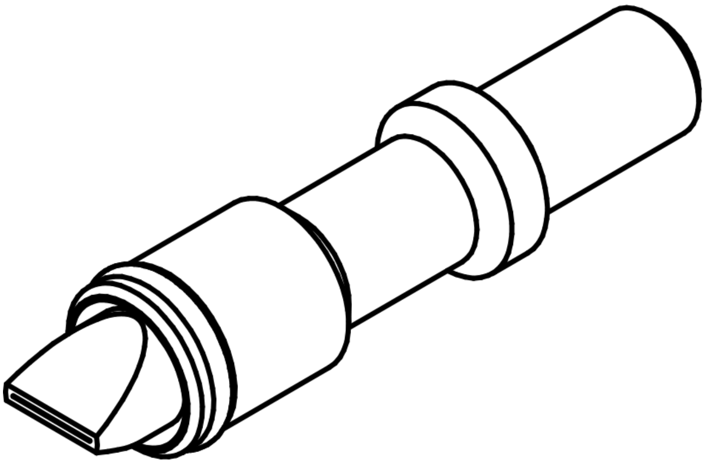

Figure 2-30: Pump valve

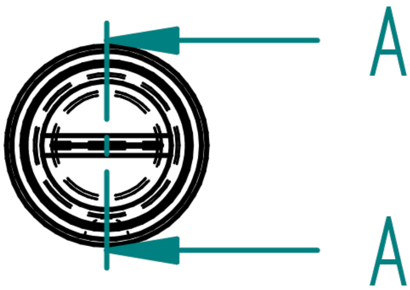

Figure 2-31: Front view of the valve

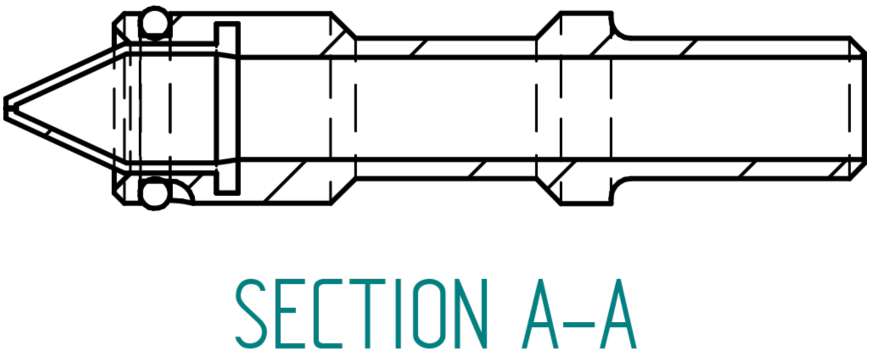

Figure 2-32: Valve section

reach a high efficiency of the machine, by reducing wasted mix, but with care taken, as running the machine with a partially empty cylinder can cause damage to it. Neither the cylinder nor the pump is lubricated by any other means except the cream itself.

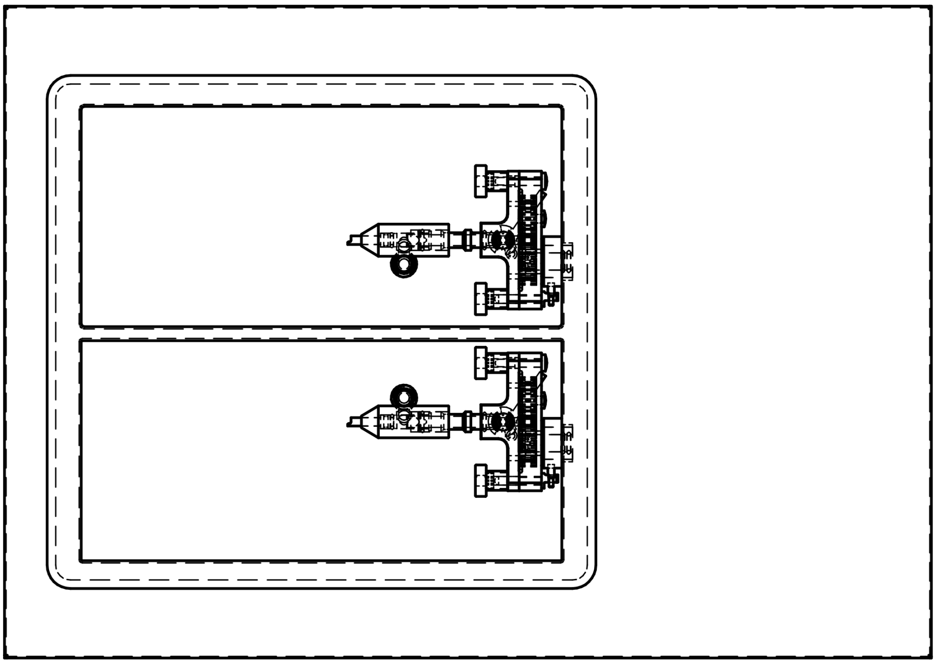

Figure 2-33: Top view of the tank assembly

Interface

Overview The interface consist of all the mechanical and digital parts the operator interacts with in order to operate the machine. The two main components are the Control panel, and the distribution header. The distribution header has the manually operated valves for releasing the ice-cream. While, the Control panel has the display and buttons. It is used to adjust the machines settings, and displays operational data like ice cream thickness, mixture temperature, ect.. Further explained in the Digital interface section.

Header Assembly

Purpose The header is used to distribute the two types of frozen ice-ream into the three ports. Assume a traditional setup where the left hand basin is filled with chocolate mix, and the right hand side is filled with vanilla. In such case the left most opening would dispense vanilla, as the right most would chocolate, meanwhile opening the middle valve the machine dispenses a mix of the two sides, chocolate-vanilla in our scenario. As a secondary, yet non-neglectable function of the header is to secure the beaters, as the outward tip of the beater assembly is pushed against the header.

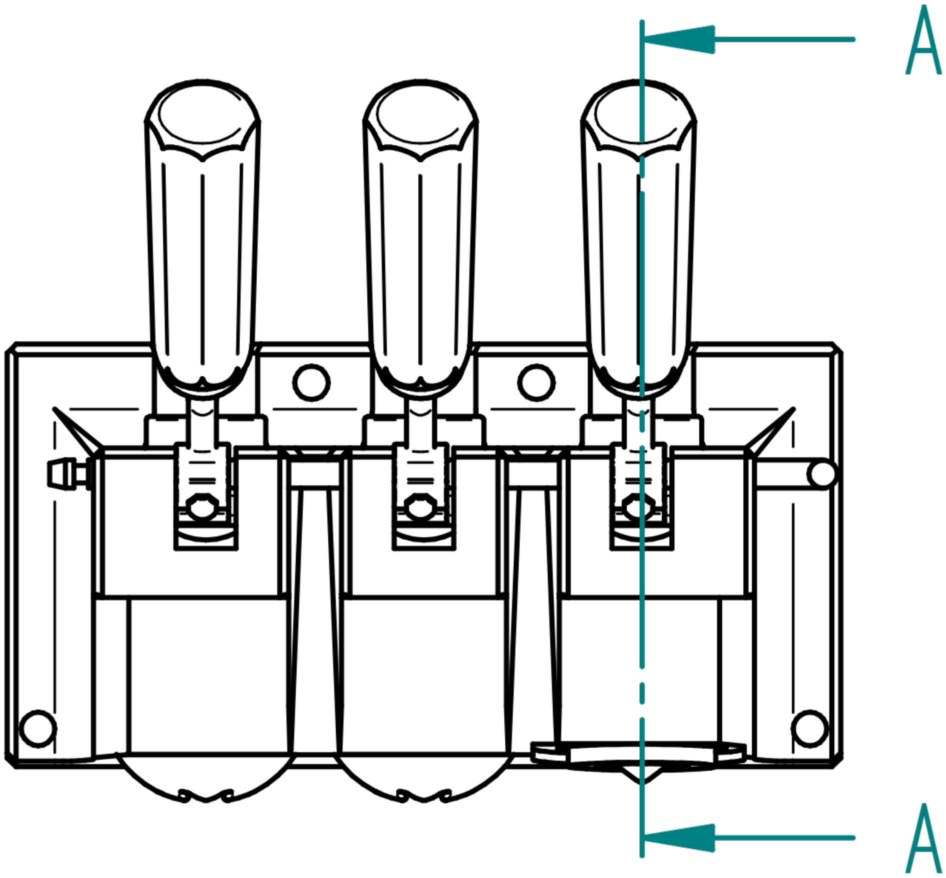

Figure 2-34: The header assembly

Operation The header has three ports, one lever for each port. Each lever controls a valve. The operator pulls on the lever, this motion moves the valve up, which opens up the distribution chamber, so the mix would flow in. From there it would flow to the shaping disk. It gives the ice cream it's characteristic star shaped profile. Also as the cylinder has a higher pressure, during outflow to the lower pressurized atmosphere it furhter contributes to a creamier texture[22]. When the lever is pushed down it would cut the flow of ice-cream, and in the meantime the downward motion squeezes out the leftover ice-cream in the chamber. As the header is also securing the beaters it is a sturdy piece of nylon it has been designed molded, and machined to high quality standards. The assembly is secured in place by four hand tightened screws. These screws are mounted directly to the freezing assembly trough the inner frame.

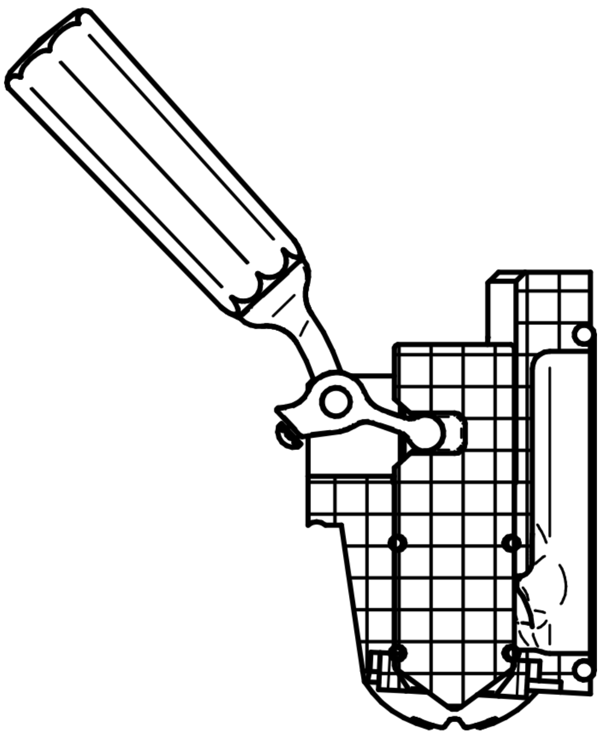

Figure 2-35: Chamber closure of the header

Build

Block The block, or distribution header has five chambers. Two input chambers, and three output chambers. The two input chambers directly cover the freezing assembly's opening, they are sealed by rubber gaskets. They are planted in a machined channel around the chamber opening. Both input chambers have two output channels. One to the single flavor output chamber, and one to the mixed. These chamber openings are locked by the valve piston. As the head is not cooled chamber sizes were designed to minimum. The block also features three lever posts, thees are adjacent blocks with a removable stainless rod that acts as the lever's shaft. The posts are molded parts of the head. As this is the center of attention when serving ice cream the bold was designed with different chamfered, and rounded decorations.
The output chambers have a conical shape, just like the pistons. This chamber ends in the star profiled forming disk, which the ice-cream is pushed trough to get it's signature shape. This disk in reality is a bubble that has a star cut out on it. It was needed to better distribute flow in this end of the head, so less resistance, and turbulent flow would be created, and also to avoid creating dead spots where the ice cream would be trapped, and be allowed to be heated up to a non safe level.

Lever The lever is a single piece of nylon cast over a stainless base. The base has a hole and a setting screw on it, also it has a metal tongue used to cam the valve piston up, and down in the header's output chamber. The setting screw catches on the ridge of the header, it can be adjusted to restrict the levers angle of motion.

Valve There are three valve pistons in the header assembly. These pistons are used to open, and close the flow of ice-cream from the output chamber. The ice-cream is pushed out by the pressure, from the continuous agitation of the beater. There are two types of pistons The two side piston has two-two sealing rings. In closed position, the gaskets seal the output chamber, one from the top, and one from the bottom. The chamber has a channel on the middle, it is located in between the two sealing rings. When the lever is pulled the piston emerges from the chamber (which is open from the top) and when the bottom ring rises above the cut out channel opening the ice-cream starts to flow, and both the bottom ,and the top gaskets seal the chamber from the top side. As the piston is pushed back into the chamber the gasket seals the channel opening, and as the conical shape of the piston fits into the channel it pushes out the leftover ice-cream ahead of itself.

