MASINAEHITUSE INSTITUUT
Tootmistehnika õppetool

MET70LT

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Rotational mold design at Cipax Eesti AS

Rotovaluvormi projekteerimine Cipax Eesti ASis

Autor taotleb
tehnikateaduste magistri
akadeemilist kraadi

Tallinn
2016

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2015 aasta sügissemester

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MAGISTRITÖÖ TEEMA:
(eesti keeles) Rotovaluvormi projekteerimine Cipax Eesti ASis
(inglise keeles) Rotational mold design at Cipax Eesti AS

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Eessõna

Käesolev magistritöö on valminud tööülesannete täitmise käigus Cipax Eesti ASis mis tegeleb toodete tootmisega rotatsioonivalu teel. Ettevõtte asub Taebla alevikus, Lääne maakonnas.

Üks esimeseid ülesandied, mida töö autor on saanud peale antud firmas tööle asumist, oli suurenenud nõudluse tõttu täiendava rotovaluvormi projekteerimine 150 L liivatuskasti jaoks. Alguses oli plaanitud teha juba olemasoleva vormi koopia selleks, et selgeks saada rotovaluvormide projekteerimise teoreetilisi ja praktilisi aluseid. Kuid projekteerimise käigus on otsustatud liivatuskasti kuju niivõrd ära muuta, et project kasvas kiiresti uueks iseseisvaks tööks. Mainitud muudatused sisaldasid uusi kaane hingeid, käepidemeid ning võimaluse mugavalt tõsta liivatuskasti tavalise või kahveltõstukiga.

Töö esimese osa sisaldab rotovaluvormi projekteerimiseks vajalikke teoreetilisi aluseid. Sinna kuulub rotovalu protsessi ning selles kasutatavaid toormaterjalide ja masinate kirjeldus.

Teises osas on välja toodud rotovaluvormi projekteerimise üldiseid printsiipe ja reegleid. Samuti on kirjeldatud rotovaluvormide põhitüüpe, vormide konstrueerimiseks kasutatavaid materjale ja nende olulisemaid omadusi.

Töö viimases osas on kirjeldatud rotovaluvormi projekteerimise protsess kahe konkreetse näite põhjal. Üks on eelnimetatud 150 L liivatuskast ning teine on 3000 L maaaluse septilise mahuti juurde kuuluv pikenduskael selle kaane jaoks. Mõlemal juhul alustati tööd toodete CAD mudelitega ning lõpus ettevõtte töökojas said valmistatud rotovaluvormid, mida hakati edukalt kasutama ka tootmises.

Töö autor soovib tänada Sven Strandsoni (insener), Andres Sirkelit (vanem kvaliteeditehnik) ning Peeter Kuusksalut (kvaliteeditehnik) osutud abi, juhendamise ja tagasiside eest.

Abstract

The work of this thesis was conducted at Cipax Eesti AS – a rotational molding company situated in Taebla borough, Lääne county, Estonia.

One of the first tasks given to the author upon being hired was to design a rotational mold for one of the company`s products - the 150 L grid bin – due to increased demand. What started out as a task of copying an already existing rotational mold in order to study and apply the basic principles of rotational mold design quickly developed into something more complex after it was decided that several modifications needed to be done to the grid bin. These modifications included different lid hinges, handles and the possibility to easily lift the grit bin with a fork lift or hand pallet truck. After these changes were implemented it became clear that the new mold would no longer be simply a copy of the old one but a new project with its own design.

The first part of this thesis explains the theoretical foundations needed to succesfully design rotational molds. It contains information on the proccess itself, the raw material and different machines used in the industry. Following are the different steps of rotational mold design itself, including guidelines and basic principles to be followed during each of them.

This thesis uses two products as examples: one is the 150 L grid bin mentioned before. The other is an extension neck offered as an option for a 3000 L underground septic tank. In both cases work started with CAD models of the desired product and resulted in two rotational molds being made in the company`s workshop and successfully used in production.

The author expresses gratitude to Sven Strandson (engineer), Andres Sirkel (senior quality technician) and Peeter Kuusksalu (quality technician) for their guidance, valuable input and feedback.

1. Introduction

1.1 About Cipax Eesti AS

Cipax Eesti AS is a company making products by means of rotational molding. The company was founded in 1994 by Axel Friberg under the name Romo Plast AS. The company became part of the Swedish Xano Group in 1997. There are currently 75 people employed – with most working in the postproccessing and production departments. Production is set up around four gas-fueled independent-arm rotational molding machines. Three working shifts allow for 24-hour operation of the molding machines so no energy is wasted on cooling and heating up between shifts. Both the postprocessing department and storage areas have been recently expanded to a total of 10 500 m^2 to accomodate increased rates of production and the growing number of new molds [2]. The company`s inventory includes almost 1000 different molds, most belonging to the clients, the biggest one having a volume of about 3000 L. Molding of products up to 7000 L in volume is possible on the current machines [1]. The list of typical products produced in Taebla includes:

- fuel tanks for Scania and Volvo, which are considered the companys flagship product because of their complex shape and high quality standards (Figure 1.1)

Figure 1.1 Fuel tank produced at Cipax Eesti AS for Volvo and Scania. [3]

- toolboxes for Yamaha snowmobiles
- instrument panels for Fiskars Buster boats
- air intake tubes for Valtra tractors
- chemical and wastewater storage tanks
- buoys, pontoons and dock floats

Figure 1.2 150 L sandbox produced by Cipax Eesti AS [3]

Additionally, over one hundred standard products, such as sandboxes and trash containers (Figure 1.2), many of which can also be seen here in Tallinn and even around the TUT campus, are being manufactured for clients that do not require a special solution. Still, 95% of products are exported, with nearly 80% being shipped to Sweden. [1][2]

1.2 Rotational molding as a proccess

Rotational molding, also known as *rotomolding*, *rotocasting* or, in case of liquid vinyls, *slush molding* is a proccess for manufacturing hollow plastic products. Although it competes with such proccesses as *blow molding*, *thermoforming* and *injection molding*, it is a very efficient way for the production of large (over 2 m^3 in volume) hollow objects in one piece. [4]

The proccess of rotational molding starts with the introduction of a certain amount of plastic in the form of powder, granules or viscous liquid into a hollow shell-like mold. The mold is then closed and rotated or rocked about two axes at relatively low speeds (4-20 min^{-1}) while being heated. The plastic material inside the mold melts and adheses to the molds inner surface, forming a monolithic layer. The mold is rotated through the cooling phase of the proccess as well, so that the plastic material retains the desired shape as it solidifies. When the plastic is sufficiently rigid, mold rotation is stopped and the plastic product is removed from the mold for further proccessing. The proccess can then be repeated. [4][6][7]

The four basic steps of rotational molding are shown in Figure 1.3.

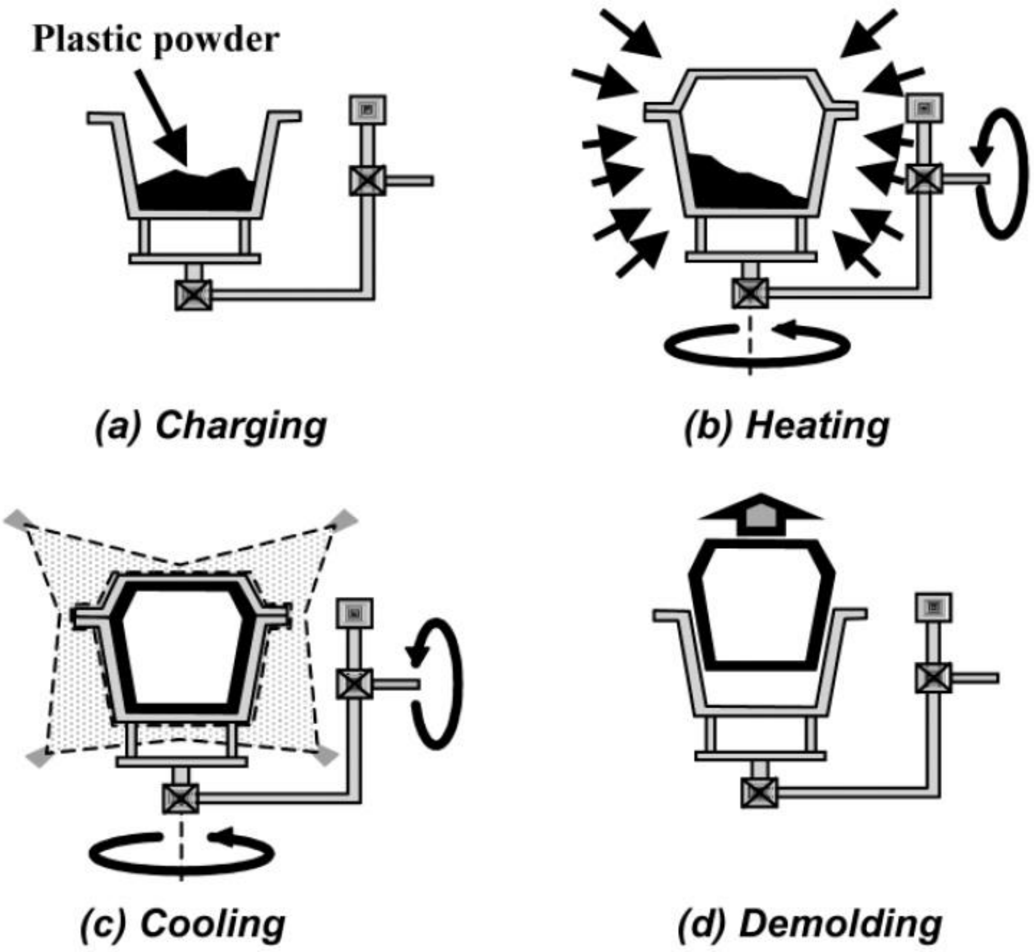


Figure 1.3 Principle of rotational molding [4]

What makes rotational molding unique is that raw material is inserted into the mold at room temperature, then the whole assembly is heated up to the melting temperature of the plastic and finally both the mold and the plastic within it are cooled back to room temperature. This means that the proccess is mainly controlled by oven temperature, time in the oven and rate of cooling. «Undercooking» the product generally leads to low strength and stiffness of the material, while «overcooking» results in excessive brittleness. Cooling time also affects the properties, dimensions and shape of the finished product, with rapid cooling making the product tough but less stiff, and slow cooling resulting in greater strength and stiffness, but weaker impact resistance. [4]

When compared to other competing proccesses involving plastic, such as blow molding and thermoforming, rotational molding boasts several advantages:

- a hollow part can be molded in one piece with no weld lines or joints
- thin-walled and relatively inexpensive molds with short manufacturing times
- multiarmed machines allow molds of different size and shape to be run simultaneously
- molding of complex double-walled shapes is possible
- uniform wall thickness of molded parts
- in-mold decoration with quality graphics and «in situ» inserts is possible

The shortcomings of rotational molding include [4][6]:

- limited choice and high price of usable raw materials
- shapes to be molded need to include generous radii – sharp corners are difficult to mold
- coarse surface texture
- long manufacturing time and high labor intensity

1.3 Raw material

The most widely used raw material in rotational molding is polyethylene (PE) in its many forms [4]. One of the most common plastics today, it is a thermoplastic polymer consisting of long hydrocarbon chains. All polymers exhibit glass transition temperatures. The glass transition temperature (T_g) is defined as the temperature at or above which the molecular structure exhibits macromolecular mobility. Typically this is when fifty carbons along the molecular chain can move in concert. More practically, it is defined as the temperature range where the molecular structure is transformed from being a brittle solid to being a ductile or rubbery solid. Thermoplastic polymers are generally of two morphological types. Amorphous polymers (PVC, ABS, polycarbonate) which have no crystalline structure or crystalline order. Amorphous thermoplastic polymers and essentially all thermosetting polymers have only one thermodynamic transition, the glass transition. Thermoplastic polymers simply get softer and softer as the temperature is raised above T_g. Crystalline polymers, on the other hand, have ordered molecular structure above T_g. [4]

Polyethylene is a chemichally simple molecule [8]:

$$CH_3\text{-}CH_2\text{-}(\text{-}CH_2\text{-}CH_{2\text{-}})_x\text{-}CH_2\text{-}CH_3$$

The molecular weight of high-density polyethylene (HDPE) which is typically used in rotational molding is about 35,000 (or x is about 1250). Its nominal density is around 950 - 960 kg/m^3. It has a glass transition temperature of about -100°C and a melting temperature (T_m) of about 135°C. The crystalline structure of polyethylene allows parts to retain their shapes at boiling water temperatures or more than 200°C above its T_g. Its relatively low price and high resistance to chemicals and UV light also contribute to its suitability for rotational molding. [4]

Low-density polyethylene (LDPE) is also popular among rotational molders. With a density of 910 kg/m^3 to 925 kg/m^3 this type of polyethylene is relatively soft and has low enviromental stress crack resistance. Nevertheless, LDPEs mold well at low temperatures and accurately replicate the surfaces of a mold. [4]

Medium-density polyethylene (MDPE) has a density of 925 kg/m^3 to 940 kg/m^3 and combines greater strength and stifness then LDPEs with better surface quality and lower porosity than parts molded using HDPE. [4]

Raw material used in rotational molding can come in a variety of forms (coarse granules made of nylon or liquid PVC), but the vast majority comes in the form of powder or micropellets [4][9]. Polyethylene powder is produced by pulverization (also called grinding) between rotating metal plates (Figure 1.4).

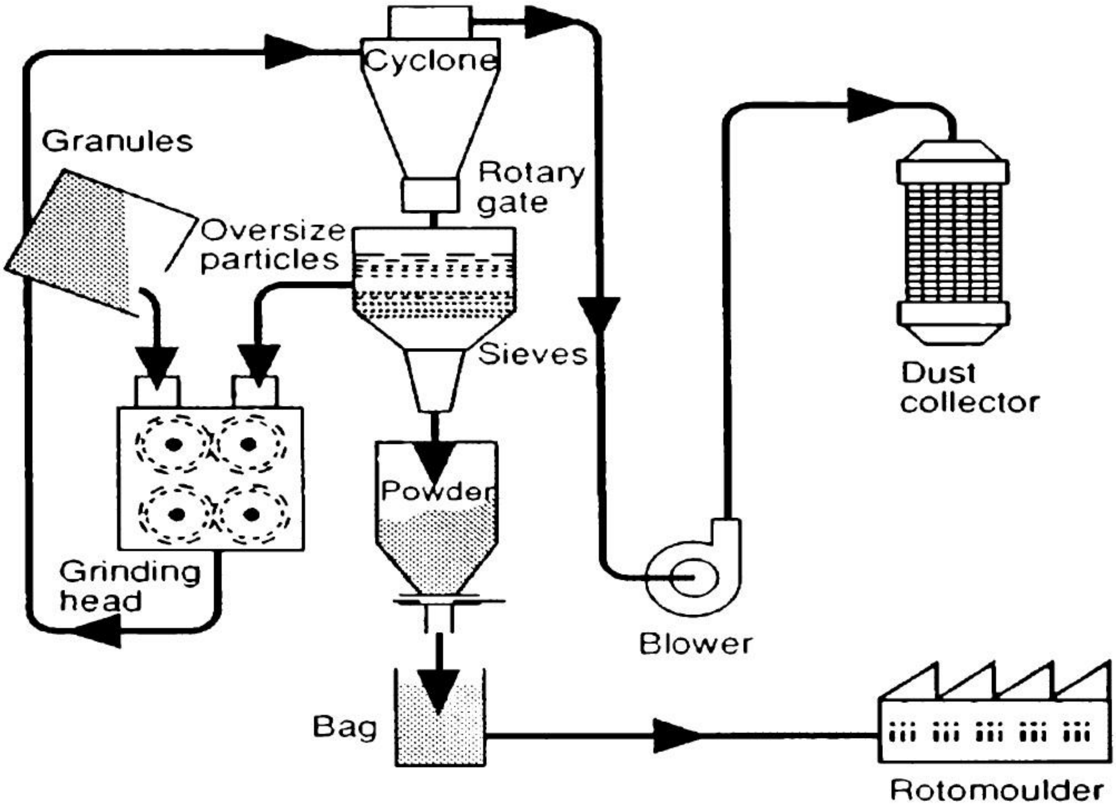


Figure 1.4 The basic stages in the grinding of polymers for rotational molding [4]

During the grinding proccess, control over the temperature of the cutting faces is critical, as frictional heat can result in temperatures higher than the melting point of polyethylene, resulting in blockages inside the grinder.