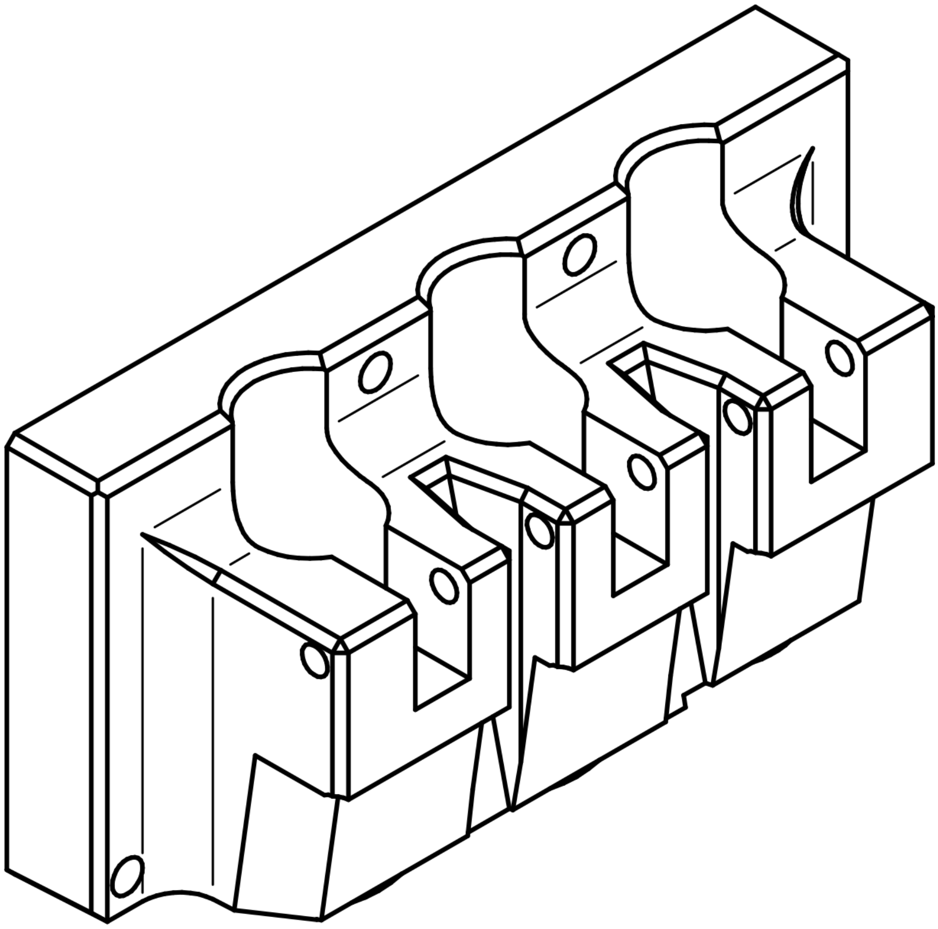

Figure 2-36: Beveled front of the header block

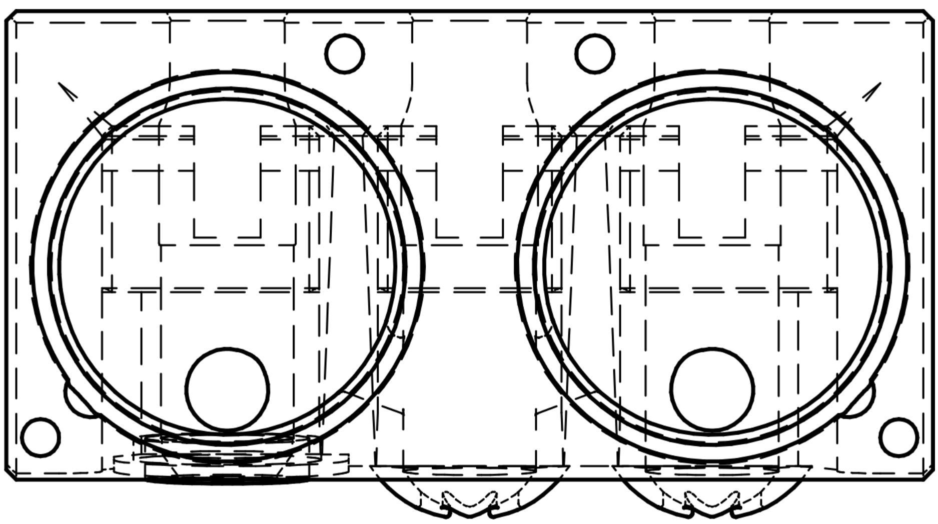

Figure 2-37: Back side of the header, (connects to cylinder)

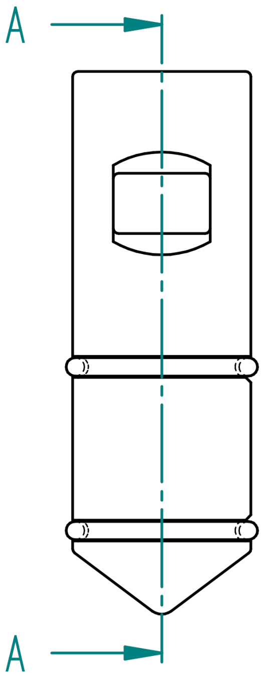

Figure 2-38: Single valve front

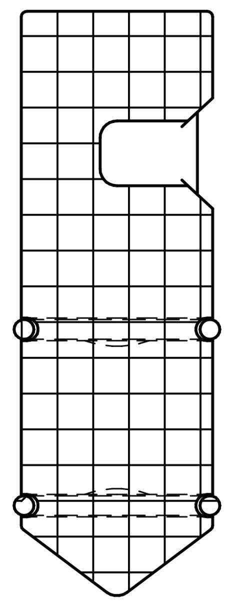

Figure 2-39: Valve section

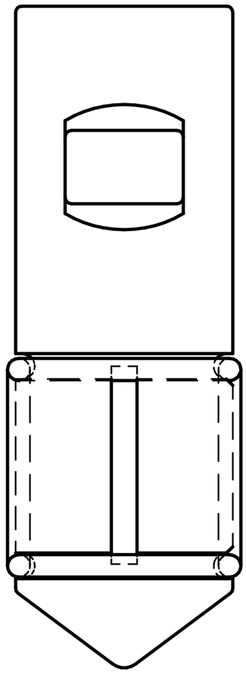

Figure 2-40: Double valve

Misc There are three switch camforks above the pistons. They serve the purpose to switch the overhead micro-switches hidden behind the protruding step of the top cover plate. There are three switches. They are used to detect which lever has been pulled. This switch is read by the main board. There have been three are adjusting screws added to behind the top cover, that can be used to fine tune the trigger point of each micro switch. There is a push button on the injector head in the tank, as it can be used to release excess pressure, by the operator, it is also considered as a manual control interface. The Cross section, and detailed explanation of the working principles of this button can be found in the Injector section of the Tank Assembly chapter.

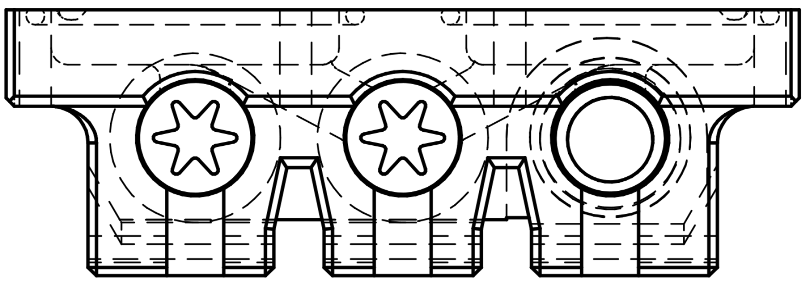

Figure 2-41: The star shaped output ports

Notes The two head input chambers are connected to the three output, as so there are two channels from each input chamber to the outputs. As of the construction of the machine the middle output chamber has the longest channels, and neither of the channels nor the chambers. Are being cooled, still it would have the most chance of melting. That could pose a potential problem in case of infrequent use. Nevertheless, testing showed that it is the most common flavor, partially because people rarely think ahead of what they would want and when we are challenged with options of similar properties, people tend to opt for the middle ground. Furthermore, considering the melting time, the two single flavors should melt identically, but as of the traditional chocolate vanilla setup, the chocolate tends to melt slower even in similar conditions. Note that by melting the most important factor is not temperature but consistency. With all that said, by recipe Chocolate mix has a higher solid content because of the added cocoa powder. Practice shows that it seems to contribute to the melting. It has been discussed, that additional "Locust bean gum", which is a flour like powder (E410) could be used to increase the thickness of the vanilla mix to counter this effect. Although these theories were not tested, nor directly part of the thesis discussion, or research.

When the piston is pushed back into it's closed position it slowly decreases the flow of ice-cream to a point where it stops to flow. It happens when the bottom gasket seals the cutout channel opening. Nevertheless this position is reached at around a halfway between the lever's fully open, and fully closed state. Note that the output chamber is still filled with ice-cream under the piston. As the lever is retracted to it's fully closed state, it pushes out this leftover trough the bottom plate. The operator should be aware of this, as it can be as much as a third, or quarter of a whole portion of ice-cream if a traditional cone is used.

Digital Interface

Control Panel The machine has a simple control panel, with minimal hardware, even tough many functions had to be scrambled into this seemingly simple interface. The panel consists of two buttons, and a three character 7-segment display, there are also four+1 LEDs for status indication. This has to enable the user to cycle trough all the available functions (discussed in the Functions section), without being overly complicated, by having all sorts of Morse-like combinations.

Functions

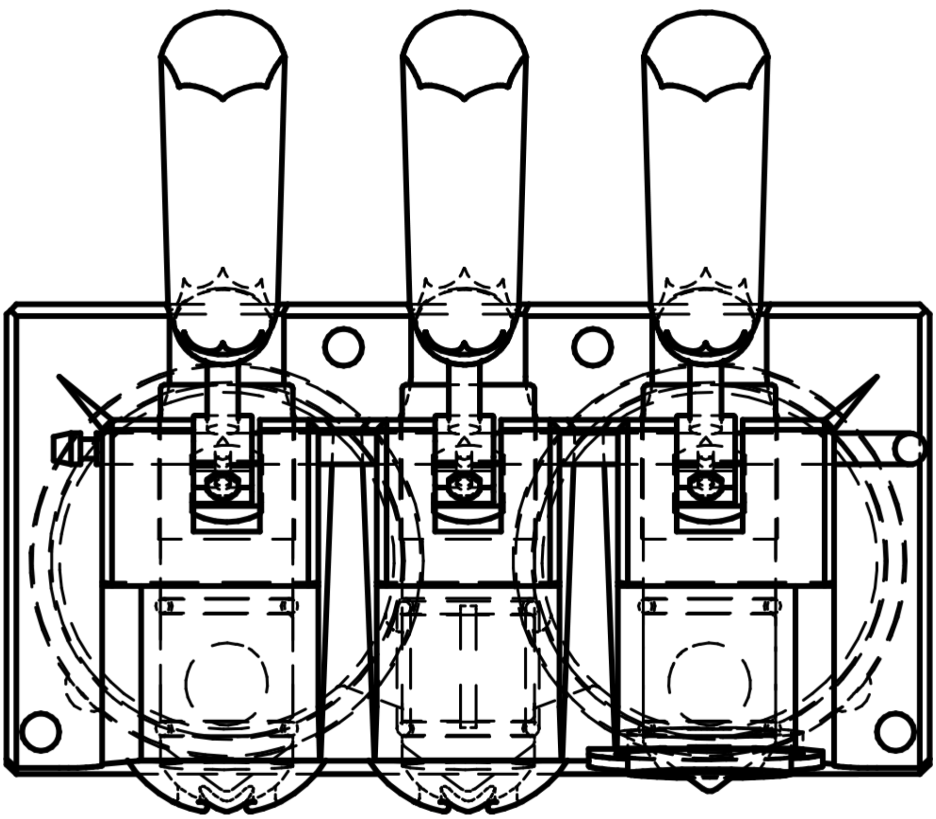

Figure 2-42: Buildup of the header assembly

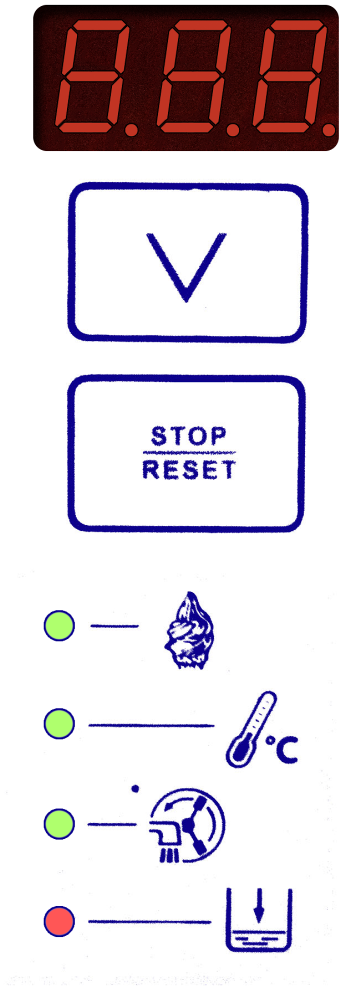

Figure 2-43: User Interface

Overview There are three basic modes of operation, that need to be implemented for general use. The first is the normal operation mode further referred to as production mode. This enables the operator to dispense ice-cream in the normal rate of units described in the machine's specification. The functionalities include, but not limited to: Freezing the cylinders, and agitating the mix, keeping the liquid supply at a food safe temperature, and pumping mix from the tank to the cooling chambers, while maintaining safe operation by supervising the inputs, and sensory readings, ready to take corrective action. The Conservation mode is to keep all the edible ingredients in food-safe condition while maintaining minimal power consumption. It is used mostly if the machine is on hold for a longer period of time. Fully safety supervision is carried out. The Cleaning mode is used during the disassembly of the machine, in this mode there is limited safety supervision and so the disassembly should be carried out by a trained operator only.