Success of the rotational molding process depends greatly on the quality of the used raw material. High quality plastic powder must meet the following requirements [4]:

- good heat transfer
- high initial bulk density
- good cavity filling
- no pinholes
- good surface finish
- no degradation in the mold
- no dusting

Powders for rotational molding come in a wide range of colors, with pigmenting being the main method for coloring rotomolded parts [4]. The pigment of a desired color is added while plastic granules or pellets are produced by an extruder. This method, called *compounding*, produces the best results in terms of part surface quality and mechanical properties, but increases the price of the powder and requires the molder to keep stocks of raw material of the needed color. A popular alternative among roto-molders is *dry blending*, when uncolored raw material is mixed with the desired pigment prior to its placement into the mold [4]. Different kinds of additives, such as dispersants, flow enhancers, antistatic agents, UV and impact modifiers can also be added to the powder at this stage. This eliminates the need to stockpile raw powder of different colors and properties, but increases the workload, as additional equipment in the form of blenders and mixers is neccessary. Care needs to be taken, as the amount and type of pigment used can have a tremendous impact on the mechanical properties of the finished part as seen in Figure 1.5. Another disadvantage is the inferior color quality of the molded part when compared to compounding. The difference between these two coloring methods can be inferred from Figures 1.6 and 1.7.

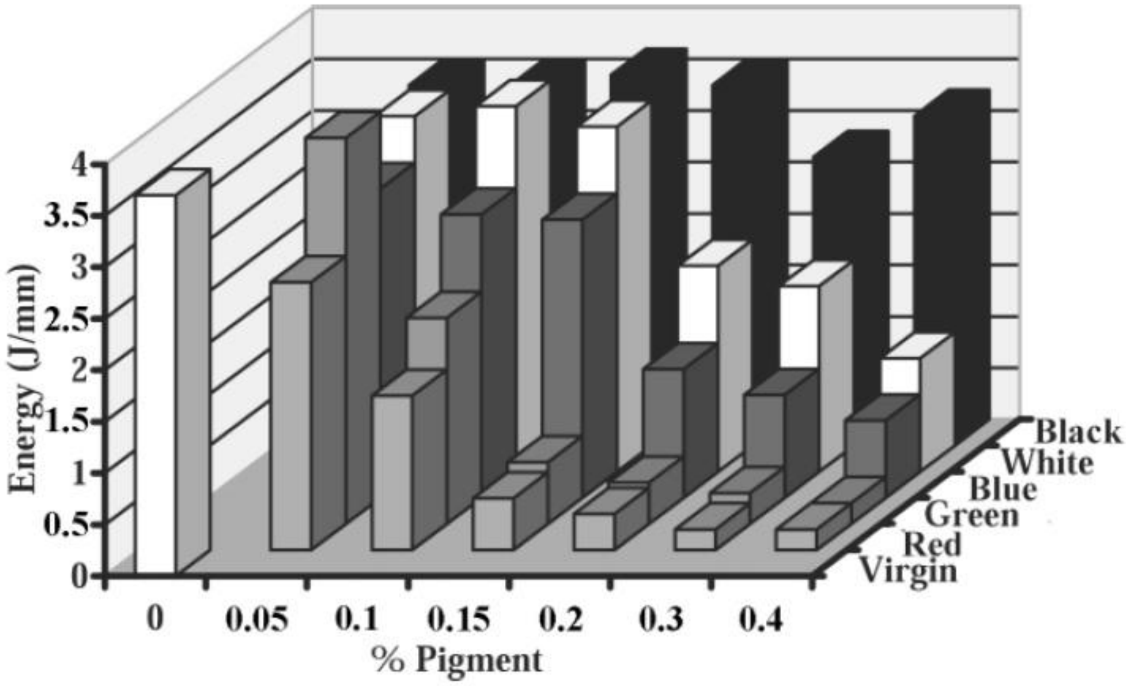


Figure 1.5 Effect of pigmentation level on impact strength of rotationally molded polyethylene [4]

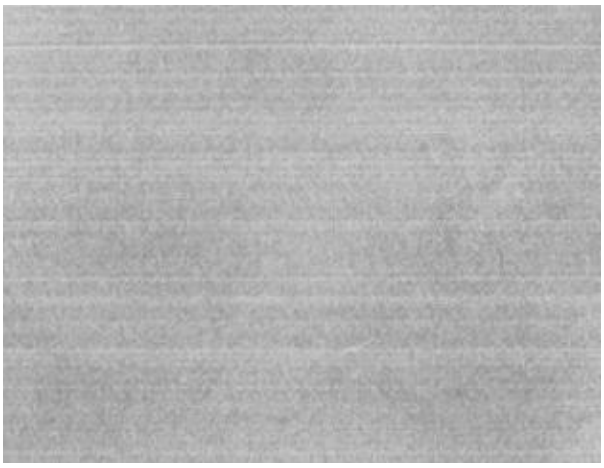


Figure 1.6 Microstructure of rotationally molded polyethylene part using powder colored by compounding [4]

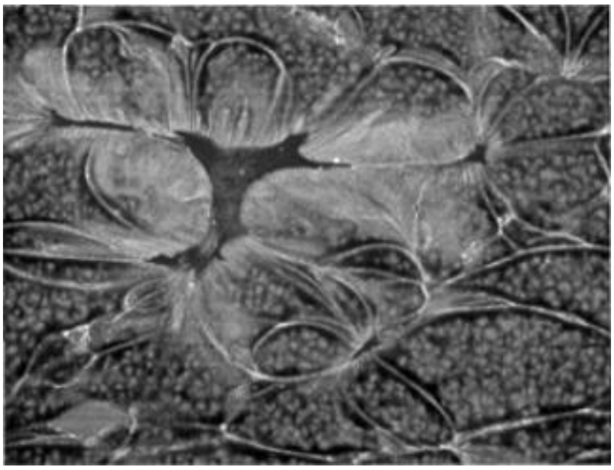


Figure 1.7 Microstructure of rotationally molded polyethylene part using powder colored by turbo blending [4]

1.4 Rotational molding machines

There are several basic types of purpose built rotational molding machines. One of the earliest designs in the industry is the *rock-and-roll machine* (see Figure 1.8), where, typically, a single mold is mounted on the machine and is rocked about one axis at an angle of less than 45° and fully rotated around another axis at relatively slow speed (about 4 min^{-1}). Direct gas impingement is an effective heating source for such a case. The process is better suited for products which can be produced using simple sheet metal molds and have a cylindrical shape or are symmetrical about a central axis.

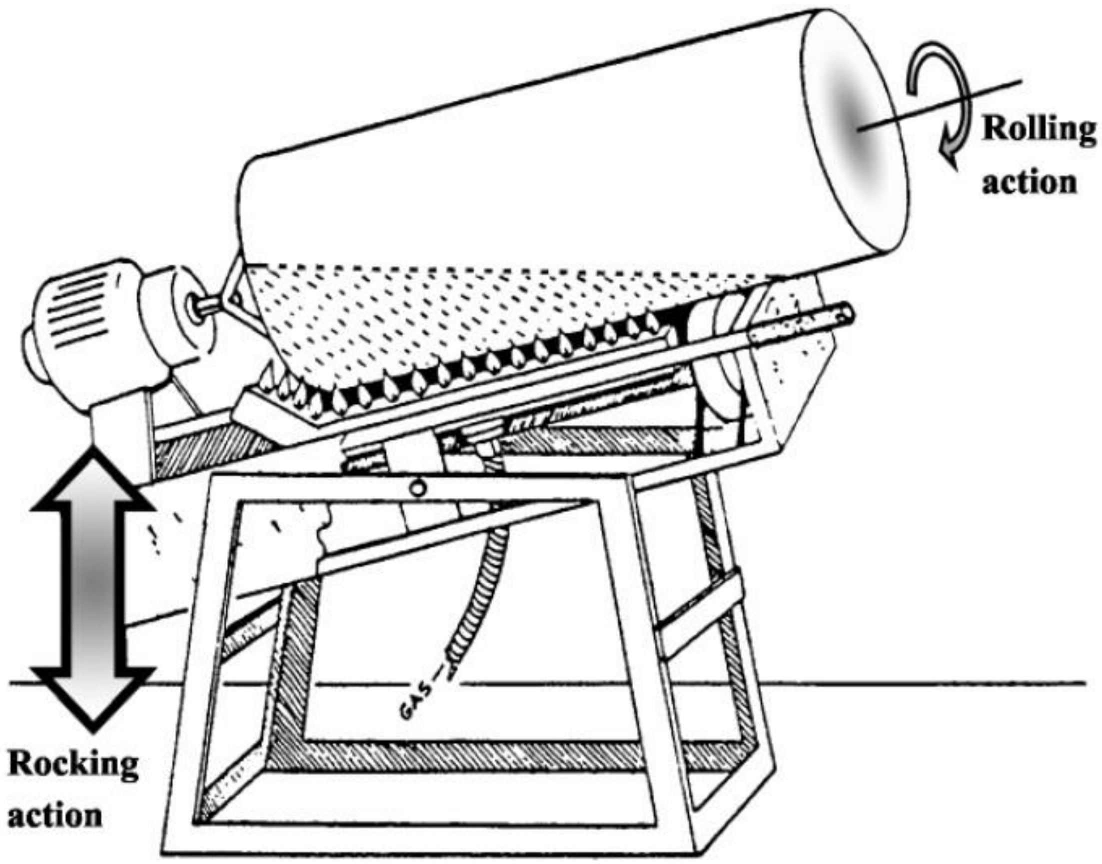
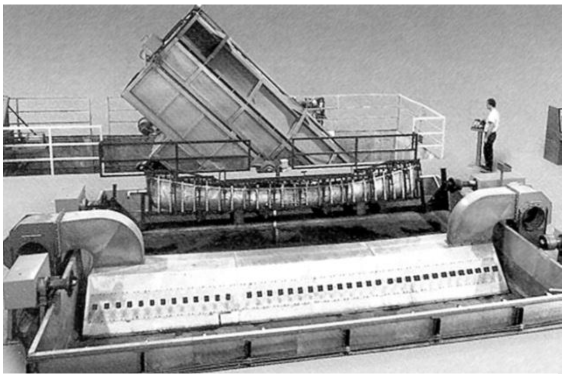


Figure 1.8 Rock-and-roll type rotational molding machine [4]



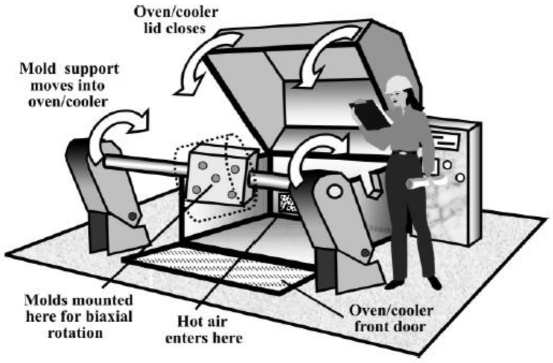


Figure 1.9 Rocking oven type rotational molding machine [4]

Figure 1.10 Clamshell type rotational molding machine [4]

In a *rocking oven machine* (Figure 1.9) both the mold and the oven are rocked about an axis together. Such machines are well suited for producing large products.

Smaller products can be roto-molded usind *clamshell oven machines* (Figure 1.10), where the oven closes over a mold. Such a design offers several advantages, such as small size and secure support of the main horizontal shaft of the machine at both ends. Molds are placed on assemblies, which in turn are mounted on turntables geared through the main shaft. During the process, both the main shaft and turntables rotate around their respective axis, while heated air circulates inside the oven. Cooling can be achieved by using cold air or water mist, or by simply removing the molds from the oven to cool down at room temperature, meanwhile the machine can immediately be used again for another set of molds.

The more modern *vertical machines* (Figure 1.11) allow high volume production of small products using very limited space. Molds are placed on arms, which move them into the oven, then the cooling area and finally into the service zone in sequence.

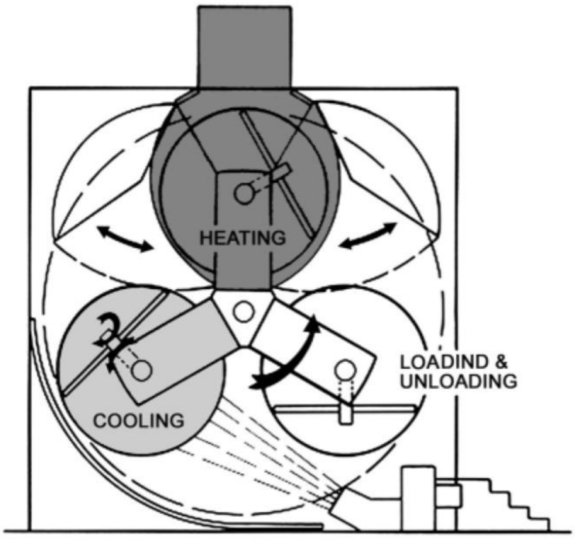


Figure 1.11 Side view of a vertical type rotational molding machine [4]

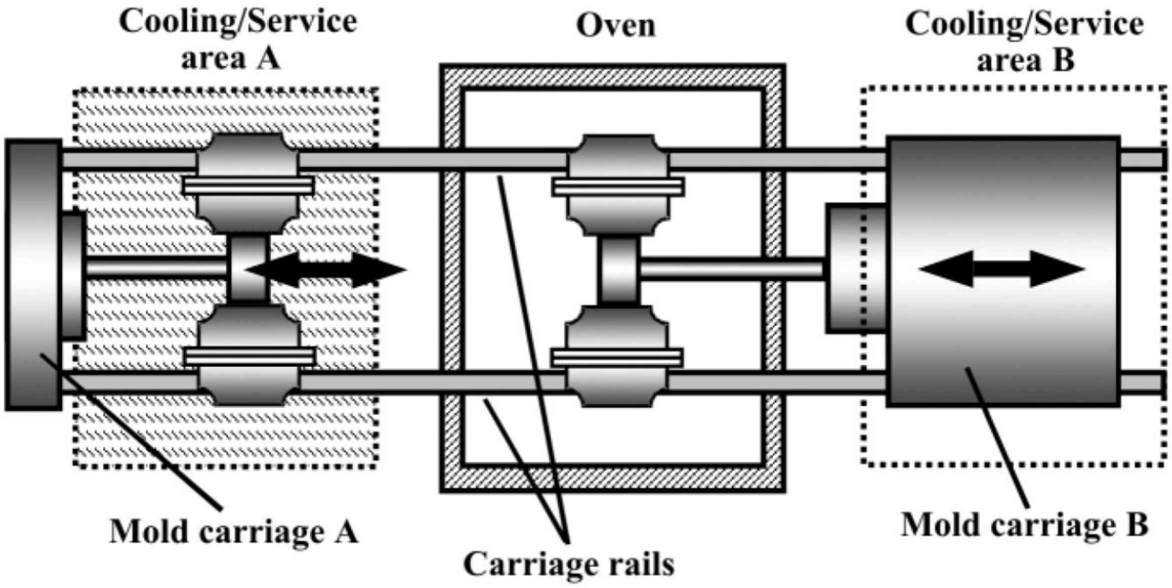


Figure 1.12 Shuttle type rotational molding machine [4]

Shuttle type machines (Figure 1.12) use a dual rail carriage system, which shuttles mold assemblies from the cooling/servicing areas into the oven and back. Such machines offer great flexibility and high output rates, but the drive system needs to be protected from excessive heat and corrosion.

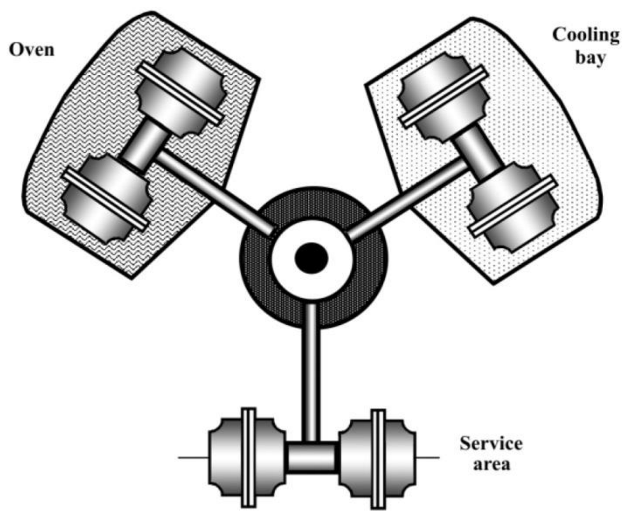


Figure 1.13 Fixed-arm carousel type rotational molding machine [4]

One of the most commonly used rotational molding machines is the *fixed-arm carousel type* (Figure 1.13), which specialises in long term production of medium to moderately large parts. Its advantages include great versatility in production schedules, as different combinations of molds can be placed and interchanged on each arm. Optimal results can only be achieved if the heating, cooling and servicing times are evenly matched, however. Otherwise, the slowest stage may become a bottleneck in the proccess.