Production mode  In this mode the machines primary purpose is to keep the cylinder full of mix, and get it to the set consistency as soon as possible, so it can be dispensed. This action can be divided into two sub actions. One is to cool the mix. Where the pump, and the agitator continuously work, to keep the cylinders contents at pressure, in a homogeneous state. So as the cylinder that is evaporating the cooling gas to quickly bring down the internal temperature. As so the compressor should also operate. As the ice-cream reaches the desired consistency the cooling stops followed by a refectory period of agitation, to prevent the walls to over-freeze. After that the machine goes into a supervising mode that periodically checks the consistency, stirs up the cylinder contents, and may jump back to the cooling phase if needed. There are other side functions the Ice-cream operation covers. Like checking the level of the mix. If the level is below critical it would display a warning by lighting up the low level indicator, in the meantime it starts a countdown, and tries to estimate the level of mix left in the tank below sensor level. After some units of ice cream it would display an error message preventing a possible fatal failure. The machine also keeps the liquid mix storage at food safe temperatures further discussed in the temperature section. There is also an Auto freeze function witch triggers as the front lever is pulled. It starts to agitate the mix, and as the agitators are organized in a helical order it acts as a transfer auger forwarding the ice-cream to the header. In the meantime it also starts the pump, to resupply the cylinder with fresh mix, while also starts to cool the outer walls to quickly cool the freshly incoming liquid mix. It can be taught

of as a mandatory switch to the freezing stage for a time-out period.
As freezing occur periodically the machine have to monitor the heat cycle the mix goes trough as it can greatly affect the consistency. In short the same mix on the same temperature can have different textures based the heat curve, and agitation it went trough during the freezing process[2].

Temperature 

In conservation mode the primary goal is to keep both of the ingredient mixes at a food safe temperature (below 9 °C) It is also a side function during Ice-cream operation. It is done by controlling the evaporation in the helical coils around the tank assembly. It is important to note that due to hardware limitations the two tanks have to be cooled collectively. As in this mode the cylinders are not freezed they also have to be cooled. This operation is purely the same as In ice-cream mode, but with instead of consistency as a control parameter temperature is the main goal, also reduced to 9 °C, as well as agitation periods shortened, and check-up times are less frequent. Safety measures are also enforced during this mode.

Cleaning

Process  In cleaning mode the machines goal is to ease the cleaning process, and lift some limitations to make it possible, and efficient to maintain top hygiene requirement. To better understand the operation the cleaning process is shortly described: The leftower ice-cream from the pressurized cylinder is discarded trough the main header. As the ice cream surplus have to be cleaned the overhead tank is filled with hot water. To flush the tanks, and melt the ice-cream in the chamber. After multiple hot water washes the machine is disconnected, and disassembly begins.

Lifted Limitations Some limitations are lifted as follows: Auto freeze disabled: It would be impossible to clean the machine if it was continuously freezing the mix, so as the lever is pulled to discard ice-cream surplus only the agitation and the pumps trigger. Temperature control disabled: As all the ice cream is discarded, both the overhead tanks, and the cylinder temperature checks are disabled Ice cream level restrictions lifted: in the event of the depletion of the overhead tank the machine produces a software generated alarm and stops that side of the machine altogether. In the event of a cleaning these restrictions are lifted and the machine can be started again. Although the tanks should still be filled with water, and theoretically it disables the alarm any ways.

Specific functions Some functions are changed during this operation. In a nutshell the agitator continuously agitates in this operation, while the freezing is permanently disabled. The pumps are still continuously pumping the contents of the tank to the cylinder.

Misc There are some notable side functions. In Ice-cream or temperature operation, both of the cylinbders and the overhead tank assembly is being cooled periodically. As they all require pressurized gas for evaporation the compressor should also operate periodically. Nevertheless it does not. As the compressor is a high duty unit of the machine and during full operation power it would be needed almost consistently, other times it is just too powerful as to continuous would be needed.
Compressor control: All of the cooling operations can trigger the compressor but it has a separate closed loop control that keeps the pressure at a set level, if it is reached it would stop even if continuously triggered. This function acts as a layer of protection against blasting the pressure lines. Although the compressor is equipped with a high pressure unloading valve. It is a special unit that would seep back over pressure to the low pressure side in case a main board failure, to prevent damaging the hardware.
Safety: There are various safety features that have to be enforced. These are important to preserve the unit from accidental damage, and the operator from suffering injuries in case of unsolicited use, or machine failure.

Misc.

Overview The machine also contains several sub components that will be mentioned here, but are not being further discussed in detail. As they are transparent part of the structure, or simply too trivial for detailed description.

Agitation Motors: The agitation of the cylinders is achieved by two three phase synchronous motors. They can be turned on, or off through relays further discussed in the Electronics section.
Coupling: The motors are coupled to the beaters coupling shaft by an other coupler. It is in place to ease the sudden load on the motor in case tryal to start it with a frozen cylinder.

Belt transmission: The pumps are also operated by the beater motors, and the transmission is done by a system consisting of two pulleys and the belt itself.

Cooling The cooling system has many miscellaneous parts. Some of them are safety measures, and some of them are needed for proper operation. The deign of the cooling system taken up countless hours yet it is not discussed further.

Compressor: One of the most important part of the machine. It compresses the fluid gases from the evaporator to be cooled later in the condenser. The compressor is a semi closed three phase unit. Mounted to the frame.

Condenser: The condenser is placed to the back of the machine, it is a fan cooled multi-flow plate and tube unit. It cools down the pressurized hot gas to liquid state.

Receiver: It collects the output of the condenser and ensures constant liquid coolant flow to the liquid line.

Solenoid valves: These valves are controlled by the main board, and the open the flow of liquid coolant to the expansion valve

Expansion valve: The valve is more like a mechanical controller that has a "feeler bulb" at the evaporator. It is used to sense the remote temperature, and controls the flow of refrigerant into the evaporator according to it. The TEV is used to control the flow of refrigerant into the evaporator to maintain a preset superheat.

Evaporator: This is the compartment consisting of the shell around the cylinder and the cylinder inner wall. It is further discussed in the freezing assembly section.

Misc. There are a few minor systems in the machine that serve purposes such as fastening, cables, and similar. The notable ones are listed below:

Insulation compartment: This is an area of the machine that is sealed off by molded heat insulation foam. It is adhered to the front wall of the machine, and covers all components of the the freezing assembly, the tank assembly, and also the coupling, and covers part of the belt transmission. The insulation is although a very important part of the machine, as without it the heat losses would render it inoperable, and there would be an immerse amount of condensate on the inside of the machine, the insulation cannot be removed because of the way it is molded in a single piece.

2.2.4 Electronics

Overview

The following part contains the description of all all the electrical related parts of the machine that are required for the operation keeping in mind safety, protection, power, and control, and sensing requirements. Most of these components are housed in the electrical cabinet at the back of the unit.

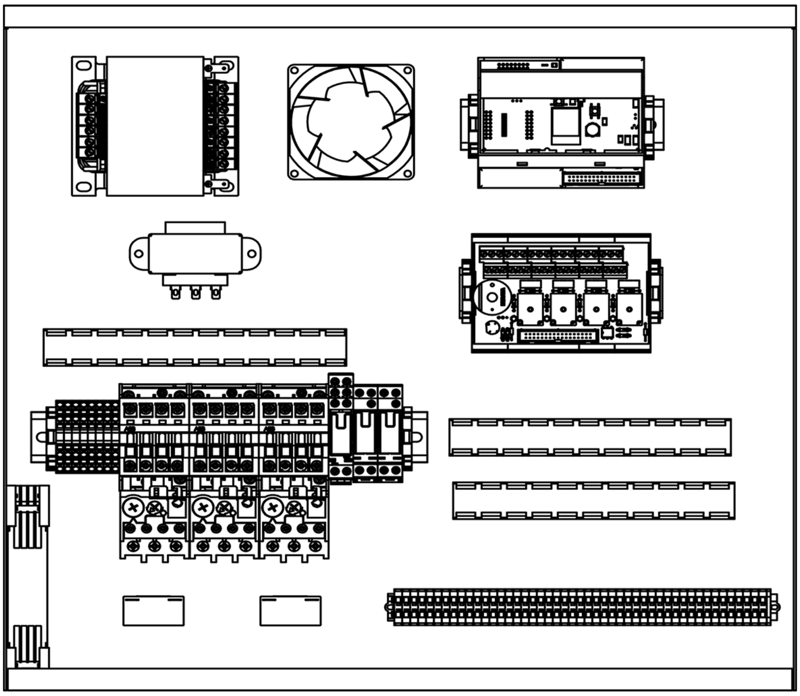

Figure 2-44: Electronic cabinet (Cables, and aux board removed for better vis.)

Safety

Safety: There are various safety functions embedded into the system. These functions run continuously and can not be disabled like the ones during cleaning. Some of these implemented in hardware, and some in software only, but all of them are detected by the main board, and an error message appears on screen. Motor Overload: Even tough the beaters load is constantly measured a temperature overload may happen. In case of a beater motor overloading(which is common in case the beater freezes into the cylinder) an overload protection relay clicks, and would mechanically separate the motor from the system. It would protect the beater motors even in case of a main board failure. Both the beater motors, and so does the compressor is equipped with this layer of protection.

Missing Header: In case the header is not mounted on the machine, an alarm trips. In no case should the machine be operated without the header properl mounted, as the header keeps the beaters in place. There is a magnet casted into the header, and a hall sensor would detect it's proximity

The reading of the different probes are constantly monitored. Multiple alarms can be triggered relating to misbehaving sensors. Probe malfunction: If a probe reads unexpected values an alarm would trip. An in depth investigation would be needed. This alarm can be triggered by the cylinder probe, the evaporator probe, and the conservation probes as well. Icing Alarm: If the evaporator temperature drops below -30 °C the compressor must shut down. It is important as in the machine there is no place for a suction accumulator, and as so if the evaporator cools down to a point where fluid coolant can not evaporate totally, and it would make it's way back to the compressor, it would proove to be fatal for the crutial piece of the machine.

There is an extra protection for the compressor for the motors. Motor stress: If the compressor runs for more than 15 minutes it shall be shut down. It would rarely be possible for the compressor to run for 15 consecutive minutes. (except if the lever is pulled down continuously, which is not part of normal operation)

Protection

The machine is also designed with self protection in mind. It is to ensure that in case of a simple mistake or likely component fault the system be less likely to suffer serious damage.

Unused Natural line: The electronics system of the machine has low voltage components like the relays, the main board, and the sensors, but the compressor, an motors are three phase synchronous devices. Usually these are powered from 230V (Natural - Live), but in this case it is transformed with a Multiple Winding Transformer from 400V (Live - Live). As so in the unlikely but possible event of faulty installation, where Natural line is switched with a Live the low voltage components would not suffer permanent damage.

Thermal overload protection: Every three phase motor (two beaters and compressor) are driven trough three phase contactors equipped with thermal overload relays. This ensure that in the event of a main board failure, or unskilled manual override the motors would be protected from overload, or phase failure.