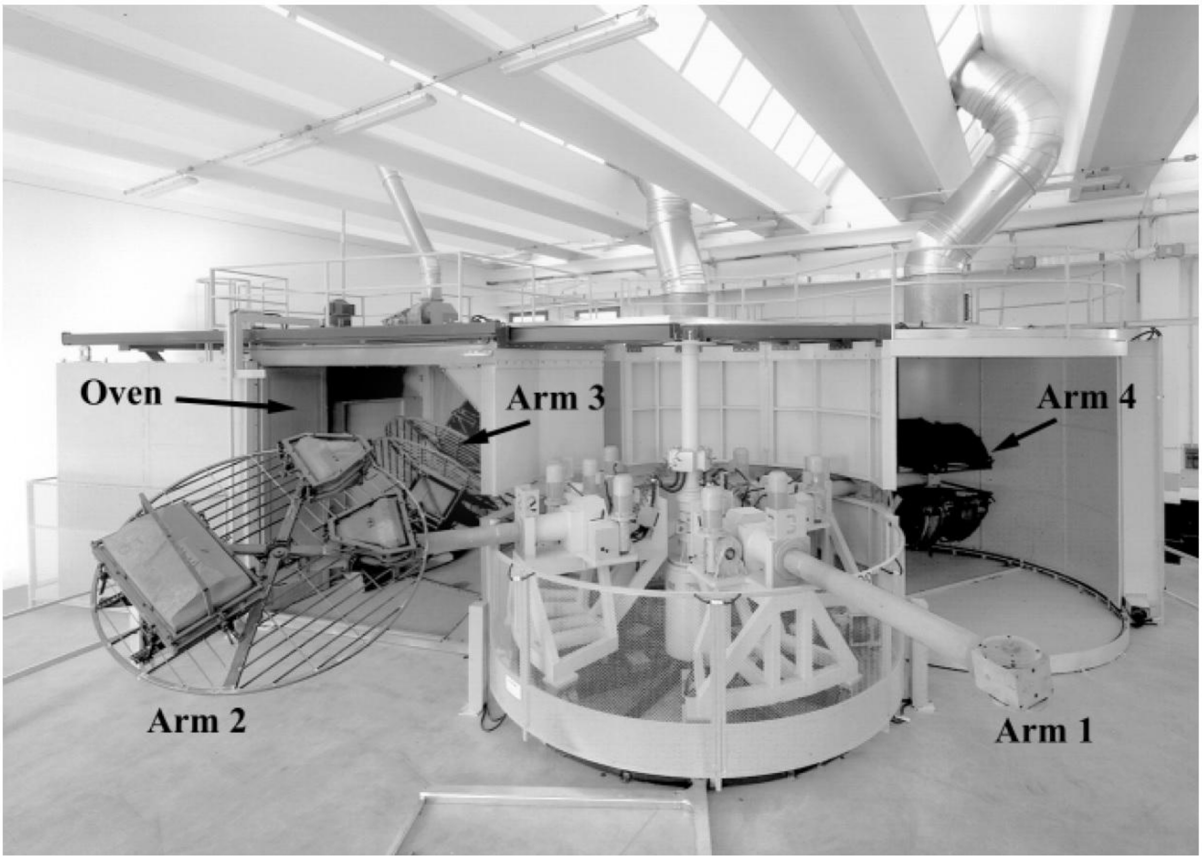


Figure 1.14 Independent arm rotational molding machine [4]

The market for new rotational molding machines is now dominated by the *independent arm* type (Figure 1.14), which is a fairly recent development [4]. Typically, they have five designated stations (including the oven, cooling and servicing stations) and up to four arms that can be sequenced individually. Though one of the most expensive, this type is ideal for molders making many types of products in different sizes and in large numbers. Cipax Eesti currently has four independent arm machines with gas ovens, with three of them in operation [1].

Oil jacketed machines, where the mold is heated using liquid instead of air in an oven, are more exotic and are mostly used in cases where the molding material requires higher temperatures (over 300° C), such as with polycarbonate. Though the heat transfer is more efficient, such machines are plagued with oil leaks between the rotating joints and remain rare in the industry.

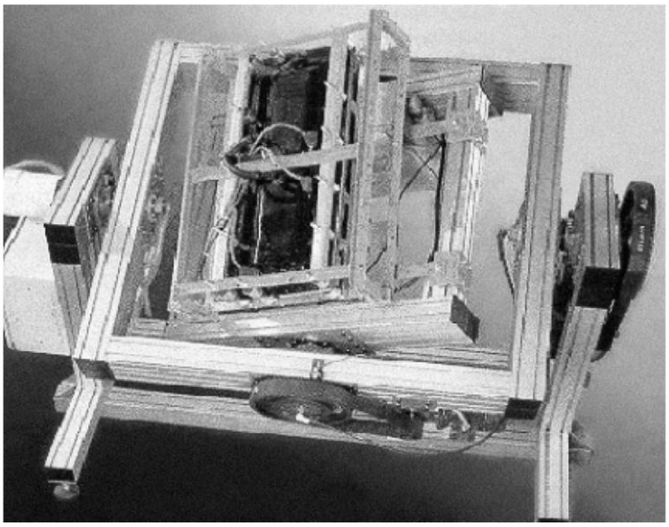


Figure 1.15 Ovenless electrically heated rotational molding machine [4]

Another way to achieve a higher effectiveness of the heating proccess is to use innovative *electrically heated machines* (Figure 1.15), where a network of electrical wires and ventilation channels is embedded in a cast, nonmetallic mold (Figure 1.16). With direct heating of the mold up to 80% of the energy can be used to melt the raw material, instead of the 10-40% in case of an air oven machine [10].

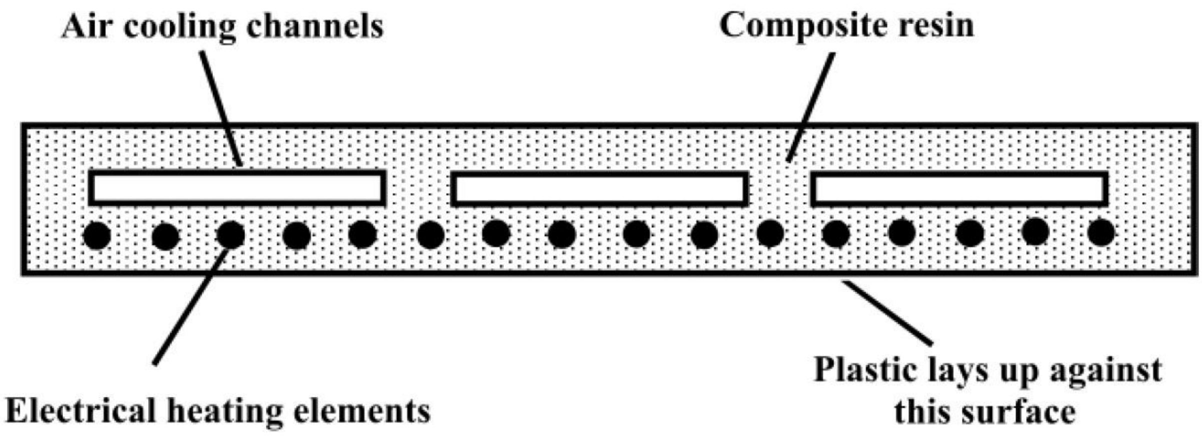


Figure 1.16 Cross section of an electrically heated composite mold [4]

However, molds used in electrically heated machines are more expensive and cannot be as easily modified, as their sheet metal counterparts. Long cycle times are another disadvantage, as heating, cooling and servicing of the molds have to take place sequentially. This makes these machines more suited for small scale production and prototype work.

As most standard commercial rotational molding machines, the ones used at Cipax Eesti AS feature two types of arms (Figure 1.17):

- an *offset arm*, typically used for single large molds up to 7000 L in volume
- a *straight arm*, typically used for carrying several smaller molds

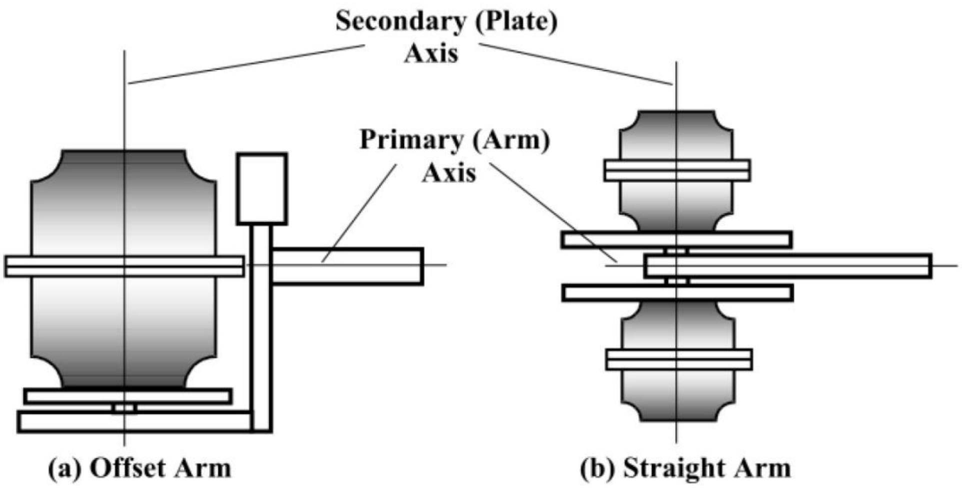


Figure 1.17 Two types of mold support arms used on an independent arm rotational molding machine [4]

As such, the capacity of a rotational molding machine is specified by two parameters:

- maximum weight of the mold
- mold swing (Figure 1.18)

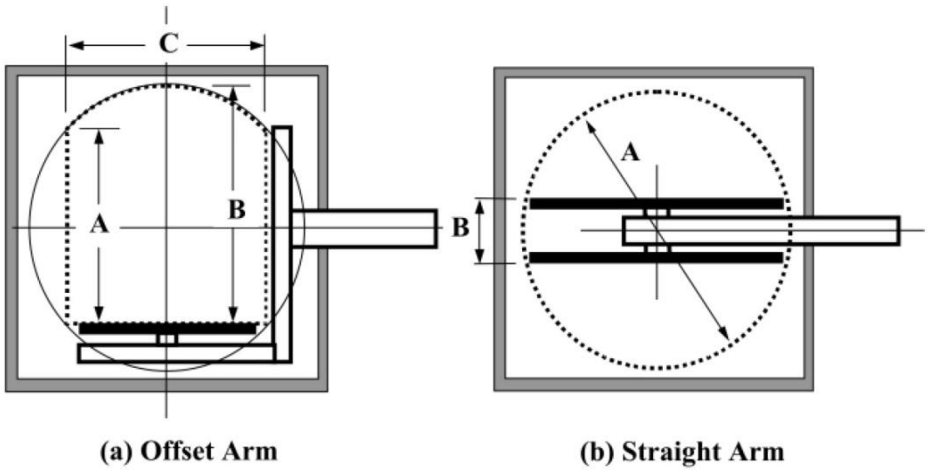


Figure 1.18 Mold swing dimensions for offset (a) and straight arm (b) [4]

Mold swing characterises the limits on the size of a rotational mold and is directly linked to the dimensions and shape of the oven and cooler (if such is used). The mold swing of a rotational molding machine is provided by the manufacturer in the specification sheets and is an important factor, that needs to be taken into account during mold design. The mold could otherwise come into contact with the oven or cooler as it rotates.

2 General Principles of Rotational Mold Design

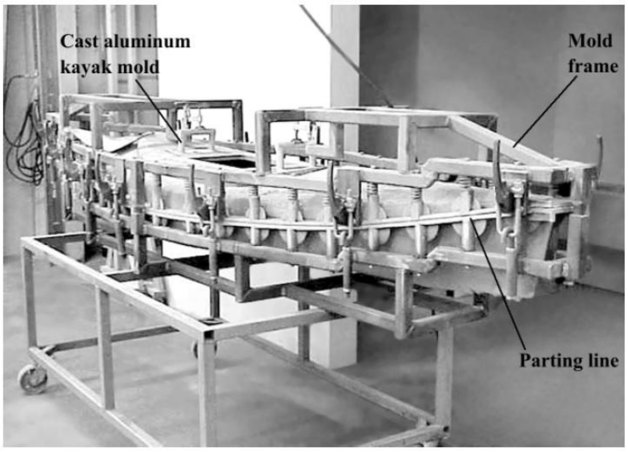


Figure 2.1 Rotational mold made from cast aluminium [4]

Figure 2.2 Rotational mold made of from steel sheet metal

Most rotational molds used in the industry are made from one the following materials [4]:

- fiberglass/composite – used for prototype work and small scale production
- carbon steel/stainless steel sheet metal – used for medium to large size products with a simple shape, such as waste water tanks and plastic containers (Figure 2.2)
- CNC machined cast aluminium – for small to medium sized products with a complex shape, such as fuel tanks and exhaust vents (Figure 2.1)
- electroformed nickel – for highly detailed parts made of liquid vinyl, such as childrens toys

The majority of molds used at Cipax Eesti AS are made from cast aluminium and carbon steel sheet metal, with efforts being made to produce simpler examples of the former in-house.

Material	Density, ρ kg/m³ (lb/ft³)	Thermal Conductivity, K, W/m K (Btu/ft h F)	Specific Heat Capacity, C_p J/kg K (Btu/lb F)	Elastic Modulus, E GN/m² (Mlb/in²)	Coefficient of Linear Thermal Expansion, α_T 10^{-6} K^{-1}
Aluminum (Duralumin)	2800 (175)	147 (153)	917* (0.4)	70 (10.2)	22.5
Nickel (Monel 400)	8830 (551)	21.7 (22.6)	419 (0.18)	179 (26)	14.1
Carbon steel (medium C)	7860 (491)	51.9 (54)	486 (0.21)	206 (29.8)	12.2
Stainless steel (304)	7910 (494)	14.5 (15.1)	490 (0.21)	201 (29.2)	16.3

* Value for pure aluminum

Table 2.1 Properties of materials used for rotational molds [4]

Low carbon steel is considered most suitable for most applications in rotomolding, because stainless steel is both much softer and has a lower thermal conductivity (see Table 2.1)[4]. Use of stainless steel is warranted, when there is a danger of chemical attack from the polymer or a high risk of corrosion due to water used in the cooling proccess or storage conditions.

Rotational molds made of sheet metal are, generally, relatively cheap and simple to make. Most parts needed can be produced using CNC bending and pressure rolling, although, given that most molds are also one of a kind, some parts may be made by hand using traditional blacksmith techniques such as bending, punching and hammering. The preformed parts are put together using conventional arc or inert gas welding. The internal mold surface is then finished by grinding, abrasive blasting and polishing.

Aluminium has excellent thermal conductivity but is much softer and less stiff then stainless steel [4]. This results in thicker walls of aluminium rotational molds. CNC machining is used for production of smaller roto molds, while atmospheric and pressure casting is required for larger ones. This makes rotational molds made from aluminium very expensive to fabricate. Possible modifications, to be made according to the customers wishes, are also costly and labor intensive. This makes such molds viable only for large scale production and extremely high quality standards, such as the case with fuel tanks made by Cipax for Volvo and Scania or exhaust vents for Valtra tractors.

Most rotational molds are openable in a clamshell manner for servicing and are therefore comprised of at least two pieces. Products of complex shapes can require molds made up of three pieces or more. The interface between different mold sections is called the *parting line* [4]. Parts with a relatively simple shape, such as wastewater tanks and waste containers, usually have planar parting lines. However, in the case of products with a more complex shape, such as fuel tanks or exhaust pipes, the parting line would have to be of a highly nonplanar shape (see Figures 2.3 and 2.4 for examples).

Figure 2.3 Sheetmetal three-part mold of an extesion neck for a wastewater tank with 2 planar parting lines highlited in red

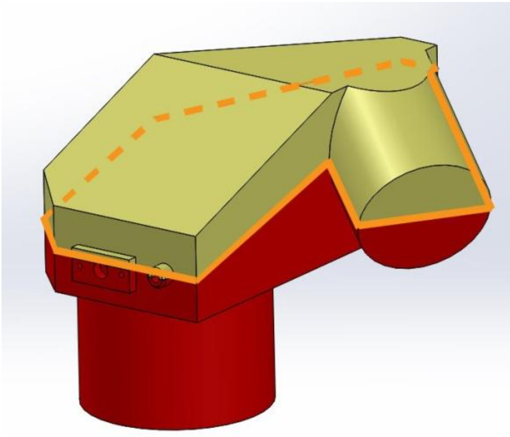


Figure 2.4 CAD model of an air duct with a complex shape, requiring a two-part mold with a nonplanar parting line (different mold parts colored in yellow and red, parting line highlitghed in orange)

Choosing a suitable parting line is one of the first steps in the design proccess of a rotaional mold, as its shape defines the general construction of the mold, the number of mold parts, ease of servicing etc. The integrity of a parting line is also of high importance, as the different parts of the mold must remain closely mated during rotomolding.