Isolation: The low voltage parts of the machine are to be isolated from the high voltage side according to industrial regulations. This is done by galvanic isolation on the power line, and trough a series of relays, contactors, and opto-isolators in the control loop. There

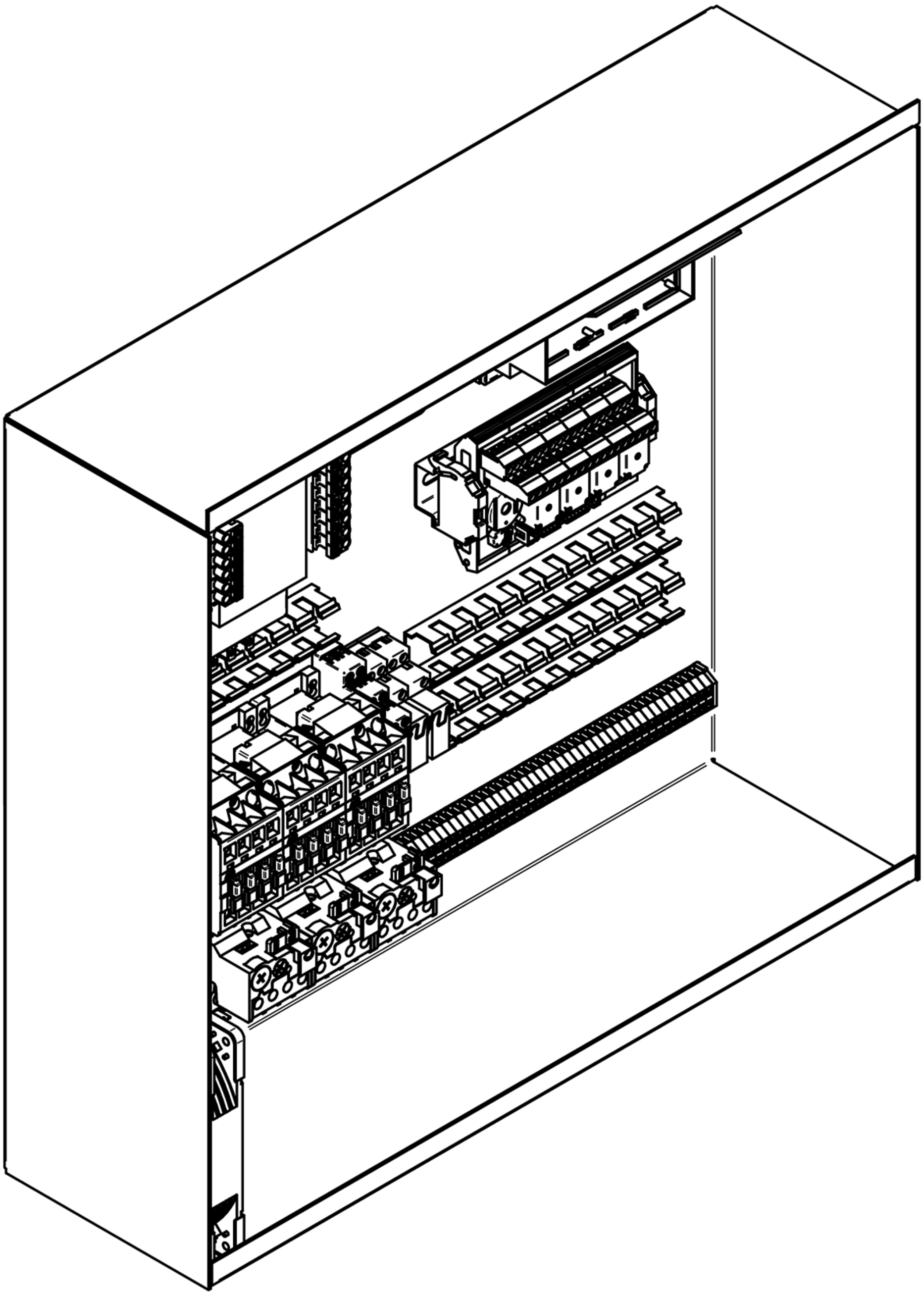

Figure 2-45: Electrical cabinet Isometric

are multiple lines of isolation. This way it is ensured that the operator does not come in contact with the high voltage line even in case of a short.

Schematic layout

Switching The machine has multiple high voltage 400 V, and low voltage 24 V components that have to be controlled by the man board 5 V. The main-board has both incoming, and outgoing lines, that have to be switched between the voltage lines. The three phase components of the machine are switched by a series of contactors, and relays, those relays are driven by opto-couplers placed on the main-board. In the event of a thermal overload separation, the overload protectors would kick in and trigger an other low voltage relay, it could be than sensed by the main-board and an alarm can be displayed to the user.

Power The entirety of the machine is running from industrial power (400 V) and the different lines, and subsystems are powered either directly or through the multi winding transformer. Motors: The three phase motors are directly connected to the input lines. (but controlled by contactors) Switching (12 V): The low voltage lines are transformed, and so galvanically isolated. The transformer has a 12 V secondary output that is driving the relays contactors, and some other electronics without regulation, as these are not prone to voltage fluctuations, and the line is relatively stable. PCBs (5V): The boards voltage lines are also galvanically isolated. Direct current is rectified from one of the multiple secondary windings (8.5 V) of the transformer by a full wave rectifier, and regulated for constant Direct-current power supply. Super capacitor Brownout backup: If the machine is planned to be operated from an unreliable voltage source such as a generator, as the beaters, and the compressors kick-in it can cause a short, but significant drop in voltage. For this the machine compensates it in software by turning on these high power components with a delay, yet if need arises an extension board can be attached to the main circuit board for compensation. This board charges superconductors, and constantly monitors line voltage. In the event of a brownout it would switch to drain the charged capacitors, and could operate for minutes without loosing data. Naturally only the main board would operates during this period, and even the interface has limited functionality. This is needed for the advanced software features (ambient temperature curve prediction, mix level prediction, logging, ect. . .) to keep their previous operation data.

Sensors The main board drives the different parts of the machine based on sensory readings. There are multiple operational sensors around the machine that monitor the

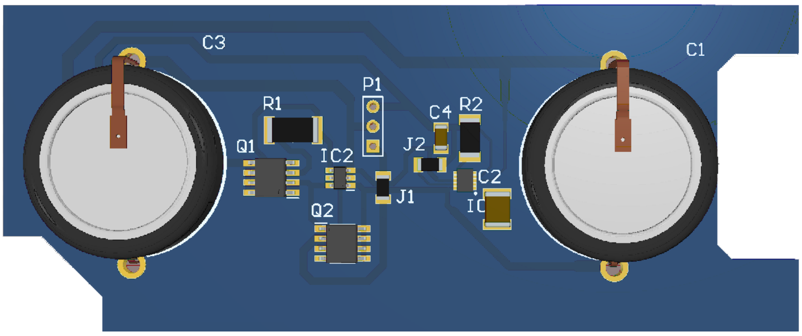

Figure 2-46: Super-capacitor extensionboard

conditions of the ice-cream making process.

Temperature: There are four external and one internal temperature sensors logging data continuously. Sensors are as follows: Cylinder evaporator thermostat: This sensor measures the temperature of the evaporator casing of the cylinder assembly. This reports instant temperature change as the cooling starts. Cylinder thermostat: This measures the temperature of the cylinder inner wall, it reports a temperature closer to the ice-cream itself. Tank thermostat: This reports the temperature of the overhead tank, and the condition of the liquid mix. Tank evaporator temperature: This probe is placed directly to the overhead coil, and reports the cooling speed of the liquid tank.

Lever micro-switches: When ice-cream is dispensed the operator pulls down on the front lever of the machine that opens the charmer in the header. It is further discussed in the Mechanics section. The piston triggers a micro-switch trough a series of fork, and levers mechanism. The switch reports it to the main-board that can turn on the auto-freeze function. (Discussed in the Function block)

Beater Load: The consistency of the ice-cream is measured by the load of the beater motor, that continuously agitates the mix inside the tank during freezing. It can be used to co-relate to the consistency of the ice-cream by a formula that is based on the shape of the helical blades of the beaters. The measurement is achieved through a current clamp attached to a driving line of the motor. It outputs an alternating signal that can be further processed electrically, and in software by the main board. This singal is pre processed in multiple ways for fidelity.

Main Board

Overview All the peripherals of the machine are connected to the main board including the sensors, the motors, and the fault detection mechanisms. As the master board operates

from low voltage, and is directly connected to the as well, love voltage interface trough a ribbon connector. All the other connection are interfaced through a secondary board further referred to as the “Relay Board”.
They are placed inside the Main cabinet with rest of the electronics components needed to operate the machine.

Master Board

Overview The master board is the hearth of the machine. It controls all the sub systems with the sole purpose of creating perfect ice-cream, and maintain long operation. The board reads all the sensors, and adjusts the output values according to the user set parameters, and general coefficients based on the machine design. It has many functions both in hardware and in software. It filters the sensor readings, and provides a definite output signal.

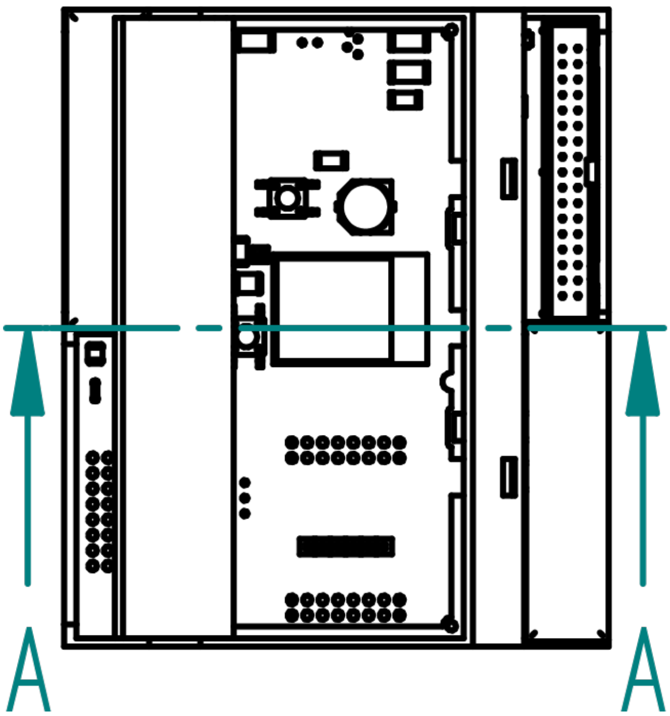

Figure 2-47: Main board (connectors on side)

Power Supply

Overview The required power is coming form the industrial input of 400 V, it is then transformed with a multi output transformer. For the Main board the 13.5 V secondary

winding is being used. This transformer allows for galvanic isolation to the high voltage line.
The different line voltages used by the components across the circuit are sequentially regulated from this source. The axillary super-capacitor board acts a separate power supply but also connected to the input to charge up.

12V Line The 12V line is only used to interface with components outside of the board. As the input voltage is 13.5 V alternative current it led to a hard decision as after the rectification voltage drop, a voltage regulator cannot be used. It is because even an low dropout voltage regulator has a 1.5 V voltage drop which was against a constant 8 V. Finally an unregulated path was taken in design, because the mentioned external components are not so sensitive to short voltage drops.

5V Line This line supplies the interface and the 3.3 V regulator. Also this line is in parallel to the super capacitor extension board that may be installed to the system. Although in an event of power loss the interface would not be supplied, just the regulator to allow a longer brownout operation for the micro-controller

3.3 V line Most of the logic components work from this line, and it may be supplied from two separate sources. This rail has been over design in a sense that it is supplied by a 3 A regulator but would consume around the third. It can be a little worrying, because regulators efficiency tends to drop on low utilizations, which would not be a necessarily big problem, but in low power mode it can frain the super-capacitors in an increased rate.

Input Most of the inputs that come to the master board are analogue, and require post processing, and filtering. Also as the choosen micro controller is an ARM core with only a few, and low resolution ADCs, multiple analogue-digital decoders were added to the system. The ADS1115 IC was chosen as the small footprint was beneficial, and with I2c capability an easily extendable, system can be achieved. The temperature signals are coming from thermistors. After the pulled up lines they are electrically filtered, and directed to the ADC. The MCU periodically reads it's values, and further filters them in software. As the thermistors are only connected to the main board, this input is not isolated.
There are some digital signals such as the micro-switches, overload relay, and the tank level sensor. They are opto-isolated, and connected to the micro-controller.

Sensors

Temperature There are multiple temperature sensors across the machine, as this date is crucial to the operation of the unit.
All of the external measurements are done by NTC thermistors. They have been chosen as they have better response to the target temperature range (-20;-50). For the measurements they are pulled up, and a high resolution 16 bit analogue digital converter reads their value.
There is an extra temperature sensor mounted on the main PCB inside the master assembly. It is further away from other heating, or cooling components of the machine, and used for ambient temperature measurements. After the cylinder reached its target temperature it starts to cool in intervals. The length of these are heuristically found by the main board, and adjusted based on the ambient temperature.

Consistency The consistency is measured during the periodical agitations of the mix inside the cylinder. It is done by measuring the motor tongue, as it increases when the beater blades friction increases due to viscosity change of the cream in the cylinder[2].
Current clamps are attached to one line of the motors driving three phase power line. The clamp generates as a transformer and induces a 50 hz sine wave in the secondary windings of the clamp. The amplitude of the current co relates to the power consumption of the motor which also co relates to the torque of the beaters. The above described current can be measured by observing the voltage drop across a shunt resistor.
Multiple approaches were tested. One with a full wave rectifier to rid of the alternating current, and an other one with a voltage divider where one terminal of the secondary coil is connected to the mid-point of the divider instead of ground raising the whole waveform above 0 V.

Lever The levers are measured by micro switches that are triggered by cam arms positioned above the header piston valves. The three corresponding micro switches trigger the cooling of the #1 Chocolate Cylinder, #2 Vanilla Cylinder, and #3 Vanilla syrup.

Remaining Ice-cream The ice cream level sensor is a simple stainless contactor in the tank. It is insulated from the chassis by a Teflon™[21] (PTFE) sleeve underneath. The sleeve is 15 mm high to give enough margin for the user to refill the tank before it reaches

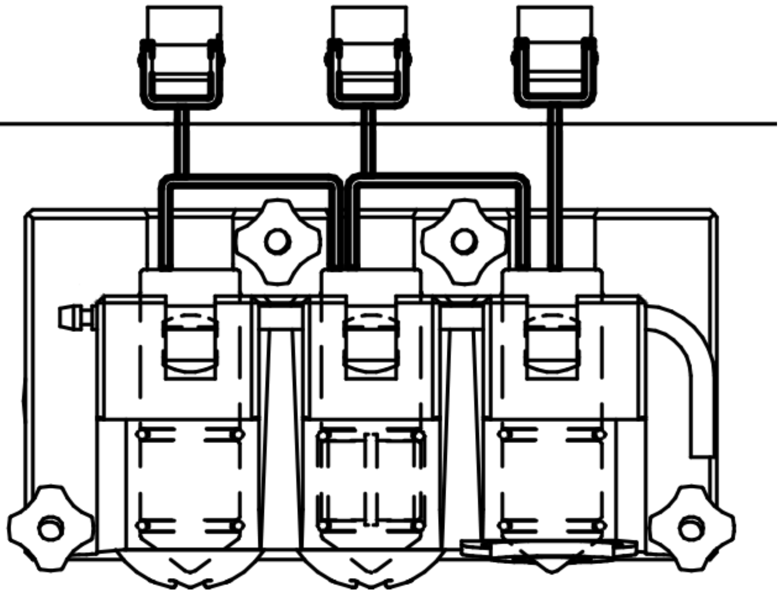

Figure 2-48: Latch arrangement

the pump snorkel suction tip. Which is highly not desirable as running the empty gear pump can damage it.

Safety

Thermal Overload The thermal overload protection mechanism is provided by RTA1, and RTA2. ABB TA25DU-14[19] thermal overload relay. The Beater motor is powered by contactor TTA1 which is wired to the motor troguh the protection relay. As a secondary level of protection the Relay board's RL1 powering TTA1 is powered trough the NC(95,96) contactor of the protection relay, so with the protection activated both the switching circuit and the AC motor circuits are interrupted.

Missing Header The header has a magnet molded into it's lower right corner. As a safety feature it trips a NO Reed relay if placed in the correct position. This in turn triggers R1(in the control box, not to mistake with RL1 on the Relay board). This relay opens, and the control board can log this change as a serious error, seizing all operations.

Micro Controller The micro controller is the brain of the machine. It is powered by a 32 bit Dual core, equipped with Wi-Fi capabilities, I²C, SPI, I2S, UART, and many more features.

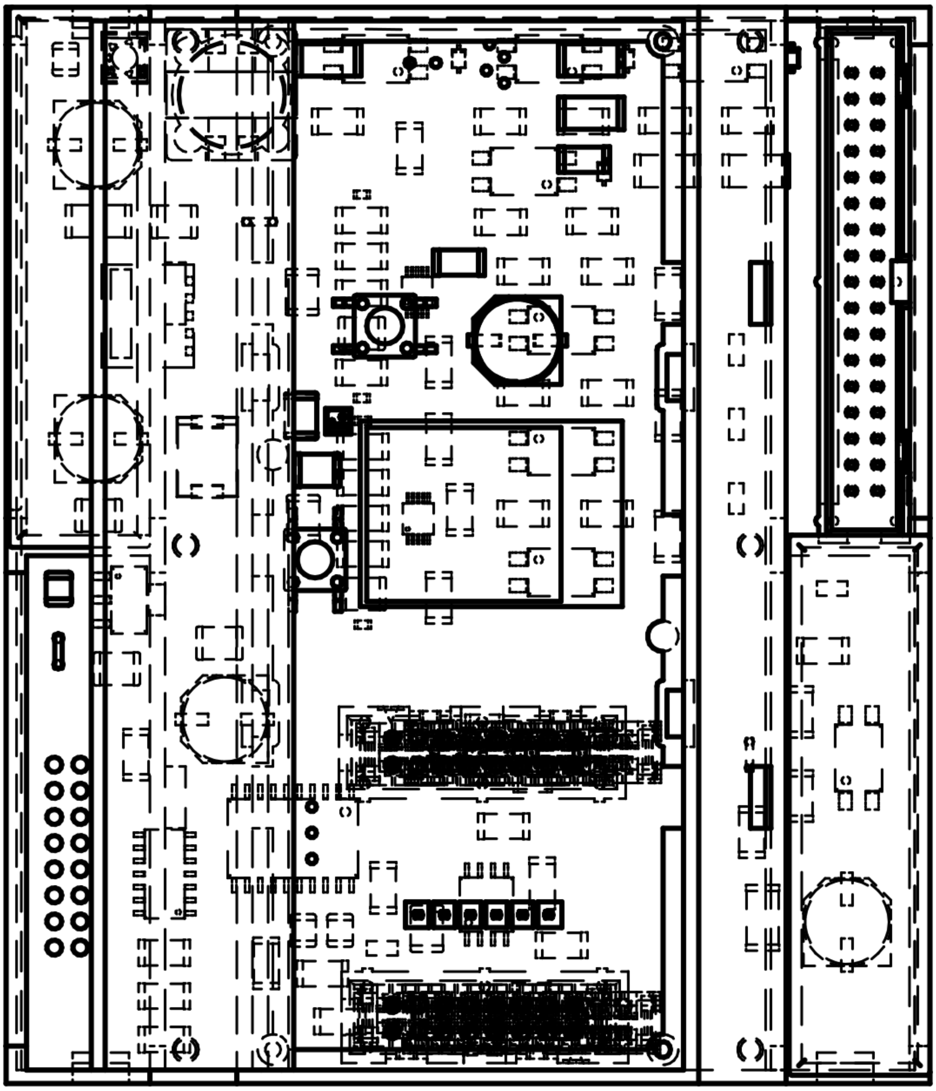

Figure 2-49: Components of the main board

Output

Interface

Segment Display The main user output is the 3 Digit 7 Segment display. It can be used to output the most important values of the current operation (Viscosity in cooling mode, Tempo in thermostat mode…) It is also used to navigate in the menu, and set different paramaters

Indicator LEDs The Indicators display the current status of the machine. There are 4 mode LEDs and a "Low liquid level" indicator.

Buzzer The buzzer is used as a secondary user feedback for button presses, and a notification for alarms, and condition changes throughout the states of the machine's operation.

Relay Driver The motor contactors, and solenoids are driven from the 24V supply. This is achieved through the relays on the Relay Board. The relay board relays are driven by a traditional transistor which is isolated using an opto-coupler.

Misc Printed Circuit boards: The finished master board consists of two to four printed circuit boards. It is so as there are two base boards, but two miscellaneous boards can be added to the system. The original two boards have to accommodate the connectors, and the idea of these upgrades had to be kept in mind throughout the design process. As the connectors are somewhat general, other extension boards can be designed in the future if the need arises.
Housing: The master board is housed in a DIN rail mounted shell designed to have three layers, one for an extension board, but due to the design of the extension boards multiple can be mounted simultaneously. The housing has four general port openings, for symmetry, though only two is being used. The other two is covered by two port caps. The housing has a hinging top cover that can be opened to access reset, service, and programming functions. It is made of a transparent material, covered by a film. The film has cutouts to allow visibility for the status indicator LED's.

Relay Board

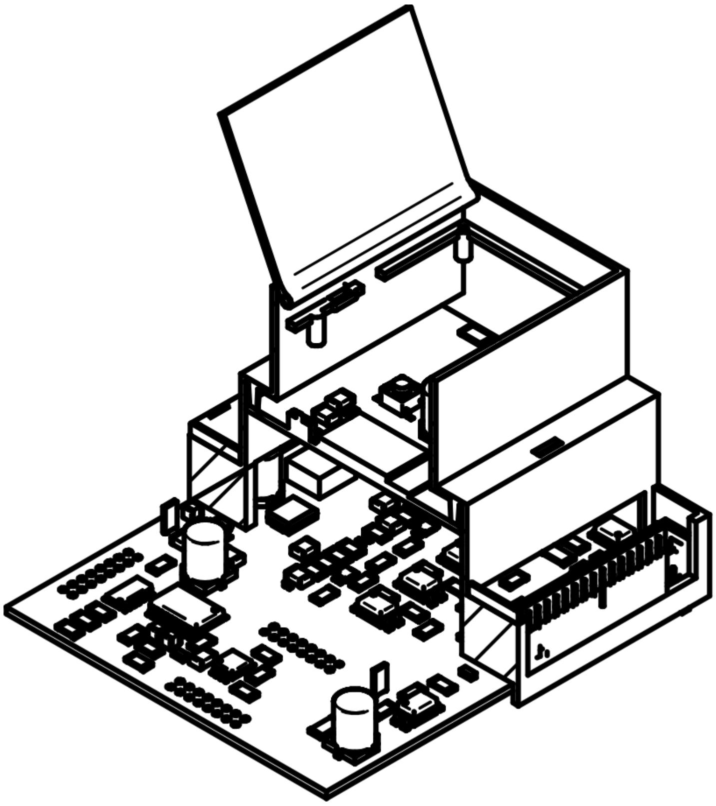

Figure 2-50: Buildup of the Master module

Relay Board The relay board acts as an interface between the individual components of the machine and the master board. It has two rows of input connectors 36 in total, in the form of wire terminals with a single 34-pin ribbon connector as an output linking it to the master-board.

Relay The board accommodates for four relays that are switching The compressor, the cylinder cooling solenoid, the tank cooling solenoid, and the beater motor. These are all connected to the actual components trough external high current contractors, and relays(24V), and as none of them are in direct contact with those components provides as a line of galvanic isolation between the interfaces.

Beater Load There is a wave rectifier that converts the alternating signal of the beater load clamp to a direct current to be processed by the main board, where it is converted to analog signals, and read by a submodule.

Isolation This provides a safe and reliable connection between the 24V interface of the thermal overload protector of the three phase beater motor and the main board's 12V net.

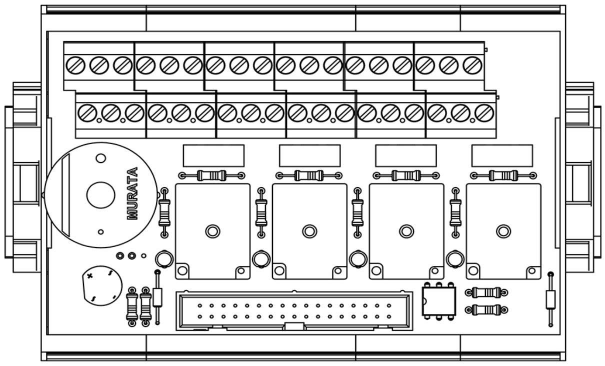

Figure 2-51: Relay Board Draft

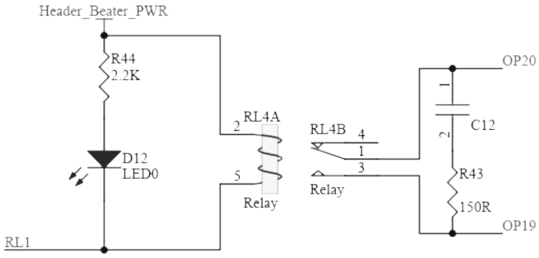

Figure 2-52: Relay with low side switching

Buzzer The buzzer that gives feedback to the user in case of button presses, alarms, warnings, and so. The buzzer also takes place on the Relay Board module, and as so it is using the 12V supply. Driven by an opto-coupler for proper isolation from the Master board

Implementation

Cabinet

Setup An existing cabinet have been modified and set up, so that the schematic would match with the design.
The terminal blocks have been wired with the inputs accordingly. Such as sensor lines, mains, power nets.
Relays are populated with the current protection according to the manufacturers specification[1], with the secondary protections implemented as described under the Protection section. Relay lines between the overheat protection, and the motor contacs have been equipped with the current transformers. On a side not only one phase passes through

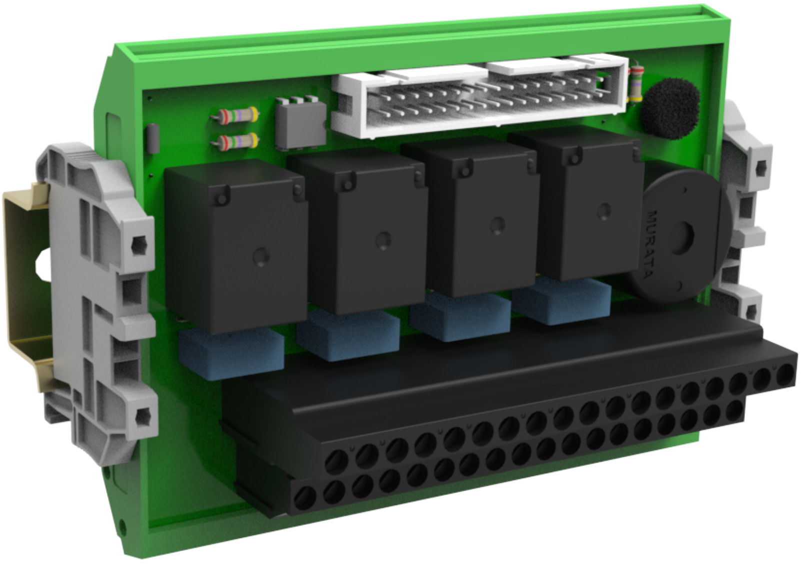

Figure 2-53: Relay Board on DIN Rail

the clamp, but as the three phase motor has a distributed load, it could be still used to approximate motor loading.