There are three common parting line designs for conventional, non-pressurised rotational molds [4]:

- butt or flat parting line (Figure 2.5) – where flanges are added by welding steel (in case of sheet metal molds) or cast in (in case of aluminium molds). This design is also used in molds made for Cipax Eesti.

- lap joint (Figure 2.6) – usually achieved by machining mating edges into the welded or cast mold body. While more expensive and labor intensive than the flat parting line, it ensures easier maintenance and superior seating for the mold parts.

- Tongue-and-Groove (Figure 2.7) – where grooves are added at the corners of the mold parts. While being self-seating and providing the best surface finish for the molded product, this design is also the most expensive to manufacture and maintain.

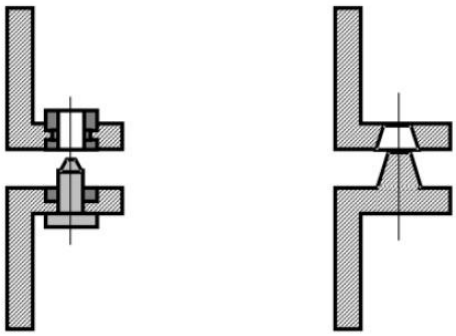


Figure 2.5 Butt or flat parting lines with alignment pins (left) and keys (right) [4]

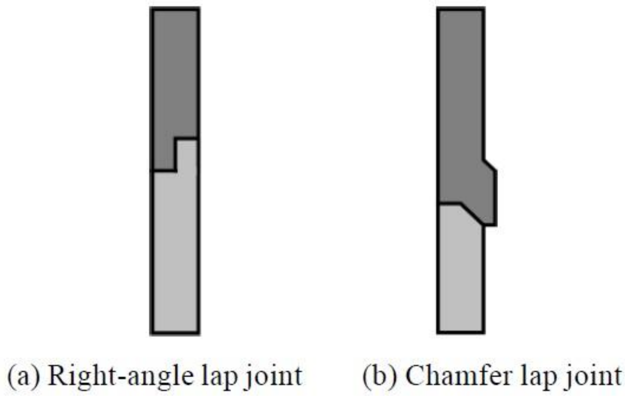


Figure 2.6 Two types of lap joint parting lines [4]

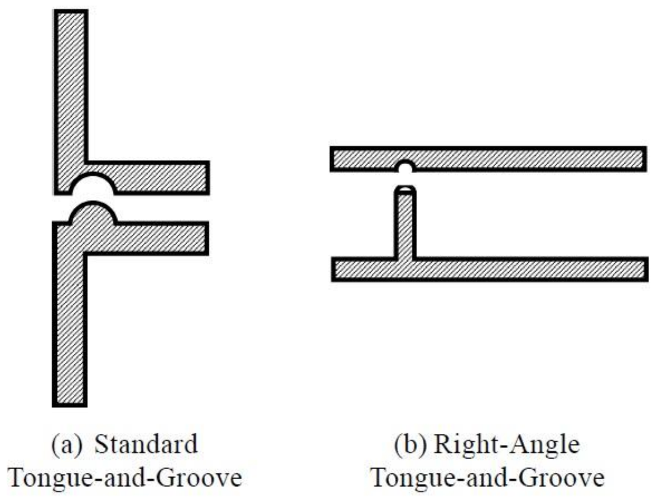


Figure 2.7 Two types of Tongue-and-Groove parting lines [4]

3 Rotational Mold Design at Cipax Eesti AS

3.1 Problem/Task Definition

Figure 3.1 The original Cipax 150 L grit bin [3]

What follows is an example of the rotational mold design proccess at Cipax Eesti AS. The company produces, among many other products, several types of grit bins used to store sand, salt or granite grit to be used during the winter months. In fact, several such grit bins can be seen even today on the TUT campus. Demand for these products had surpassed the output capability so the decision was made to increase production rates of the 150 L (see Figure 3.1) and 300 L grit bins by ordering another set of rotational molds for them. Rather than being just copies of the existing ones, the new molds would have to incorporate changes to make them more ergonomic. In other words, the author of this thesis was tasked with designing a *new sheet metal rotational mold* for a 150 L grit bin that would fulfill the following requirements:

1. compatibility with existing lids used for the old grit bins
2. better ergonomics for easier manual handling
3. liftable with a forklift or hand pallet truck
4. shape that would allow several empty grit bins to be placed on top and partly inside of each other to save space during transport and storage

Fulfilling the first three requirements meant two things:

- the top part of the new rotational mold would have to be identical to the old one
- the shape of the lower part of the new grit bin would have to be completely reworked

3.2 Defining the Shape of the Product to be Molded

Making the new grit bin more ergonomic and better suited for manual handling was the first and easiest task. The shape of the old 150 L grit bin, as seen in Figure 3.2**,** already provided with a suitable position for handles in the form of a rectangular cut-out about 20 mm in depth on each side of the bin (see Figure 3.3).

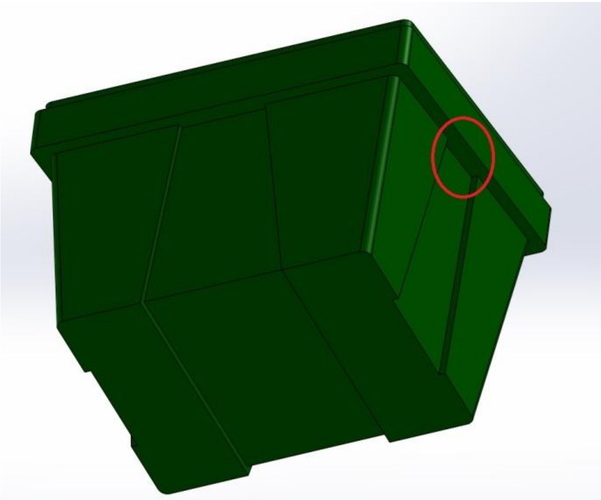


Figure 3.2 Bottom view of the CAD model of the original 150 L grit bin. Place chosen for the added handles is circled with red

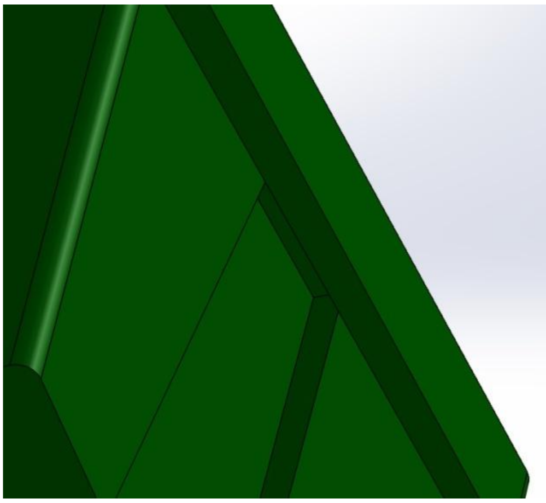


Figure 3.3 Magnified view of the cut-out that will serve as handle on the new grit bin

The requirement for the new bin to be liftable with a forklift or hand pallet truck proved to be a bigger challenge. The lower part of the product needed to be modified accordingly. However, the need for the new bins to be stackable on top of each other (with the lower part of the bin placed on top fitting inside the bin on the bottom) limited the freedom and scale of such changes. Some of the proposed versions the author has come up with to fulfill this requirement can be seen in Figures 3.4 and 3.5**.** Eventually the „six-foot" design seen in Figure 3.6 was chosen as the most suitable and aesthetically pleasing. Its main advantage is the possibility to lift and transport the new grit bin from the front, back and both sides.

With these changes made to the shape of the new grit bin approved, the next step in the design proccess of the mold could begin.

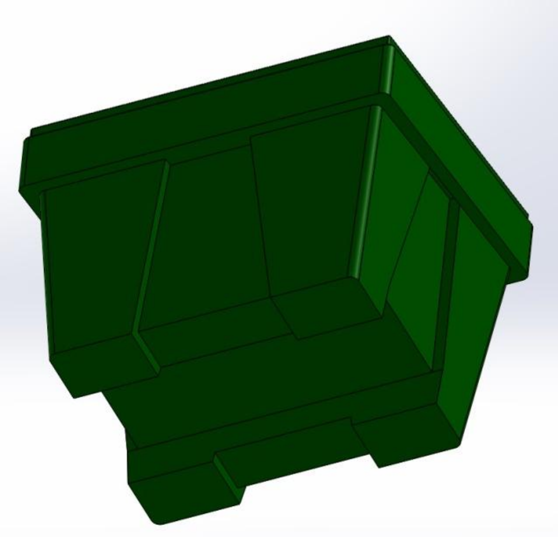


Figure 3.4 CAD model of proposed bottom shape for the new 150 L grit bin, eventually rejected

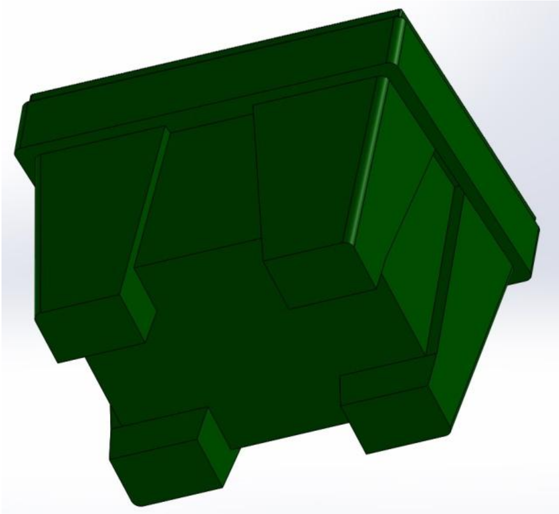


Figure 3.5 CAD model of proposed bottom shape for the new 150 L grit bin, eventually rejected

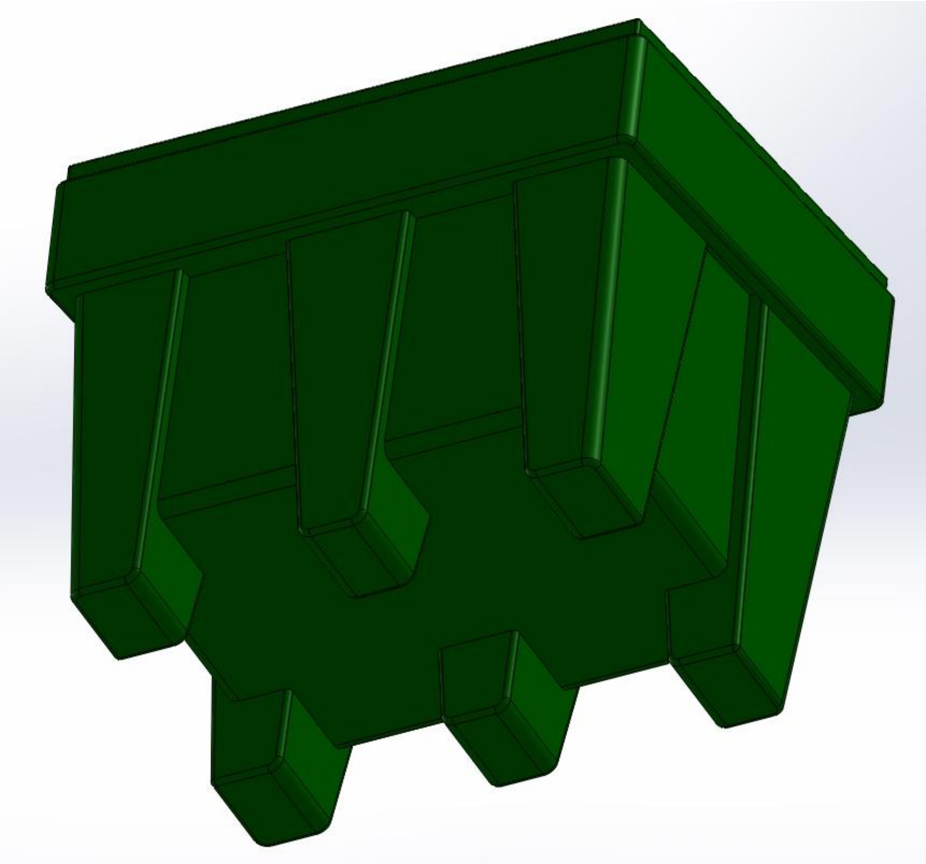


Figure 3.6 CAD model of proposed bottom shape for the new 150 L grit bin, eventually approved

3.3 Choosing a Parting Line for the Mold

As mentioned before, choosing a suitable parting line is one of the first steps in the design proccess of a rotaional mold. In the case of the 150 L grit bin, using a similar parting line design to the one of the original mold (as seen in Figure 3.7) would be the most suitable solution since the top part of the new bin needs be more or less identical to the old one in order to stay compatible with the bins lid, which would remain unchanged.

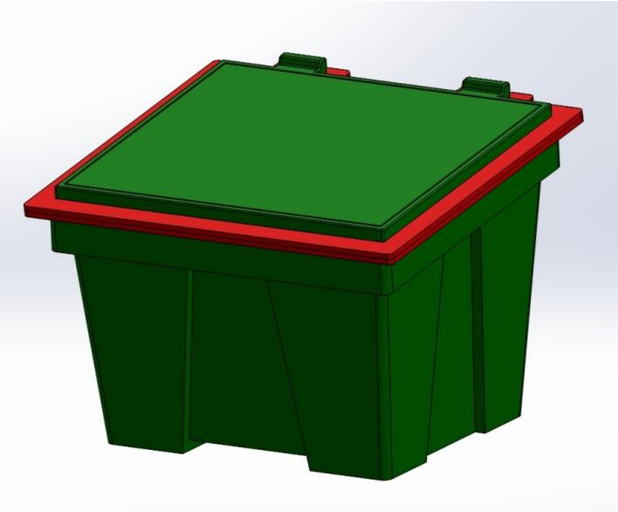


Figure 3.7 CAD model of original 150 L grit bin with parting line highlited in red

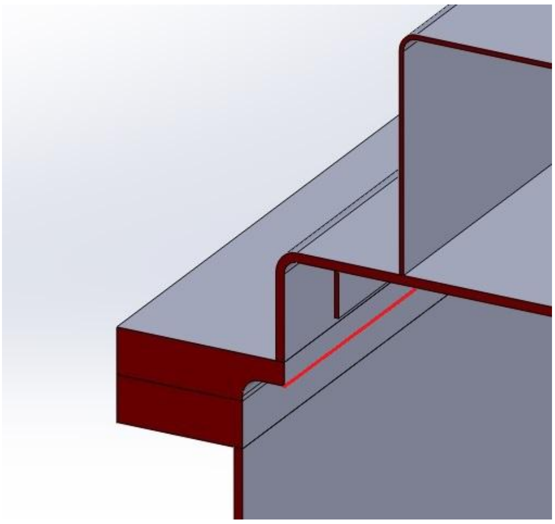


Figure 3.8 Cross section of the CAD model of the rotational mold showing the critical step (highlighted with red) incorporated into the upper parting line of the mold (made of CNC machined 10 mm steel)

Another reason for placing the parting line at that location is the fact that there is a sharp step in the shape of the bin (see Figure 3.8) that can be relatively easily machined into the 10 mm steel plate making up that line. Sheet metal, however, cannot be bend with such a sharp corner and requires radii at least equal to its own thickness.

Once the design of the parting line has been set, it is time to design the structure of the rotational mold.

3.4 Designing the Structure of a Rotational Mold

At this stage in the design proccess, it is neccessary to come up with the way how exactly the rotational mold will be built. The key rules are:

- the different parts making up the mold need to be as simple as possible for easy and quick production using inexpensive methods (usually CNC bending)
- the amount of welding neccessary to construct the mold needs to be minimised in order to avoid excessive warpage of the mold
- there needs to be open and easy access to any point of the inner surface of the mold, as it requires careful and extensive finish

Just as with the general shape of the new grit bin, the author proposed several designs of the mold structure. The design seen in Figure 3.9 was ultimately rejected because it did not offer enough access to the bottom of the «legs» of the grid bin, making finish of the molds inner surface there difficult. The design shown in Figure 3.10 was deemed unsuitable as it required excessive welding in the areas of the «legs».