Transformers have been wired according to local mains voltages, and to comply with safety requirements[9]

Testing

Power The transformers, and power lines have been connected, according to the schematics. Then measurements have been conducted to measure proper earthing, and protection for electric shock according to IEC/EN 60364–4–41[8] Power outputs have been confirmed to reach the predicted values, and isolation have been measured across the transformer's multiple windings. Furthermore Galvanic isolation have been confirmed across the transformers.

Overload Protection The Overload Protection logic have been tested by manually tripping the test latch. It was observed that if the Protection of RTA1(Protection) is triggered

- TTA1(Motor contactor) cannot be triggered using A1-A2 contacts
- Even by manually triggering TTA1 the motor would not be electrified as RTA1 stops the flow of electricity on all three phases.

In Conclusion: All three levels of safety have been implemented on the beater. It is crucial as the beater motor is under significant load in case of over-freezing. This mechanism shall protect the machine from sustaining damage during operation.
The same test have been carried out on the other overload protection mechanisms, and the appropriate safety operation has been confirmed.

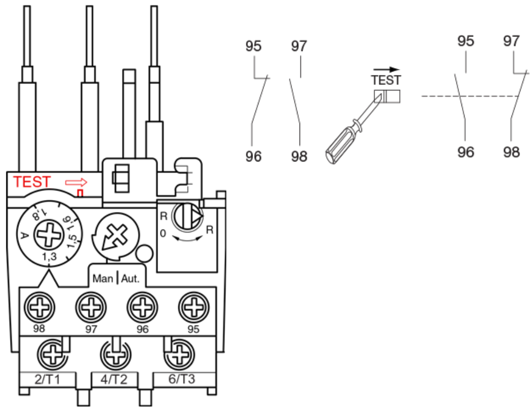

Figure 2-54: Overload protection test

Motor/Compressor The motor contactors have been manually tested, and the following effects have been observed:

- Turning action have been confirmed on all three phase motors
- The 220V fan switches on by tripping any of the motor contactors
- The Gear pump has confirmed turning action by tripping any of the beater motors. Pulley action checked.

Thermistors The NTC thermistor outputs have been measured in different temperatures to better interpolate the characteristics of the individual sensors. The temperature steps were -5°C, +25°C, +35°C. After that the Individual 'Beta' Coefficients of the devices where approximated using the Steinhart-Hart model[17] , and then the values were converted to more widely used Beta coefficients.
It was found that the individual values where not significantly different, and as so the average value was used for all three sensors in the final implementation.

Solenoids To test the solenoids, they were tripped manually from the 12V supply. Cooling was observed by combining the solenoids with the compressor on all three cooling surfaces.

Lever Microswitch The micro switches were tested with the “continuity” feature of a commercially available multimeter. Connection to the transformer’s “0V” pole was confirmed with the levers engaged. The mechanical valve operation was also observed, and a quick check for leaks was conducted.

Header Detection The detection of the header removal was tested with a strong Neodymium magnet. After confirming the operation the feature was tested with the actual distribution header, to check the embedded magnet.

Relay Board

Setup The Relay board has been installed on a DIN rail, and the 37 terminal connections have been wired to the appropriate pass-through connections, or directly to the sensors. The IDC connector was plugged into the Master development board

Testing

Overload Protection It was confirmed that while tripping the Overload protection mechanism manually(refer to testing the Cabinet), RL1 on the relay board could not be triggered from the IDC header(Master side).
Furthermore the Opto-coupled voltage detection has been tested. When the Overload-Protection kicks in the opto coupler sinks current from the 12V line.

Contactors The contactor driverrelays have been tested from RL1 through RL4 (with the overload protection on RL1). The relays were manually tripped using the GND pole of the 12V supply line using an external regulator. The contactors can be energized using the relays.

Header Removal, Thermistors, Lever, Level The pass through features can not be tested on the Relay board as it simply passes it through, from the PCB block terminals to the IDC pins. Continuity was tested on the boards at manufacturing, and after soldering to check solder joint quality.

Buzzer The buzzer was tested with the 12V supply ground using the same method as for the relays. Although sophisticated analysis could not be concluded, the speaker gave a signature “clicking sound” confirming connection, and basic operation theory.

Power The current clamps output has been tested using a Tektronix TDS 460A[20] oscilloscope and Tektronix P5205[15] differential probes. Current transfer was confirmed using an artificial load, and manually tripping the Motor contactor.

Develpment Board

Cause Because of the COVID-19 Pandemic sourcing parts from international suppliers was not possible, and a new approach was needed to continue the development of this thesis. A new second development board was designed and layed-out using other development boards as donors, or integrating complete demo boards on the surface, by castellated holes, or pin headers. Only the fully customized circuits get place on the board and they were replaced with TH(Through-Hole) Components for easier manual assembly compared to SMD counterparts.

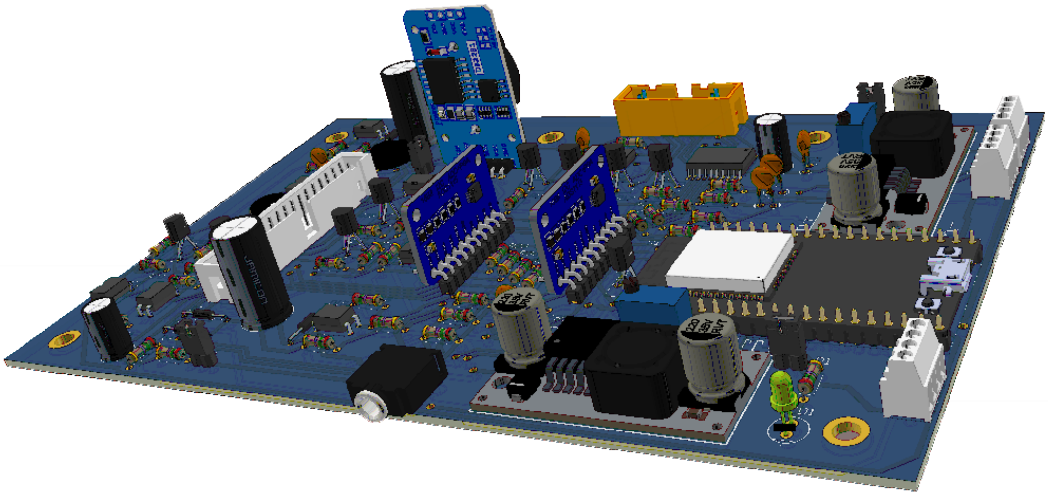

Figure 2-55: Second development board

Setup The development board was fabricated by a local manufacturer. Finally the missing components have been sourced. Different versions have been assembled all identical to the schematic design, with minor differences, to test minor different component performance.

Testing

Screen/Button interface The screen was assembled, and put in it's final place in the machine, then connected to the development board. Functionality was confirmed on all

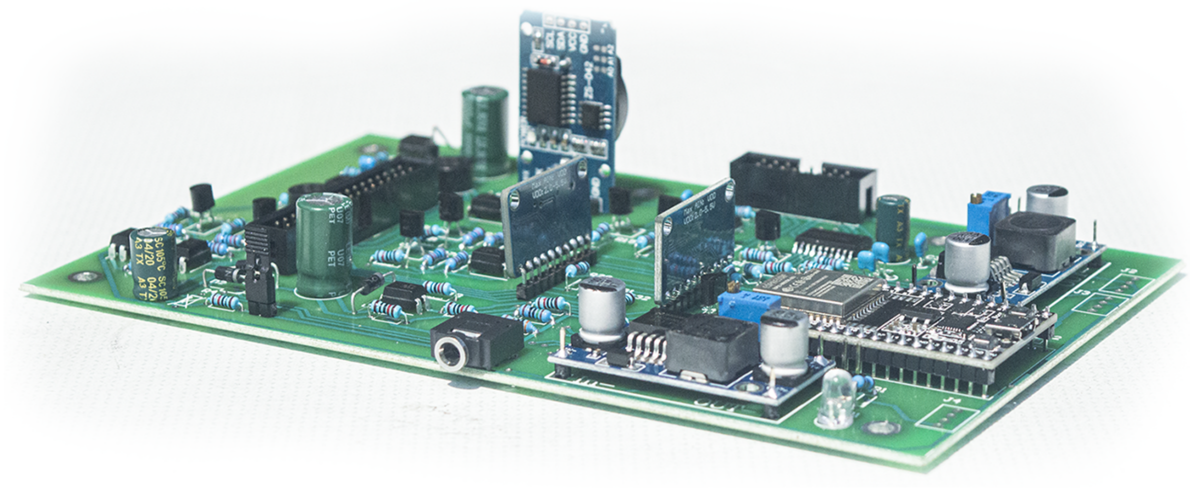

Figure 2-56: The assembled custom development board

screen segments on th three digits, the LED indicators (4th digit), and the button press sensing logic was confirmed with both micro-controllers involved, and also with signal analysis tools.

Minimal interface was quickly developed in an agile way to aid the testing of the rest of the peripherals, and server as a primary minimal output, and complement the more detailed, yet less accessible UART debug interface.

Relay Drives

Role The relay drive is achieved through the main IDC connector, being an interface between the Master board (Dev-board in this example), and the relay board. With the external relay multiple of the most important functionalities have been tested, considering all control outputs are implemented through this relay interface.

On all drives the output current was measured, and tested with artificial load. The circuit had no problem driving a sink of 150ma, which is triple of the Panasonic's retirements[10] for the relay. That not being a surprise considering the Collector current of the BC-357 being 800ma.

Beater The beater contactor (RTA1) was tested with the isolated drive using a simple sketch. The required relay tripped on the Relay Board tripping the main contactor , and turning action was also confirmed on the motor.

Compressor The compressor Contactor was tested, and the compressor started accordingly. The compressor's built in overpressure protection was also tested by running the unit without opening any solenoid valves. And with the protection kicking in the loss of voltage on the compressor line was measured.

Thermostat solenoid valves With the compressor running the solenoids could be tested. After building up some pressure on the discharge side, shutting down the compressor, the opening of the solenoids were audible. The solenoid and compressor action was also confirmed by measuring the temperature change on the cylinder inside wall. Icing was also observed on the cooling surfaces.

Lever Sensing The lever input has been tested with the development board. The lever micro-switch can be effortlessly sensed from the microcontroller board confirming the isolation circuits operation.
The signal have been measured with test equipment and no considerable bounce have been recorded.

Temperature measurement Temperature is measured with thermistors using a traditional voltage divider configuration. All four thermistors are connected to the same 3.3V supply, and individual voltage values are measured via an external Analog-Digital converter, for better resolution. The thermistor reading have been confirmed using different kind of temperature reference devices. (Mercury, Probe, and Infrared thermometers)

Motor current detection The motor current detection circuit have been tested with different appliances, by threading a single phase conductor through the current transformer, then hooking different loads to the line. There are two different techniques implemented in the board for current measurement. They use different principles, to eliminate the alternating current signal, and transform it into a simple digital output.

- Bridge-rectifier method: In this case a bridge rectifier is used to direct the flow of current, and a capacitor is used to smooth the line voltage.

- Voltage divider: In this case a voltage divider is used to shift the GND voltage of the current transformer up with half of high level (2.5V). In theory the voltage should alternate between 0 - 5V

In conclusion the rectifier method is safe, but due to the diode drop it is not applicable for detecting small current flows. Whereas the Voltage divider approach is sensitive to small changes, voltage spikes can rise outside of the threshold area, possibly causing harm to the sensing circuit.
On a side note: There is a more sophisticated Operational Amplifier based approach, but due keeping part count and cost to minimum this was not necessary as the motors measured in this application reach greatly over the threshold of the diode loss.

Liquid level detection The level sensing circuit has been tested on as separate board assembly, which was later integrated on the development board. (Ports have been previously added to the design for this purpose) Tests have been conducted with different liquids. The minimum of 5 metric liters is needed to reach the sensor. Nevertheless the sensor was tested with water, high-fat heavy cream, and ice-cream mix. In all tests the loss of contact was clearly indicated regardless of density. On a side note adding whipped cream to the top of the heavy cream layer resulted in slightly noisy results. It was merely a side experiment, and more research is needed for a conclusive study. In essence it is not a realistic problem, as small waves on the surface of the liquid can result in similar readings, and those conditions are inevitable.

2.3 Software

2.3.1 Overview

The software consists of all the machine code description of the functions the microcontroller has to tend in order to achieve the constant production of ice-cream in a safe working environment.

2.3.2 Steps

After the System design, A custom development had to be developed for the Software development to be able to begin. The board was designed, assembled (the button Input MCU HIGH speed programmed with the filter logic), and integrated with the rest of the electronic components, the control box correctly wired, the safety features implemented. After these the Software development began with implementing the safety features on the logic. The sensory inputs read ,and filtered, then the output functionality implemented, finishing up with the user-interface.

2.3.3 Safety

Goals

The safety features of the software should ensure the safety of the human operator, while optimizing product lifespan, and restricting certain operations in different states.

Methods

Logic

Safety Inputs Header removal The header removal is a logic input signaling if there is voltage on the 24V line or not. Coupled through two opto-couplers
Beater Overheat A logical input high if the Overheat protection relay tripped. Measures if there is voltage on the 12V input to RL1. Coupled via an opto-coupler.
Over-cooling Because of the design of the cooling system there is a minimum safe temperature for the evaporator. Supercooling it can reduce the pressure difference on the expansion valves, and could potentially starve the evaporator of liquid. For this the evaporator, and cylinder pressures are constantly supervised.

Settings The machine has numerous setting that are stored in the non volatile Flash memory. These parameters include crucial operation parameters such as target temperatures for the controllers, timeout, and sleep values. The memory also contains values not directly related to operation, but can be important information carriers for the user. This mostly contains statistical values, to help estimate runtime, prevent misuse, or improve service quality.
Some of these setting can be accessed via the menu, but some can only be accessed via the UART interface. The statistical values are read only.

Implementation

Overview There is a higher priority task running constantly in the background at all times, to monitor the state of the sensors, and may interrupt any process, if a fault condition arises. The Logic inputs are configured for Hardware interrupt, but also being monitored as an extra safety precaution. The temperature is read constantly by the control-loop, but there is a pre-check mechanism that gets the data directly from the sensor module, and interrupts the control loop if the value deviates from the expected.

Overfreezing The safety inputs have been tested. The reaction time of the machine was evaluated, if the safety features provide adequate protection in a realistic environment. The Beater overheat, and magnetic sensor are simple inputs. (Although the magnetic sensor detection is achieved with an AC signal) They were manually triggered, and the reaction was instantaneous.
The over cooling was tested first by setting a too low set-point temperature. The machine never reached it due to the protection activating. It was also tested manually opening the solenoid with an external power source, and manually pushing the compressors contactor to trip. The protection mechanism kicked in as expected, and the sound warning was audible.

2.3.4 Sensing

Goals

The software has to read the attached peripherals in such a way that would meet the following requirements:
Frequency: The read sample rate shall not limit the operation where the mentioned data is needed in such a way that would not allow the operation to meet it's own requirements. The sampling capabilities of the hardware were determined according to the cardinal theorem of interpolation [18], and the software shall be designed accordingly.
Accuracy: The data should be accurate within the general margin of error, and so that the machine would be considered deterministic. Meaning that under equivalent conditions the output deviation shall be non significant.
Latency: The filtered data can have different latency margins depending on its importance. Keeping in mind that different latencies could cause false interpretations of a situation.
Resolution: The resolution shall be great enough to provide the system with the capability to detect changes in the outputs, especially in critical values, with confidence.

Methods

Logic

Sensing The Master logic operates the machine based on sensory inputs that have to be converted first in hardware for appropriate signal levels. Analog to digital, or 24 V to 3.3 V for example. These signals may require filtering, and post processing before they can be used in the control logic.

Analog Digital Conversion The conversion is done in a 4 channel Integrated Circuit (ADS1115), and then the data is transmitted trough I²C. This is then filtered in software. There are two Integrated circuits in the system both housed on the main Master board. The analog inputs are then converted into appropriate readings.

Filtering The readings are filtered according to the application.
Tempearture: The readings are coming from Negative Temperature Coefficient Thermistors (NTC), and the readings are co-related to Celsius readings, then stored in a ring buffer[14] where it is later averaged, creating a moving average filter [7].
Motor Current: The readings are filtered and averaged according to the procedure mentioned in the Temperature section in a cyclical manner, but otherwise single changes are also analyzed for deviation. If a reading is suddenly changing in a trend, the event triggers a software interrupt, and the controller takes action depending on the severity of deviation, and other input factors.

Implementation

Overview These logic features were implemented in the Main CPU. Tasks involve querying the data, filtering, and processing the results.

Temperature read test The temperature sensors were tested, by reading the voltage levels, and storing the decimal values in the moving average filter. The returned value have been converted to temperature using the Steinhart-Hart equation. These values have also been confirmed with different thermometers.

2.3.5 Control

Goals

The software has to be able to direct the components of the machine to reach the general requirements such as:
Output: The machine has to be able to produce 200 units of ice-cream in an hour without wearing down it's components.
Freezing Control: The software have to control the solenoid valves in order to freeze the cylinder to a temperature, where pre-set ice cream consistency can be achieved without over-freezing, or frequent overloads to the beater.

Conservation: The overhead liquid mix should be conserved in a food safe temperature during operation. For this refrigerant flow control is necessary to the overhead evaporator coil. Also the preservation tans hall not experience extreme icing on the wall as it may be waste, and inefficient both to the conservation and ice cream production.
Compressor Control: The refrigerant shall be circulated, and compressed in the freezing system to satisfy the liquid coolant needs of the cylinders and the overhead tank. But in the meantime it shall not work unnecessarily, and prevent overpressure in the high pressure side even though mechanical countermeasures are also in action they shall not kick-in only in extreme conditions.
Interface: The micro-controller shall drive the interface, as LEDs, display, buzzer and receive the button inputs, to achieve an overall convenient user experience with understandable settings, and information display. Settings such as holding temperatures, timers, consistency, and other operations to be available for setting to the operator. The business perspective has not been considered during this development, and as so some of these functions may, or may not be disabled in a production setup for certain business models.
Safety: Above all safety of the operator, and secondhand longevity of machine operation shall be kept in mind. The software shall sense it's inputs, and regularly analyze it for anomalies, in which case it shall take preventive measures, by either stopping systems, or not letting the operator to start some functions. For example a beater start in case the header is missing. (it may cause in injuries or even a loss of limb)

Methods

Logic

Overview The logic section is to describe the fundamentals of controlling such a machine. There are multiple possible approaches to such a task and they were carefully evaluated to reach a final decision. It contains but is not limited to discussing the control of similar appliances, discussing, and comparing different approaches. Sating the reason of the chosen methods.

Controllers There are a variety of controllers in the machine that contribute to the correct operation they can be categorized into two groups. Thermostat controllers, and Motor drivers.

- Thermostat controllers have to evaluate multiple sensor readings, and co-relate them to the state, and temperature in the cooling unit, then adjust their output accordingly. They are MISO(Multiple Input Single Output) systems.

- Motor drivers on the other hand have a single input, and are operating in switch mode. They have clearly defined operation, when to run, as the motor is needed. For agitation, or pumping.

Implementation

Overview The controller runs a PID algorithm, and flips the solenoid valve. Taking care not to flip it too often, for both longevity, and safety reasons. It has a timeout, which would not allow it to be continuously flipped. The PID has a decimal output, and this kind of oscillation can occur when the output is oscillating around the set-point when crossing it over in a rare case of overshoot, or just “hovering over” it.

Tests

Overhead tank coolingtest The control loop has been tested for the overhead tank, and was found to keep the stored liquid below regulatory temperatures at all times. When tested with the traditional Chocolate-vanilla approach, a thicker icing layer was observable around the chocolate basin. Because of hardware restrictions the two basins cannot be cooled separately, but as Ice being a good heat insulator it seems to be a self regulating phenomena. Possible causes of the icing include the higher dry content of the chocolate mix, less consumption, and location relative to evaporator inlet.(The coil starts at the chocolate side), but it is not likely.

2.3.6 Interfacing

Goals

The interface shall be easy to understand and allow the operator to set the necessary parameters for operation. Such as Ice-cream texture, idle time, modes, etc.

Methods

Logic

Figure 3-57: Cooling test: final temperature after settling

Interfacing Because of the simplified hardware dedicated for interfacing, there was a need for sophisticated logic what would help the operator during use, but would also be suitable to provide debug information in case of errors, or failures. Furthermore the logic shall be simple enough to allow for the operator to browse a menu like interface, and set up different operating parameters, but has to be able to have complicated "hidden" menu options for professionals to set critical, or possibly dangerous setting, that should be transparent for the general operator.

Communication The screen is driven by a 6 grid 7 segment display driver. Commands are sent via I²C. Grid1, and Grid2 drives the buttons as well which is sensed by a separate hardware so resetting can be possible in case of main CPU failure.

WI-FI The micro-controller was chosen because of the 32-bit LX6 Xtensa 32-bit dual-core, but is also equipped with Wireless capabilities. This adds extra functionality to the device such as cloud connectivity, extra settings (that are harder to scam into the two button interface), statistics, and possibly remote SW updates with customer support.

Implementation

Screen The display is a 3 digit 7 segment common anode unit driven by an application specific IC. In software the challenge was to create a library that would encodes characters, and numbers (and LED states, as LEDs are driven as a 4th digit) to segment data, and transferred trough I²C protocol.

Buttons There is a separate micro-controller embedded into the display driver circuit. It's task is to create button press pulses, and to allow the user to reset the main processing unit in case of a failure. The buttons short one-one of the segment driving grid to a common pin. From the segment pulse timing. It can be determined which button is pressed. If both buttons are held for more than 5 seconds, the main CPUs reset pin is pulled LOW for 500 ms. Also if the Master CPU is reset three or more time in a row it returns to factory default settings. The resetting, and button pulse conversion is done by an Atmel ATTINY45 (soic8). It runs C code, and was flashed with a high voltage programmer. The highest priority was reliability.