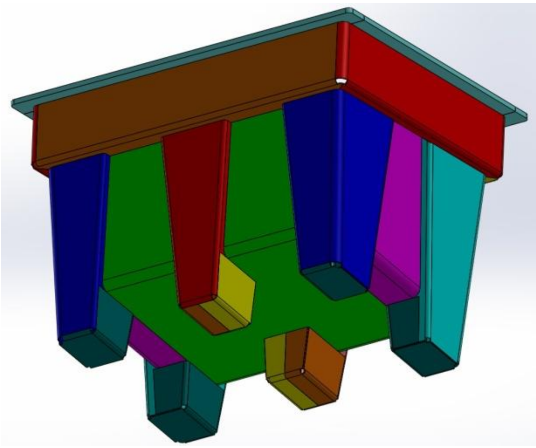


Figure 3.9 CAD model of a proposed construction design for the new grid bin rotational mold (different parts shown using different colors)

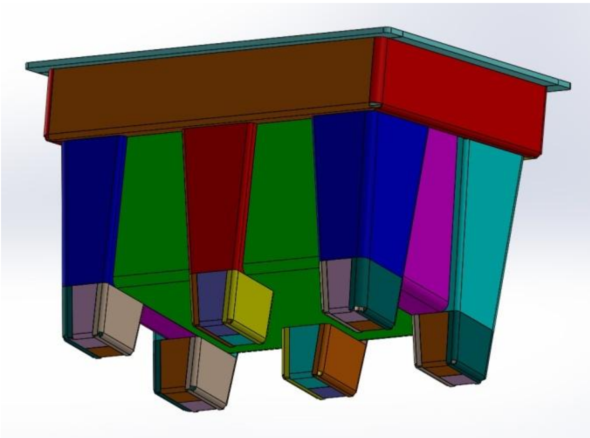


Figure 3.10 CAD model of a proposed construction design for the new grid bin rotational mold (different parts shown using different colors)

Eventually, the design seen in Figure 3.11 was developed and approved. It was decided to separate each of the six „legs“ protruding down from the main body and built them using 2 sheet metal parts. This solution offers both good access to all points of the inner surface of the mold and requires less welding than the previous two versions.

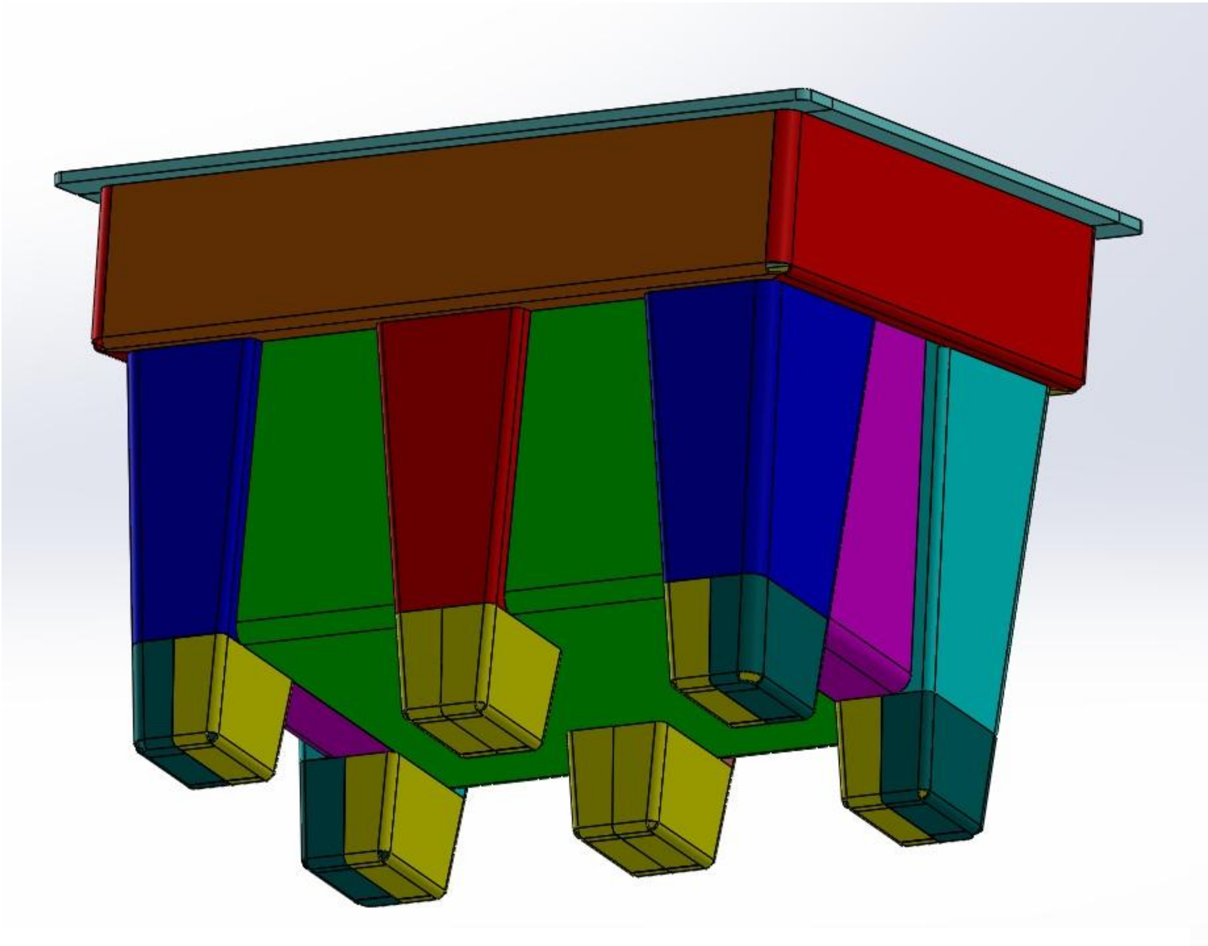


Figure 3.11 CAD model of the approved final design for the new grid bin rotational mold (different parts shown using different colors)

The next step is to create all the neccessary CAD files and documentation for each part of the rotational mold.

3.5 Rotational Mold Part Design

The author of this thesis has chosen the part highlighted in blue in Figure 3.11 to serve as an example and showcase the steps of part design of a sheet metal rotational mold. It should be noted here that, so far and from here on out, the author has used Solid Works 2013 Edition CAD software.

We start with a CAD model of the rotational molds inner surface as shown in Figure 3.12. Next we add the neccessary radii according to the ones used on the CNC bending machine, which will be used to bend the needed sheet metal part into the desired shape (in this case the radii are 3 mm and 15 mm as seen in Figure 3.13). These are neccessary not only because of the chosen way to produce the needed parts for the mold. When designing a product made by rotational molding, sharp corners should always be avoided or be kept at a minimum [4]. The powderflow of the raw material in such areas is poor, which leads to high risk of porosity and cavities appearing.

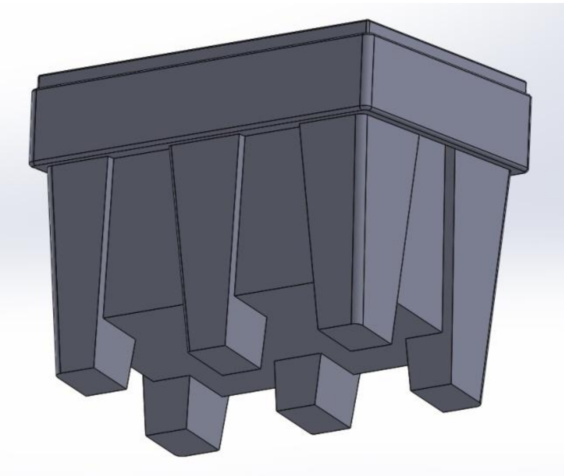


Figure 3.12 CAD model of the inner surface of the rotational mold for the 150 L grid bin

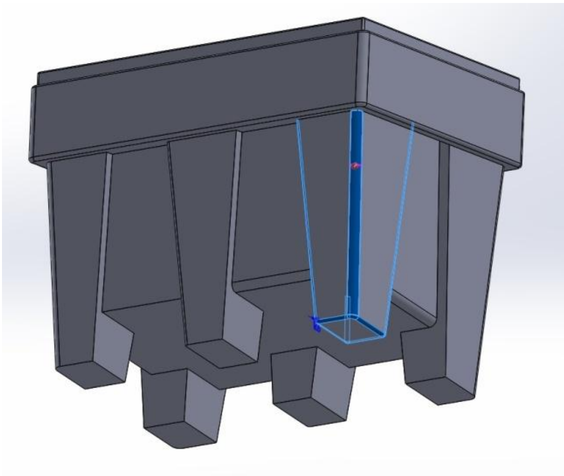


Figure 3.13 Radii of 3 mm and 15 mm (highlighted in blue) are added to the CAD model in the area of the designed part

The next step is to select and isolate the surfaces which will constitute the part we are trying to make. In this case we create a 2 mm (equal the thickness of the sheet metal used to make the rotational mold) shell around the corner of the grid bin, as seen in Figure 3.14. Since this section still includes surfaces, which will be created by a different part of the mold, it is neccessary to trim and cut the excess material until we get a suitable mold section as seen in Figure 3.15**.**

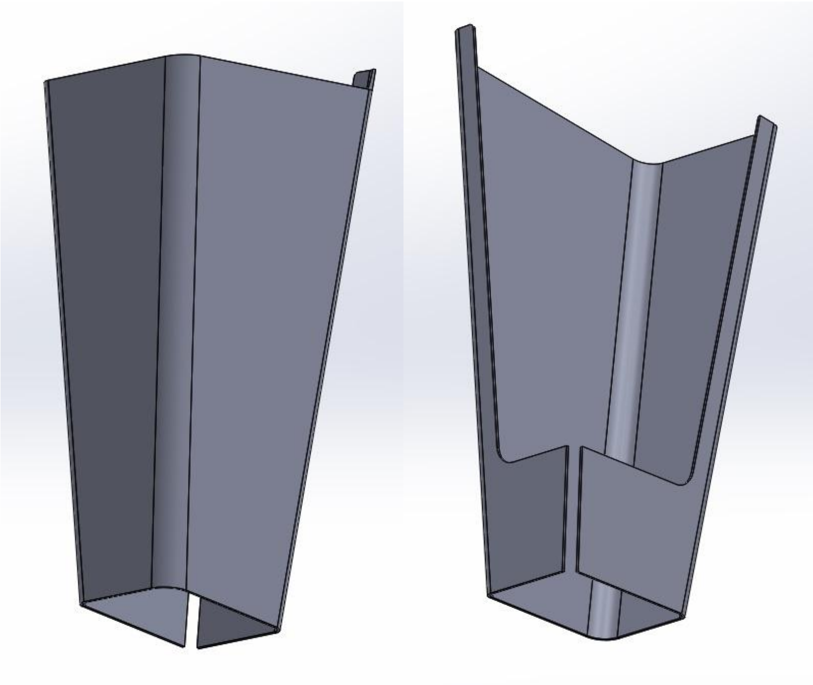


Figure 3.14 CAD model of the isolated surfaces which will make up the designed part of the rotational mold

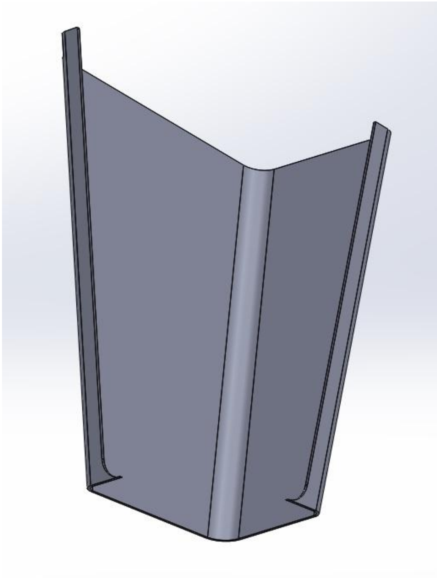


Figure 3.15 CAD model of the trimmed down mold section which will make up the designed part of the rotational mold

This part is still not finished, however. At this point it is neccessary to carefully examine it and make sure there are no defects or aberrations in its shape, which would prevent its correct conversion into a sheet metal part. In this case there is such an area - shown in Figure 3.16. After both adding and removing material where neccessary we end up with a CAD model ready to be converted into a sheet metal part. Keeping in mind that this part will be bent into shape by a CNC bending machine, we now have to examine the flat pattern of the nearly finished part (Figure 3.17). What should be noticed here is the fact that unlike the upper and lower bend lines, the middle bend line is not parallel to any of the edges of the part. As such, with its current shape, it is impossible bend it into the desired shape.

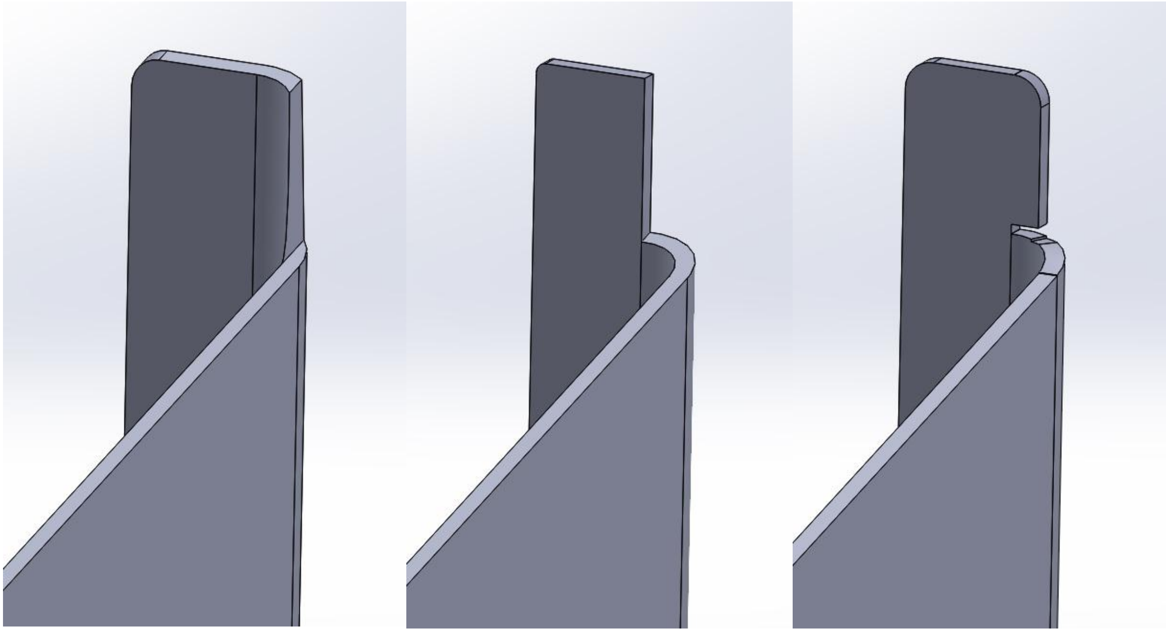


Figure 3.16 Left: area with abberations perventing correct conversion into sheet metal.
Middle: same area modified for correct conversion into sheet metal.
Right: same area after conversion into sheet metal.

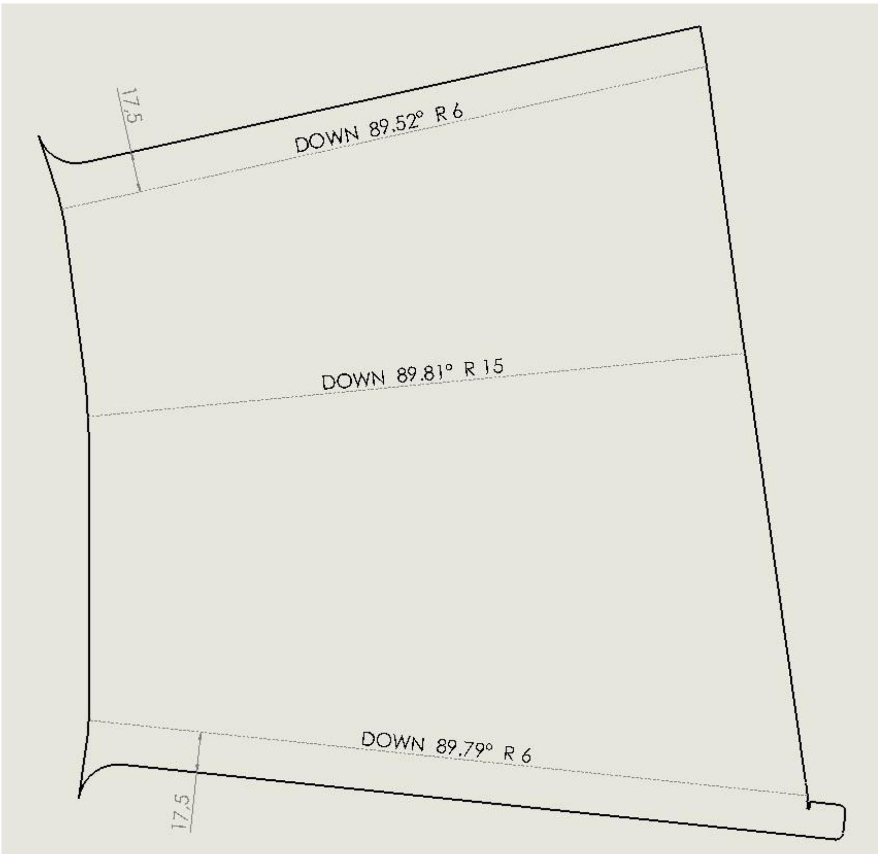


Figure 3.17 Flat pattern of sheet metal part showing bend lines

In order to overcome this problem, it is neccessary to add reference flanges, that are parallel to the middle bend line, which will be removed once the part has been bent into shape (see Figure 3.18)

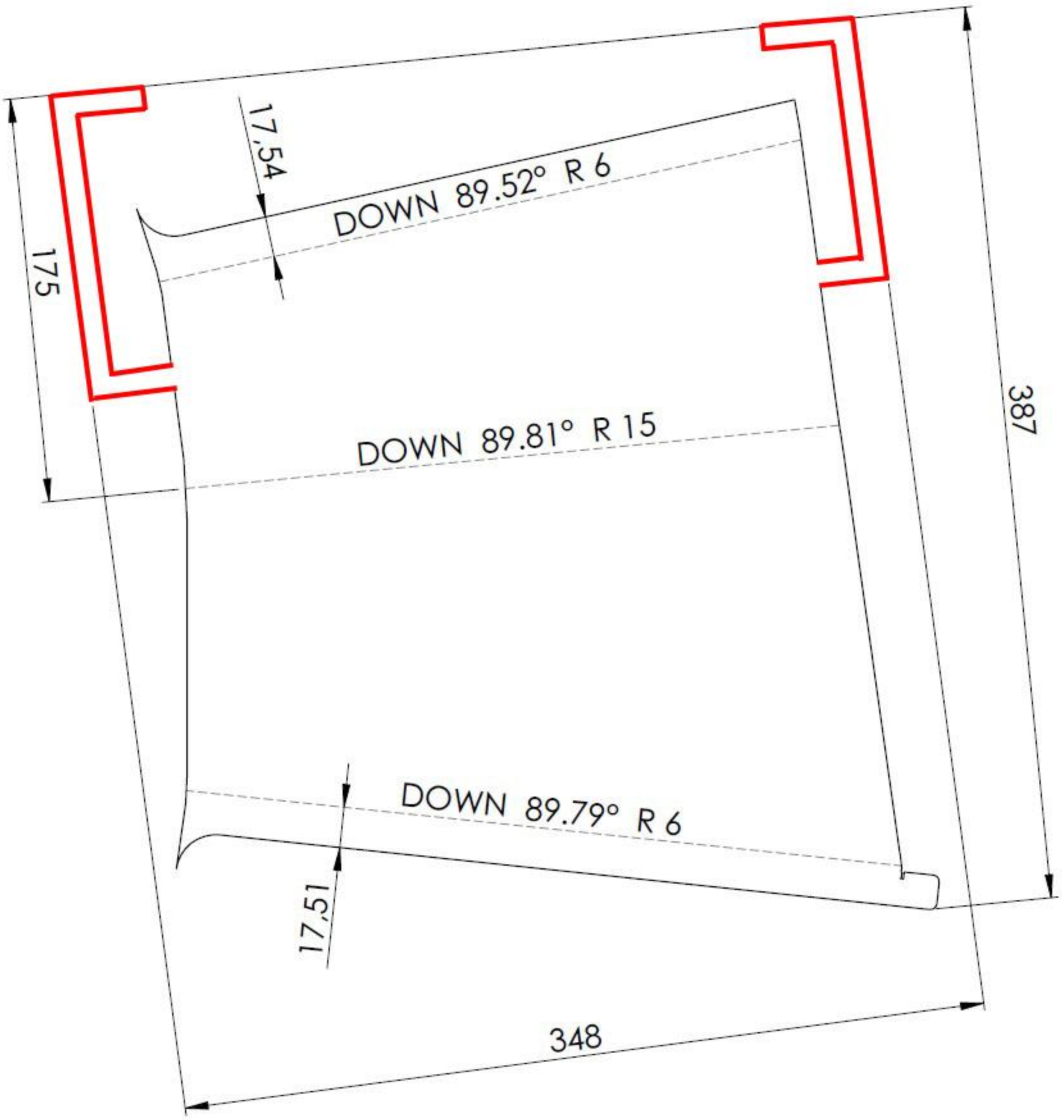


Figure 3.18 Drawing of the sheet metal part used by the part supplier to cut and bend it into the desired shape. Reference flanges highlighted with red.

With this the CAD model of the needed sheet metal part is complete. All that remains is to create the neccessary technical drawings (such as seen in Figure 3.18) and send them, along with the flat pattern of the desired part in dxf format, to the chosen part supplier. The dxf file will be used to cut out the flat pattern of the part out of cold rolled steel sheet metal with a laser or plasma cutting machine. The part will be then bent into the desired shape on a CNC sheet metal bending machine. This proccess is to be repeated with each sheet metal part needed to construct the rotational mold. Parts making up the parting line of the mold (example shown in Figure 3.19), in this case made out of 10 mm steel sheets, may require additional machining in a CNC mill.

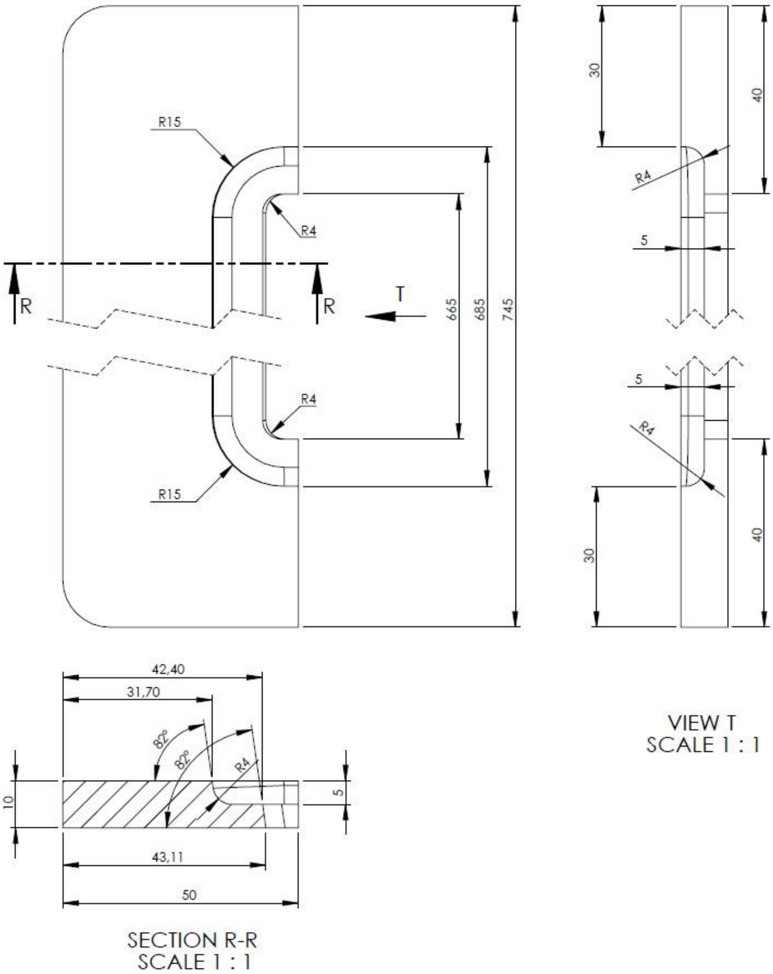


Figure 3.19 Drawing of the 10 mm thick steel part used to construct the parting line of the rotational mold of the 150 L grid bin

It should be noted that no rotational mold is quite the same. Depending on the shape of the product, the way the mold designer chooses to place the parting line and construct the mold itself, other machining and metal forming methods may be required to produce the neccessary parts. This can include roll forming and even crafting by hand using blacksmith techniques.

For example, if we take a look at the sheet metal part that will make up one half of the grit bins six «legs», we will notice gaps in its corners (Figure 3.20). Several such gaps appear in other portions of the mold. This is especially likely to happen in corners (see Figure 3.21) that cannot all be filled mith material due to the limitations of the sheet metal bending proccess. These areas will have to be filled with hand crafted steel pieces hammered into the needed shape.

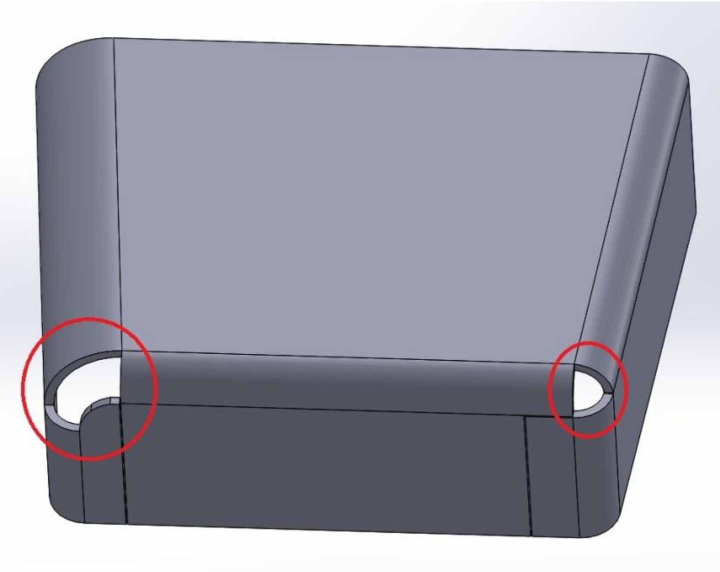


Figure 3.20 CAD model of sheet metal mold piece bent into shape. Material missing at the corners highlighted in red.

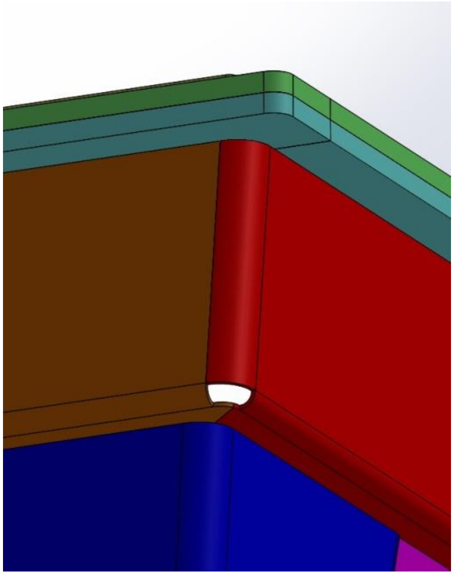


Figure 3.21 CAD model of the mold showing missing material in the corner. Different parts of the mold highlighted with different colors.

There are cases where whole mold parts, and not just small fragments, will have to be manufactured in such manner. To showcase such a situation, it is neccessary to take a look at a different rotational mold.

Another mold that the author of this thesis has designed while being employed by Cipax Eesti AS was that for an optional extension neck to be used with the companies new 3000 L undeground septic tank shown in Figure 3.22. As we can see, unlike the rectangular grit bin, this product has a cylindrical shape and is symmetric about a central axis. This means that the most suitable way to produce parts for such a mold would be by roll bending. However, there was one part that could not be produced by such method (highlighted in yellow in Figure 3.23). Forming the extension necks uppermost surface, it has R8 mm chamfers on both inside and ouside edges. Unfortunately such a part cannot be easily roll bent in one operation. Splitting this area up into several parts would lead to excessive welding, labor intensive surface finish and possibly compromise the surface quality of the product. Roll forming is an option for such cases, but only viable if there are several identical parts that can be produced in such a way. Ordering custom made rolls for one single mold part is not cost effective, however.

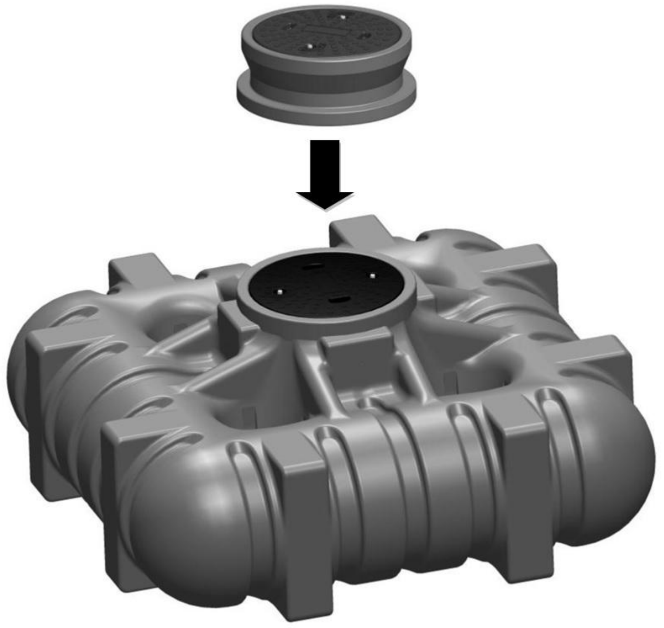


Figure 3.22 3000 L underground septic tank along with optional 250 mm extension neck produced by Cipax Eesti AS [3]

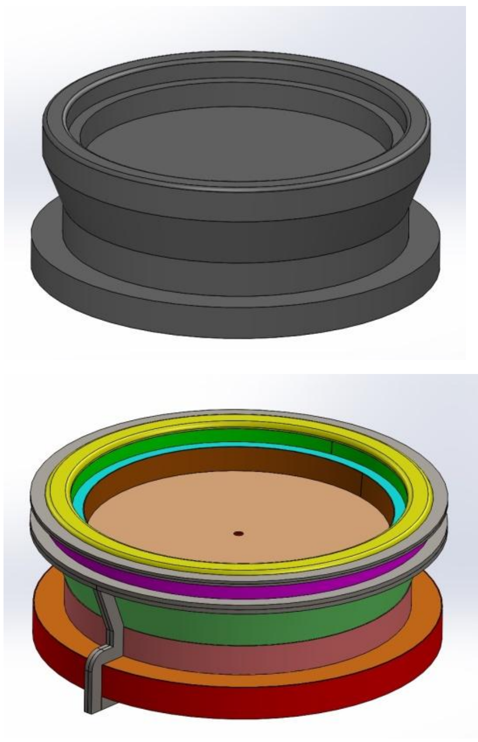


Figure 3.23 Top: CAD model of the untrimmed extension neck as it comes out of the rotational mold
Bottom: CAD model of the extension necks rotational mold (different mold parts highlighted with different colors)

In cases such as this it makes sense to make the neccessary part by hand. In order to do so, a hammering base made of 10 mm steel – the same material which is used for the parting lines of the mold – needs to be cut out first. Both of its upper edges need to be grinded down to R8 mm chamfers so the hammering base replicates the surface of the product. Next, the flat pattern of the desired part is bolted on top of the hammering base (see Figure 3.24). The mold maker then procceeds to carefully hammer the sheet metal part into the needed shape by hand (see Figure 3.25). Once finished, the part is removed from the base and the holes made for the fastening bolts are welded shut.

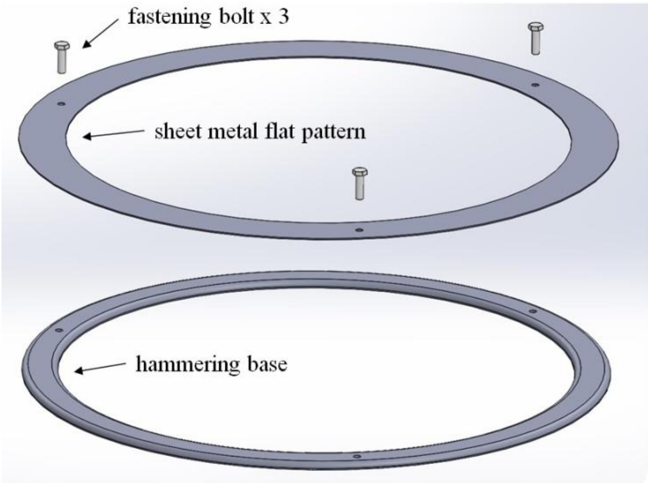


Figure 3.24 CAD model showing the neccessary parts and their arrangement prior to hammer forming

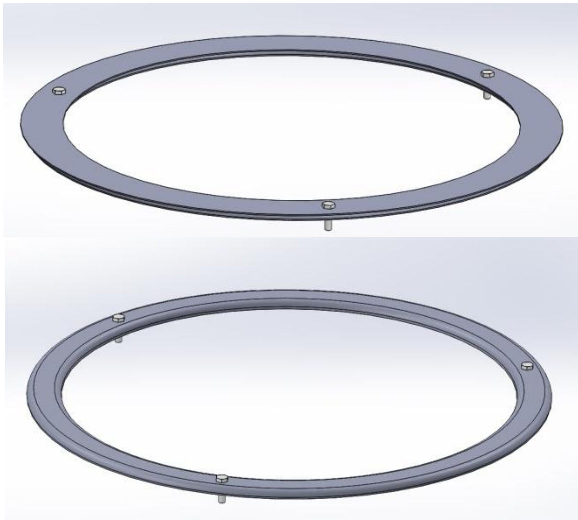


Figure 3.25 Top: flat pattern of mold part prior to hammer forming.
Bottom: mold part after hammer forming.