Menu An other library was created to handle the display, and button interactions throughout the menu navigation. It would keep track of the actual mode of the machine, and light

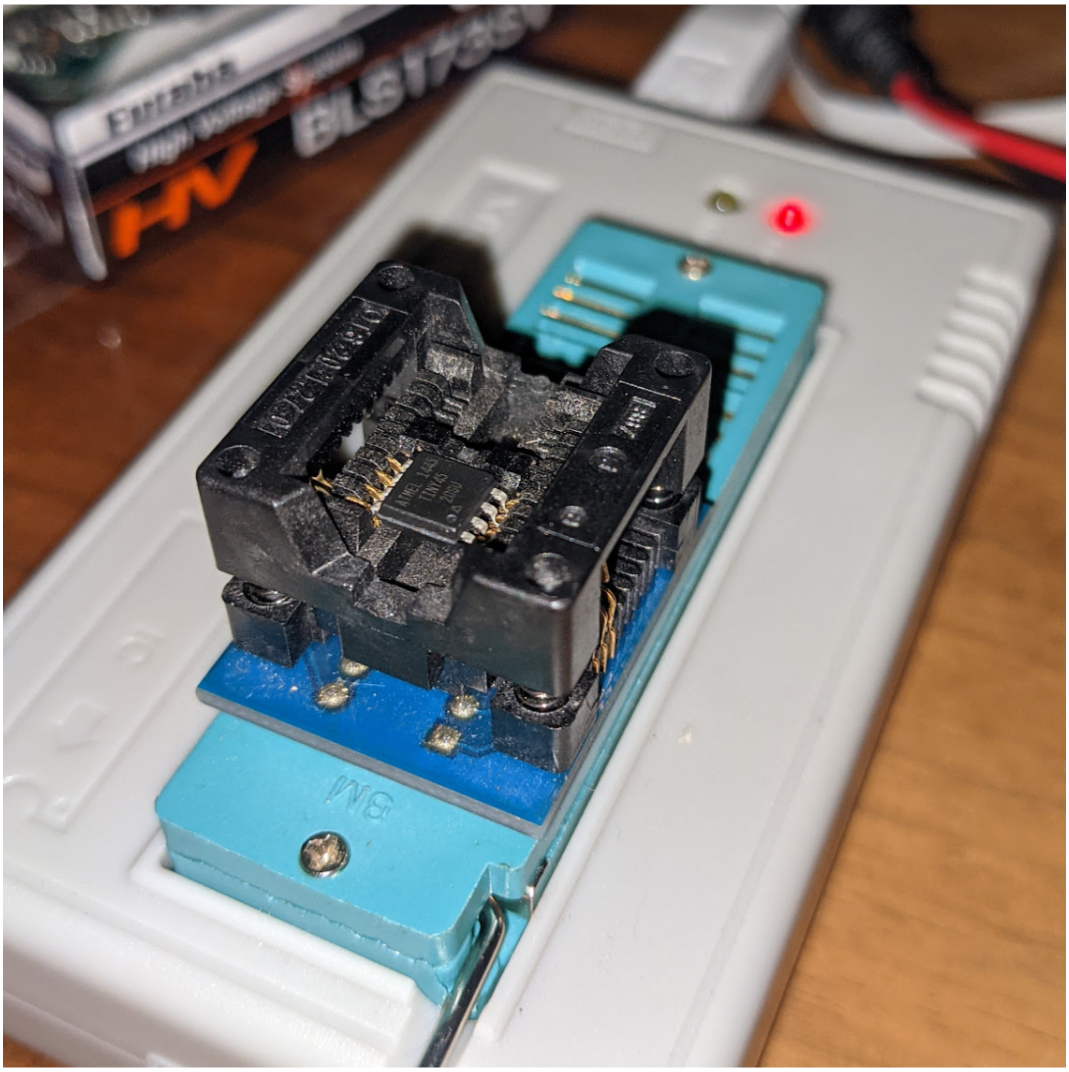

Figure 3-58: Flashing the microcontroller

up the mode selector accordingly. Furthermore the same button can cause different actions in different menu environments, and there are actions that require holding down a combination of buttons. These are all supervised by the Menu() parent object.

Settings There are multiple settings, the user have to be able to set during operation. These are critical to the functionality of the machine. The settings can be reached by Pressing and holding down the Stop $\boxed{\text{STOP RESET}}$ button (Also changes the active mode to stop) and pressing the Next $\boxed{\vee}$ button to select the appropriate setting then releasing the Stop $\boxed{\text{STOP RESET}}$ button enters the Value input mode where the value can be entered using the two buttons, and after 5 seconds of inactivity the effects take place.

Tests

Screen Print The low level functions were tested for printing individual segments, and LEDs, by turning segments on one at a time. Later the screen was tested using the Menu library by creating a dummy mode.

Button Read The button reading, and resetting circuit was tested on a breadboard setup. Signal integrity was noticeably weaker than on the implanted board. When a button(or more) is pressed one (or more) of the grid signals is imprinted over the line.

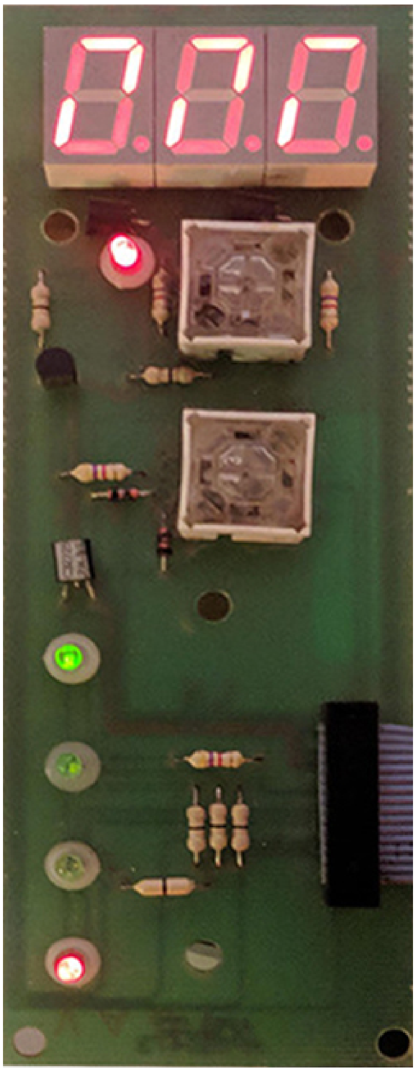

Figure 3-59: Segment Light-up test

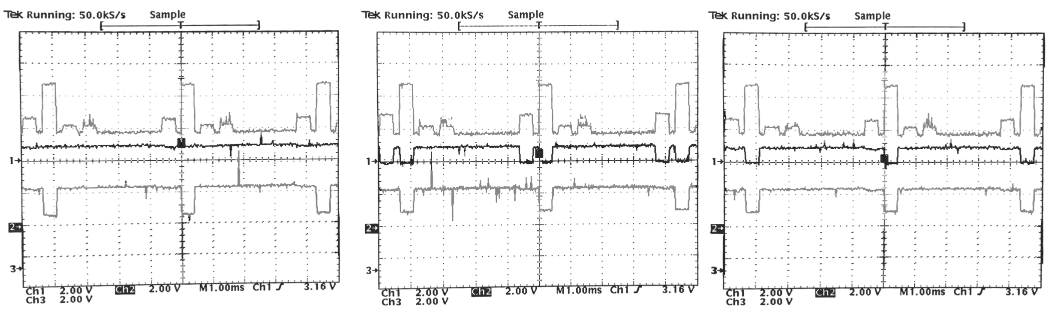

Figure 3-60: Signal test on button press

Chapter 3

Summary

3.1 Overview

Overall the goal of the study was to find out if the interfacing with such a machine, and software control would be feasible. After thorough research the conclusion is that there are optimal conditions for this task, they can be achieved in a variety of ways. This research implements one of those, and examines the possibility of others, provides insight how such a machine operates, what are the drawbacks, and what operating sensory parameters shall be considered.

3.2 Electronics

3.2.1 Compliance

The cabinet have been designed to comply with industrial standards. The design have been drawn in modern ECAD tools, and the layout, and wiring have been optimized. Schematics have been simulated in different design environments, for design optimization, and to reach retirements set by datasheets, Standards, Safety, and use-case situations. The boards have been simulated and optimized for signal integrity, while being cost effective, and provide ease of access during the continuous development continuous integration process.

3.2.2 Robustness

The subsystems have been designed with an overhead to prolong reliability, expected lifetime, and performance of the machine. For example the contactors are rated for three times the operating power of a single motor. The same logic follows throughout the switching circuitry.

3.2.3 Safety

Safety requirements have been achieved, and the machine is able to work in a safe manner continuously throughout it's operation. The machine was made to provide no harm to the user, and the electronics, and software complete this functionality. Nevertheless a maintainer who disassembles, cleans, and maintains the machine should be cautious, as not all source of danger have been eliminated relating to those use-cases, but it can be avoided with common sense, and improved with safety labels. Fore example the machine has no way of detecting a partially disassembled gear pump, yet a finger get get caught between the teeth, or a tool could be wedged in there damaging the machine.

3.3 Software

3.3.1 Features

The basic features have been tested on the machine, to prove the concept, and demonstrate the applicability in industrial conditions.

The controller is capable of serving it's purpose, and cool the ice cream to it's dedicated temperature weather in liquid form for preservation, or in the cylinder for freezing.

The menu is simple enough that a casual user can operate it after reading the manual a single time.

3.3.2 Reliability

The functions are reliable enough for prolonged use, and to trust the machine in operation as is. The sensors provide reliable data the user can trust for general operation, or troubleshooting.

3.4 Improvements

3.4.1 Need for improovements

There is no direct need for improvements, as the machine is reliable, and serves all it's purposes. Yet there is room for improvement in different fields that could uplift the user experience, or improve ease-of use.

3.4.2 Hardware

Liquid level detection

In the current iteration liquid level detection is done in a binary form. Only the presence of liquid at a specific depth can be measured, and without externally keeping track of the ice-cream mix refills, or visually confirming liquid levels the feature does not provide more help than a simple notification for a refill. In case of remote use where ice-cream mix might come from off-site it has multiple drawbacks.

- The alarm only comes up when only a small amount of mix is left in the basin ($_{20}$ units)
- The uncertainty of the measurement encourages the user to constantly check the level visually, opening the possibility for contamination of the mix reservoir.

Solution: A volume based liquid sensing would open up the possibility of software features, and greatly contribute to the usability of the machine.

- Push notification at specific volumes.
- Mix tracking, and statistics

Gear Pump

The gear pump is a highly sophisticated part of the machine. In actuality it is too sophisticated, almost fragile. This pump configuration was chosen as the simple internal parts can be disassembled, and cleaned by an unexperienced mechanic, but the tight tolerances can reduce the performance of the machine with wear. A more robust pump could be implemented.

Self Pasteurization

The machine has an open system where every component has to be washed every single day. This can greatly reduce applications in remote locations, or increase operation costs, and logistics. An overhaul of the machine for a self-pasteurizing variant would be needed to better comply with food hygiene regulations.

User Interface

The user interface is greatly minimalistic, on the edge design makes t hard to scramble even the minimum amount of features, and options into the three digit 2 button interface. A more sophisticated, visually more appealing interface would be needed to improve usability, and open up possibilities for software features in the future without complicating existing menus.

3.4.3 Software

Wireless connection

The Hardware already has a wirelesses enabled board, to ope the possibilities for future Software features such as Cloud connectivity, sending statistics, OEM error reporting , remote troubleshooting, User-experience improvement, and many more. With the extra, effortless two way communication interface there are many features that can be implemented nevertheless the lack of a better user interface on the hardware. These functions will be rolled out gradually after initial release of the Software

Smart temperature compensation

Ambient temperature compensation would be needed as the machine can be used in a variety of climates, and the condition can also change throughout the day. Fore example the sun can directly hit the machine in the morning, but the afternoon it could be in total shade. In this condition the same freezing, and mixing frequency can result in partially melted ice-cream dispensing in one case, while could lead to over-freezing in the other.

An ambient temperature sensor, and smart adjustments could allow the machine to constantly monitor the surrounding temperature, and fine adjust operating parameters in real time.

Statistics

The machine has been readied with a real time clock module to keep it up to date with time data. Using this and the future wireless interface the user can generate usage specific statistics, such as a heat-map, or graph containing what are the busiest times of a day. It could be compared with weather data to estimate the amount of ice-cream needed for future days. It can help with book-keeping to calculate the amount of ice-cream used for an event, or create an operator statistic estimating the size of portions a specific operator gives, to notify the owner, of oversizing, or undersizing.

3.5 Conclusion

3.5.1 Project retrospect

In hindsight, the machine could be further optimized, but all the golas have been achieved with overhead. The machine is reliable, while being easy to use. There is room for improvement, but future software functions, and new hardware iterations are already being worked on.

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List of figures

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Ipari dobhűtéses felsőtankos háromportú Lágyfagylaltgép valósidejű vezérlése ....

Szakdolgozat / Diplomamunka[2] címe angolul:

Real-time Control of Industrial Scraped-surface overheadtank triple port Soft-Ice machine

Intézményi konzulens: Dr. Kopják József ....

Külső konzulens: ....

Kérjük, hogy az adatokat nyomtatott nagybetűkkel írja!

Alk.	Dátum	Tartalom	Aláírás
1.	**2020.10.20.**	**Project overview requirements planning**	
2.	**2021.03.22**	**Design proposition I, format discussion**	
3.	**2021.05.01**	**Progress report, prototype proposition**	
4.	**2021.05.13**	**Deadline consultation, final adjustments**	

A Konzultációs naplót összesen 4 alkalommal, az egyes konzultációk alkalmával kell láttamoztatni bármelyik konzulenssel.

A hallgató a Szakdolgozat I. tantárgy követelményét teljesítette, beszámolóra / védésre[3] bocsátható.

Budapest, 2021.05.14.

....
intézményi konzulens

ÓBUDAI EGYETEM

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Szakdolgozat címe angolul: Real-time Control of Industrial Scraped-surface overheadtank triple port Soft-Ice machine

Intézményi konzulens:
Dr. Kopják József

Alk.	Dátum	Tartalom	Aláírás
1.	2021.05.13	Az első féléves munka áttekintése, tervezés a végleges szakdolgozathoz.	
2.	2021.08.25.	Konzultáció tervezés	
3.	2021.09.19	Konzultáció	
4.	2022.05.04.	Projekt report. Végső simítások előtt.	

A hallgató a „Szakdolgozat” tantárgy aláírási követelményét teljesítette.

Intézményi konzulens

Budapest, 2022. 05. 15.