While relatively slow and labor intensive, such method is viable for producing parts for sheet metal rotational molds as each mold is usually one of a kind anyway.

3.6 Calculation of Powder Charge Weight

Calculating the neccessary charge weight of the raw material is an important step in rotational molding and should always be made during the design phase of the mold to make sure that the mold is big enough to accomodate the needed amount of plastic powder. The reason for this is that, for example, the density of solid medium density polyethylene (MDPE) is about 930 kg/m^3 while the bulk density of MDPE powder is lower – about 350 kg/m^3 [4]. What this means is that, in certain situations, the rotational mold cannot hold the amount of plastic powder neccessary for the desired product. This largely depends on the size and shape of the product, as well as its desired wall thickness (the thicker the walls, the higher the risk that the mold will be too small). In such a situation, the mold would have to be removed from the oven, opened up and refilled with additional powder in between heating cycles, effectively doubling its production run. In other situatons, the charge weight of the product will be known and fixed to make the product economically viable, making the wall thickness into a variable.

In the case of the 150 L grid bin used as an example in this thesis, the wall thickness is fixed at 4 mm, meaning it is the powder charge weight that needs to be calculated. Since there is a CAD model of the molds inner surface already available, the needed properties of the product and mold itself can be easily found through the CAD sofware and are as follows:

- Volume of the molds inner space is 0.16470 m^3
- Volume of the molded grid bin (with a 4 mm thick wall) is 0.00875 m^3

Multiplying the volume of the molded product with the density of MDPE we get the neccessary charge weight:

$$0.00875 * 930 = 8.1375 \text{ kg}$$

Now, to make sure the needed amount of powder can fit inside to mold itself, we divide the charge weight with the bulk density of MDPE powder and get:

$$8.1375 / 350 = 0.0235 \text{ m}^3$$

which is well lower than the amount of space available (0.16470 m^3).

3.7 Rotational Mold Ventilation

Rotational molds require ventilation ports that allow air to leave the mold during the heating stage and to enter again during the cooling stage [4]. Otherwise, gas trapped inside the mold would expand during the heating proccess and build up pressure. This excessive pressure can force molten plastic outside through the parting line causing blowholes in the product and, in the worst case, distort the mold itself. Pressure generated inside the mold in such a case can be estimated using the ideal gas law:

$$P\,V = n\,R\,T \tag{3.1}$$

Where n and R are constants. If V is treated as a constant, then the pressure is proportional to T. Considering the state of the gas before and after the change in temperature, we get:

$$P_1V = nRT_1 \tag{3.2}$$

$$P_2V = nRT_2$$

$$\frac{P_1}{T_1} = \frac{n\,R}{V} \tag{3.3}$$

$$\frac{P_2}{T_2} = \frac{n\,R}{V}$$

Since both P_1/T_1 and P_2/T_2 equal nR/V, they must be equal to each other:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \tag{3.4}$$

Therefore the final pressure at the elevated temperature is given by the Gay-Lussac law:

$$P_2 = \left(\frac{P_1}{T_1}\right)T_2 \tag{3.5}$$

From the previous chapter we know that the inner volume of the rotational mold for the 150 L grid bin is 0.16470 m^3. Subtracting the volume of plastic powder put inside the mold we get:

$$0.16470 - 0.0235 = 0.1412 \text{ m}^3$$

This is the amount of air available at the start of the heating stage. We can estimate the opening force P_2 generated inside the mold when it is heated, for example, from 25°C to 200°C.

First, the temperatures are converted to absolute temperatures:

$$T_1 = (25 + 273) = 298 \text{ K}$$

$$T_2 = (200 + 273) = 473 \text{ K}$$

By the Gay-Lussac law, with an initial pressure of 1 atmosphere, the new pressure is:

$$P_2 = P_1 \left(\frac{T_2}{T_1}\right) = (1) \left(\frac{473}{298}\right) = 1.59 \text{ atm} = 161 \text{ kN/m}^2$$

The inside surface area of the mold as measured by the CAD software is 2.187 m^2. This gives us an opening force on the parting line of the mold equal to:

$$161 * 2.187 = 352.107 \text{ kN}$$

Even if we consider that more space inside the mold becomes available during heating as the powder melts and adheres to the walls, without ventilation such opening force is still capable of distorting the mold.

The same method can be used to assess another common practical problem when the ventilation vent becomes clogged after the heating stage and no air can enter the mold while it is cooling down. We are assuming that the mold is cooling down with an internal temperature of 200°C and internal pressure of 1 atmosphere:

$$P_2 = P_1 \left(\frac{T_1}{T_2}\right) = (1) \left(\frac{298}{473}\right) = 0.63\, atm = 64\, kN/m^2$$

Such partial vacuum may also be able to cause distortions if we consider that our rotational mold is made for the most part from only 2 mm thick sheet metal steel.

Another possibility to assess the required amount of venting is to estimate the volume of air that must escape from the mold during heating and enter the mold during the cooling stage so that the internal pressure remains at 1 atm. This volume of air is again obtained from the adaptation of the ideal gas law [4]:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = constant \tag{3.6}$$

Therefore

$$V_2 = V_1 \left(\frac{T_2}{T_1}\right) \tag{3.7}$$

If the pressure inside the mold is 1 atm at 25°C then, as the mold is heated up to 200°C, the volume that the air must occupy to maintain this pressure is given by:

$$V_2 = V_1 \left(\frac{T_2}{T_1}\right) = (0.1647)\left(\frac{473}{298}\right) = 0.2614\ m^3$$ - an increase of 59%

This means that the volume of air that must be first allowed to escape during heating and then re-enter the mold during cooling is equal to:

$$0.2614 - 0.1647 = 0.0967\ \text{m}^3$$

There is no straightforward way to calculate the required size of the vent tube needed for a particular mold, since we are dealing with gas flow in a situation where temperature and pressure are continuously changing. Other factors like oven efficiency, size of the rotational mold, wall thickness of the molded part, integrity of the parting line are affecting the venting proccess as well. A rule of thumb often found in guides to rotational molding suggests a vent of 13 mm in diameter for each 1 m^3 of mold volume. This approximation does not work well for molds with volumes below 1 m^3 however (as is the case with the 150 L grit bin)[5].

A way to get a rough estimate can be found in literature dealing with rotational molding, where the following example is used [4].

It is empirically known that the oven time of a cubic shaped mold (as shown in Figure 3.28) in a rotational molding machine is given by:

$$t = \left(\frac{D}{1000}\right)^{0.1} \times (h + 2h^{0.2}) \qquad (3.8)$$

Where t is the oven time in minutes, D is the side of the cube in mm and h is the wall thickness of the molded parts in mm.
Let us simplify the shape of the 150 L grid bin used as an example before and assume it is shaped like a cube with a volume of 0.16470 m^3. This would mean that, in this case:

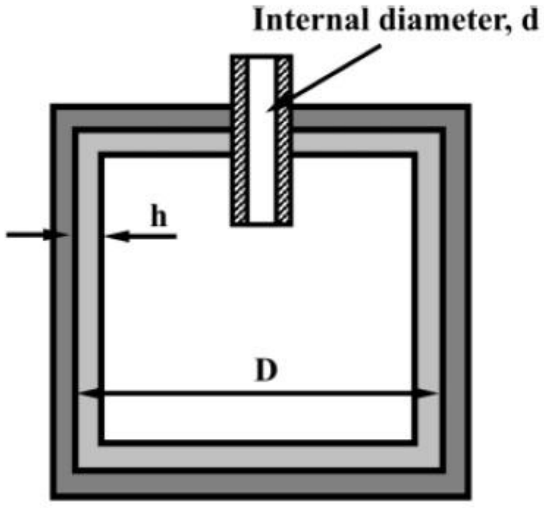


Figure 3.26 Cube mold with vent tube [4]

$$D = \sqrt[3]{0.16470} = 0.5481 \text{ m}$$

Furthermore, we assume that both mold and powder are initially at 25°C and are then heated to an internal air temperature of 200°C. The speed of the air from the vent tube may be assumed to be 2 m/s. Solid density of the polyethylene ρ_p is 930 kg/m^3 and bulk density of the powder ρ_b is 350 kg/m^3.

The volume of air inside the mold at the beginning is given by:

$$V = \left[D - 2\left(\frac{\rho_p}{\rho_b}\right)h\right]^3 \qquad (3.9)$$

As shown earlier, when air is heated from 20°C to 200°C, there is an increase in volume of 59%. Therefore the volume of gas that flows out of the mold is:

$$V_{esc} = 0.59\left[D - 2\left(\frac{\rho_p}{\rho_b}\right)h\right]^3 \tag{3.10}$$

From knowledge of the given oven time, the average gas flow rate from the mold is estimated as:

$$Q = \frac{0.59\left[D - 2\left(\frac{\rho_p}{\rho_b}\right)h\right]^3}{60\left(\frac{D}{1000}\right)^{0.1} \times (h + 2h^{0.2})} \tag{3.11}$$

Assuming that all the air passes through the vent tube, this is equal to the product of area and gas speed in the vent tube. Hence:

$$\left(\frac{\pi d^2}{4}\right)V = \frac{0.59\left[D - 2\left(\frac{\rho_p}{\rho_b}\right)h\right]^3}{60\left(\frac{D}{1000}\right)^{0.1} \times (h + 2h^{0.2})} \tag{3.12}$$

Rearranging this fo the diameter of the vent tube *d*, we obtain:

$$d = \sqrt{\frac{4 \times 0.59\left[D - 2\left(\frac{\rho_p}{\rho_b}\right)h\right]^3}{60\pi V\left(\frac{D}{1000}\right)^{0.1} \times (h + 2h^{0.2})}} \tag{3.13}$$

Thus, for molding a 0.5481 m polyethylene cube with a wall thickness of 4 mm, a vent tube diameter of 18,8 mm is predicted.

This result is very close to the 20 mm wide vent installed on the original 150 L grit bin mold which served as a basis for the new one. In this case, both calculation done using technical literature and real life experience suggest using a vent with a 20 mm internal diameter.

There are six prime requirements for rotational mold vents [4]:

- open airflow ensuring no drops or spikes in pressure
- no possibility for powder to escape the mold
- ability to withstand oven air temperature and thermal cycling
- inexpensive, easy to clean
- placement in noncritical regions of the mold, ideally in areas to be trimmed or cut away
- deep enough reach into the mold to minimise contact with the powder and the heated mold itself

Two types of vent pipes are commonly used, usually packed with glass or wire wool to prevent powder flow outside the mold [4]:

- A disposable PTFE (Polytetrafluoroethylene) vent pipe is the cheapest and most common solution (see Figure 3.29). It requires regular maintenance and inspection to prevent the deterioration of the vent tube and the wire wool absorbing powder, residual melt and moisture
- Semipermanent vents (see Figure 3.30) are used in case of a large production run, which also need periodic inspection and cleaning.

In case of the new 150 L grid bin a disposable PTFE vent pipe with an internal diameter of 20 mm has been chosen (as seen in Figure 3.29)

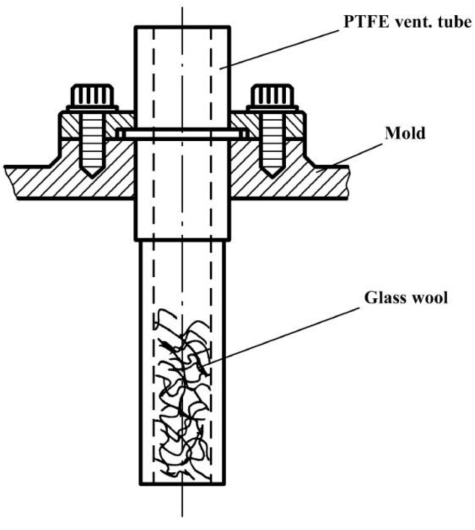


Figure 3.27 Disposable PTFE vent tube [4]

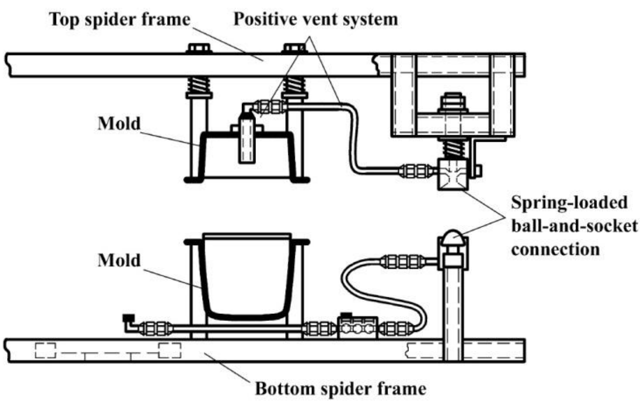


Figure 3.28 Gas transfer assembly including venting [4]

3.8 Mold Insulation

As stated earlier, rotational molding is a proccess for manufacturing hollow, shell-like plastic products. In most cases, however, the finished product requires openings which are drilled or cut into the semi-finished part coming out of the mold. Depending on the product, areas to be trimmed or cut away can range from small holes to nearly half of the initial part. That is why it would make sense to decrease wall thickness of the part in areas to be removed in order to minimize waste of raw material. A common way to do so is to add insulation (in the form of heat absorbing or reflecting materials) to mold areas, where decreased wall thickness is desired. These heat sinks lower the temperature of the mold walls, preventing the melted plastic powder inside the mold to adhere to them resulting in thinner walls.

In case of the 150 L grit bin a 50 mm thick layer of insulation is added on top of the area to be trimmed away once to product leaves the mold. The insulation material is held in place by a cover made from 1 mm thick sheet metal steel welded on top of the mold (see Figure 3.29).

Another possibility is to add heat reflective material to the outside walls of the mold, as has been done with the extension neck (see Figure 3.30).

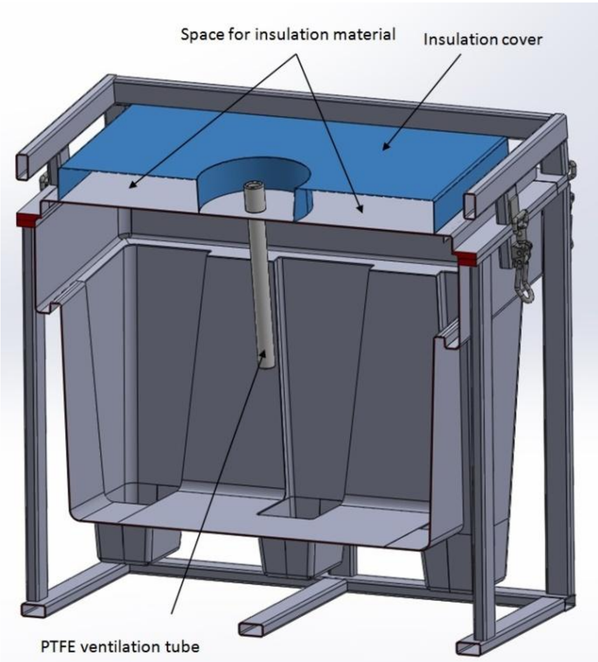


Figure 3.29 Section view of the 150 L grit bin mold CAD model showing insulation cover (highlighted in blue)

Figure 3.30 Rotational mold of the extension neck with heat reflective insulation material visible

3.9 Mold Frame

A rotational mold requires a frame in order to be serviced and put in the rotational molding machine. Its role is to ensure that during the molding proccess, assembly and disassembly all forces are placed against the frame instead of the mold shell. Mold frames are commonly constructed from angle iron, H-channel, rectangular channel and hollow square or rectangular section tube steel [4]. The stronger and more rugged the frame, the more secure is the mold held together and in place and the better the integrity of the parting line. However, while inside the oven, each attachment point between the mold and the frame becomes a heat sink during heating and a hot spot during cooling. Both need to be avoided in order to ensure uniform wall thickness and surface quality of the product. Because of this, the same rule of «as little as possible, as much as neccessary» that is applied to the number of welds in the mold, should be followed when designing the frame. Ideally, the attachment points should be placed on the flanges making up the parting line, as far away from the mold walls as possible.

Mold halves have to be clamped closed in order to minimise differential shifting due to thermal expansion while inside the oven [4]. An adjustable toggle latch commonly used for clamping small to medium sized molds at Cipax Eesti AS can be seen in Figure 3.32. Note that the latches should be welded to the mold frame (as seen in Figure 3.31) and not the mold body or the parting line to avoid damaging them.

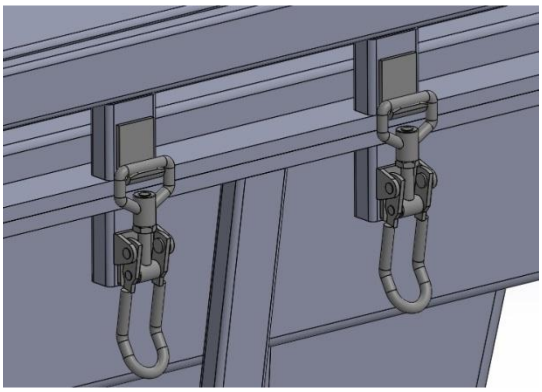


Figure 3.31 CAD model of the 150L grit bin mold showing the position of the toggle latches

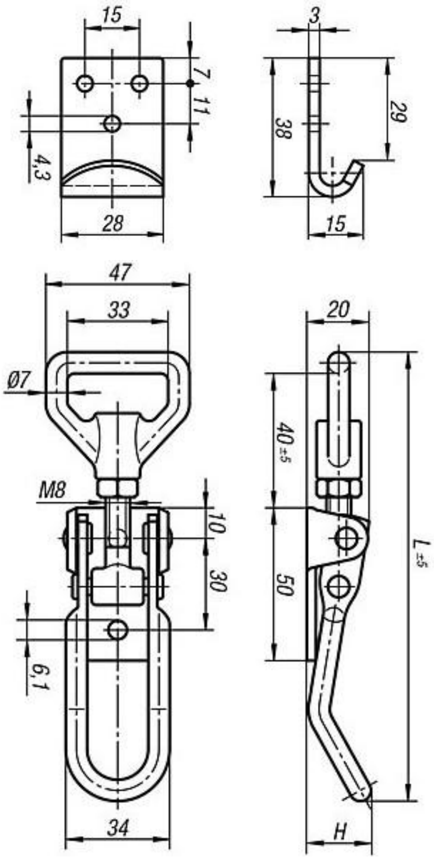


Figure 3.32 Toggle latch commonly used on medium sized molds at Cipax Eesti AS [11]

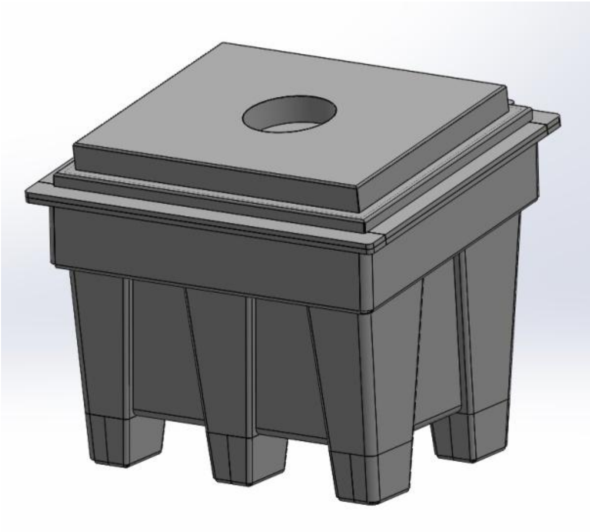


Figure 3.33 CAD model of the rotational mold for the 150 L grit bin without frame

The rotational mold for the 150 L grit bin has a relatively simple rectangular shape and planar parting line, making the design of the frame for it an easy task. The frame itself (seen in Figure 3.34) is made up of 40 x 20 x 2 mm rectangular tube steel. The two mold halves are clamped together by thirteen toggle latches.

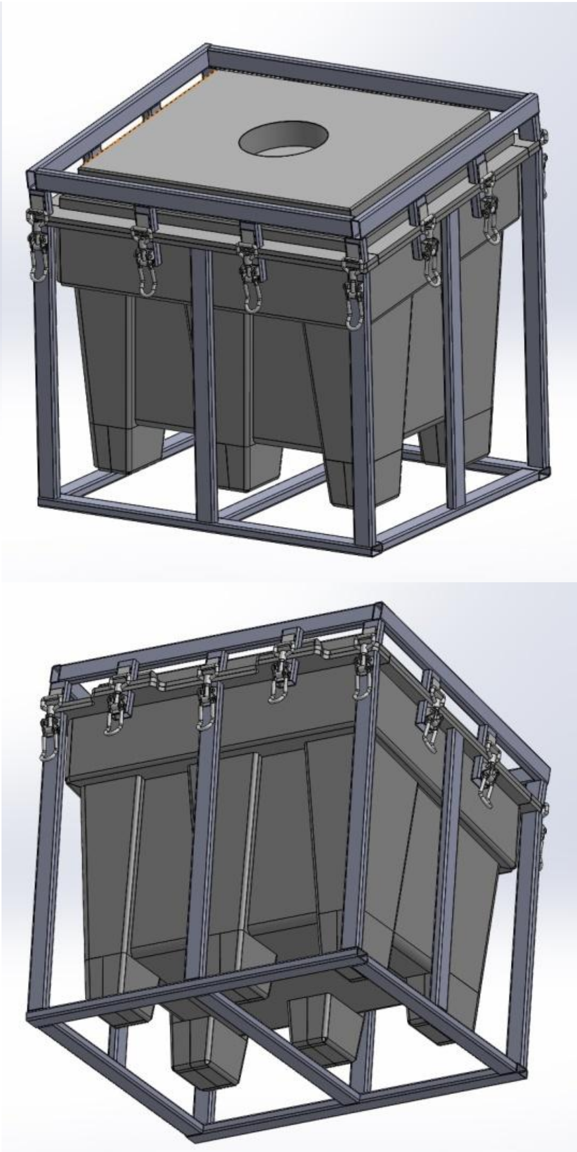


Figure 3.34 CAD model of the rotational mold for the 150 L grit bin with frame and toggle latches

If we look at the rotational mold for the extension neck – used as the second example in this thesis – we can see that in this case both the products shape and parting line design is more complex. Since the mold is made up of three parts the frame will have to be that much stronger to garantee minimal shifting of the mold parts.

There were several proposals made for the molds frame, including different possible positions of the mold while being mounted on the spider of the rotational molding machine. A frame design placing the mold in the vertical position can be seen in Figure 3.35. This version was ultimately rejected, as it required the mold to be always placed close to the spiders center in order to fit into the machines mold swing. Another design as seen in Figure 3.36 was then drawn up, leaving the mold in the horizontal position. This frame was then further refined into the one seen in Figure 3.37 and ultimately chosen for construction.

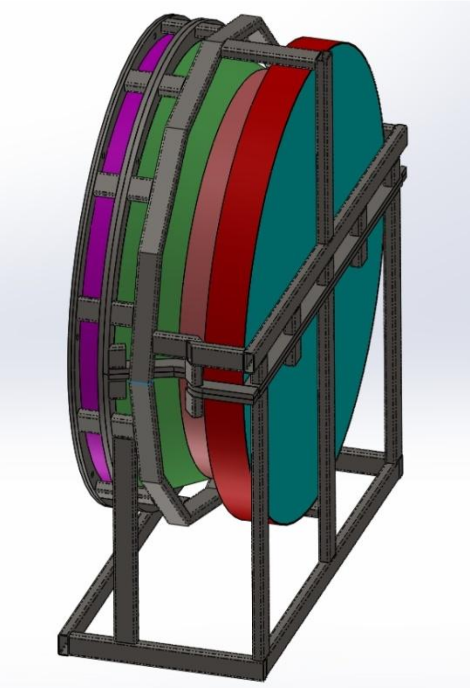


Figure 3.35 CAD model of the extension neck mold mounted on a proposed vertical frame

As with the frame for the grid bin, it was made from 40 x 20 x 2 mm rectangular tube steel. The three mold parts are clamped together with twelve toggle latches and two stronger reverse action toggle clamps.

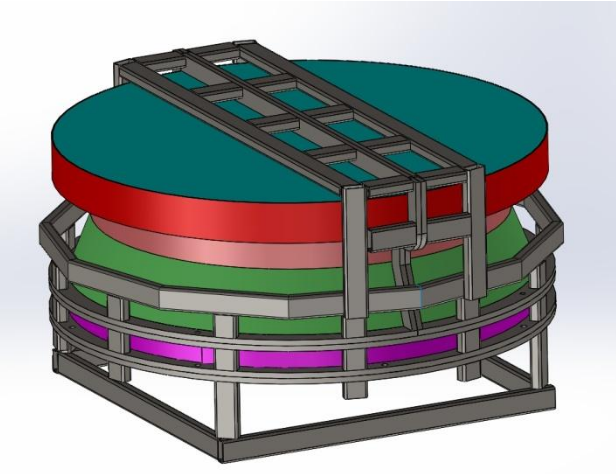


Figure 3.36 CAD model of the extension neck mold mounted on a proposed horizontal frame

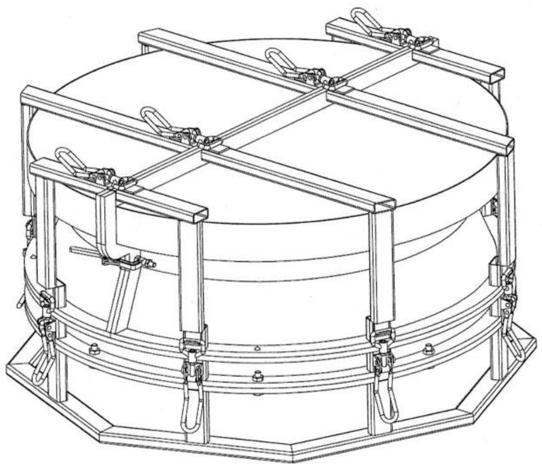


Figure 3.37 CAD model of the extension neck mold mounted on the final version of the vertical frame

Summary

The aim of this thesis was the design and construction of two rotational molds to be used in production at Cipax Eesti AS:

- one for a new 150 L grid bin
- one of an optional extension neck to be used with the 3000 L underground septic tank offered by the company

The first part of the thesis explains the rotational molding proccess, its advantages and disadvantages, offers information on the kinds of raw material used and their properties as well as an overview of rotational molding machines most widely used in the industry.

The second part deals with the general principles of rotational mold design and lists the different types of molds used in the proccess. There is also information regarding the most relevant for such a case mechanical properties of the materials used to construct rotational molds. It also includes the different metal working and forming techniques used to create parts for rotational molds.

The third part of this thesis shows all the different steps of the rotational mold design proccess, using the two aforementioned products as examples. The proccess starts with coming up with and creating CAD models of the desired products. Next the overall design and construction of the mold is chosen, starting with the parting line and moving on to the separate parts that will be making up the mold shell. Following this are examples showing how to calculate the raw material charge weight and ventilation tube diameter for a rotaional mold. Finally, each mold receives the required insulation and mold frame and is ready to be used in production.

The author regards this thesis as successfully finished because both the rotational molds for the 150 L grid bin and the septic tank extension neck were designed, built and eventually used by the company to produce the desired products. The results of this work can also be seen in the following Figures 3.38 - 3.43.

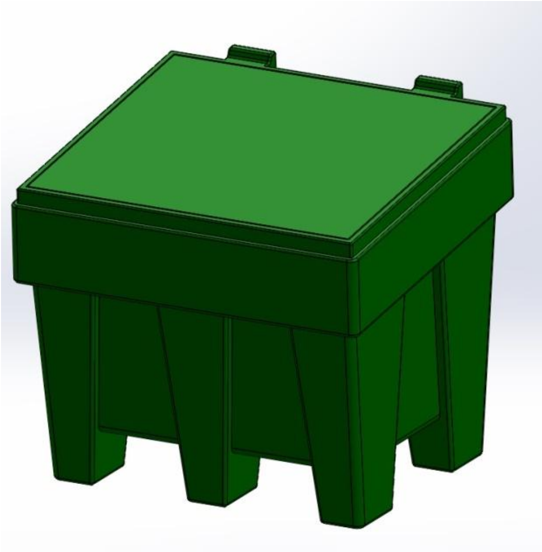


Figure 3.38 CAD model of the untrimmed 150 L grid bin as it comes out of the mold

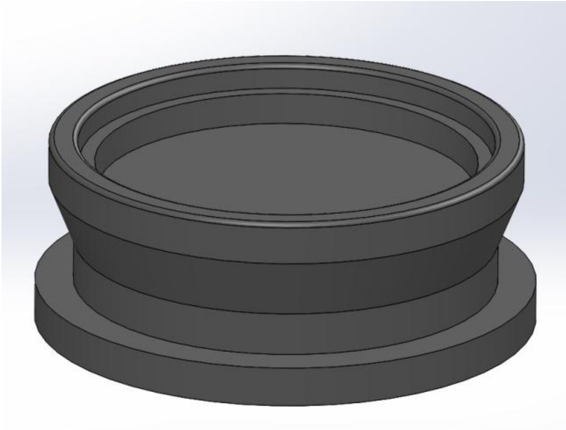


Figure 3.29 CAD model of the untrimmed septic tank extension neck as it comes out of the mold

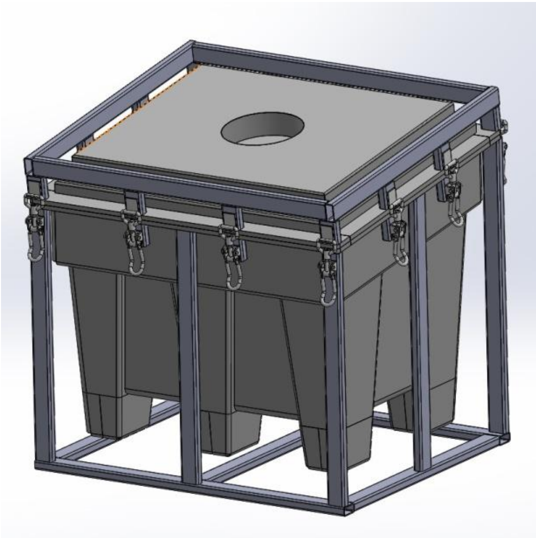


Figure 3.40 CAD model of the rotational mold of the 150 L grid bin

Figure 3.41 The finished rotational mold of the septic tank extension neck

Figure 3.42 The finished 150 L grid bin with lid [3]

Figure 3.43 The finished septic tank extension neck

Kokkuvõte

Antud töö eesmärk oli projekteerida ning konstrueerida kaks rotovaluvormi Cipax Eesti ASi jaoks:

- valuvorm uue 150 L liivatuskasti jaoks
- valuvorm 3000 L maaaluse septilise mahuti juurde kuuluva pikenduskaela jaoks

Töö esimeses osas räägitakse üldiselt rotatsioonivalu protsessist, selle eelistest ja puudustest, selles kasutatavatest toormaterjalidest ning erinevatest rotovalu masinate tüüpidest.

Töö teine osa tegeleb rotovaluvormi projekteerimise protsessi üldiste printsiipide ja reeglitega. Samuti loetletakse rotovaluvormide põhitüüpe, vormide konstrueerimiseks kasutatavaid materjale ja nende olulisemaid omadusi ning vormi detailide valmistamiseks kasutatavaid metalli töötluse ja vormimise viise.

Viimases osas vaadeldakse läbi kõik rotovaluvormi projekteerimise etappid, kasutades näidisena kaks eelnimetatud toodet. Projekteerimise protsess algab soovitava toode CAD mudeli loomisega. Saadud mudeli alusel määratakse rotovaluvormi ülesehitust, lahutuspinna kuju ning vormi ehitamiseks vajalikke detailide kujusid. Edasi näidatakse viise, kuidas kalkuleerida toode tootmiseks vajalikku plastpulbri kogust ning rotovaluvormi ventilatsiooniava sisemist diameetrit. Viimasena saavad mõlemad vormid tootmiseks vajalikku isolatsiooni ning raami rotovalumasina kinnitamiseks.

Töö autor peab antud diplomitööd edukalt lõpetatuks. Nagu alguses plaanitud, said nii uue 150 L liivatuskasti kui ka maaaluse mahuti jaoks mõeldud pikenduskaela valuvormid projekteeritud, valmis ehitatud ning vastava toodete tootmiseks kasutatud. Töö tulemusi saab samuti näha Seledel 3.38 - 3.43.

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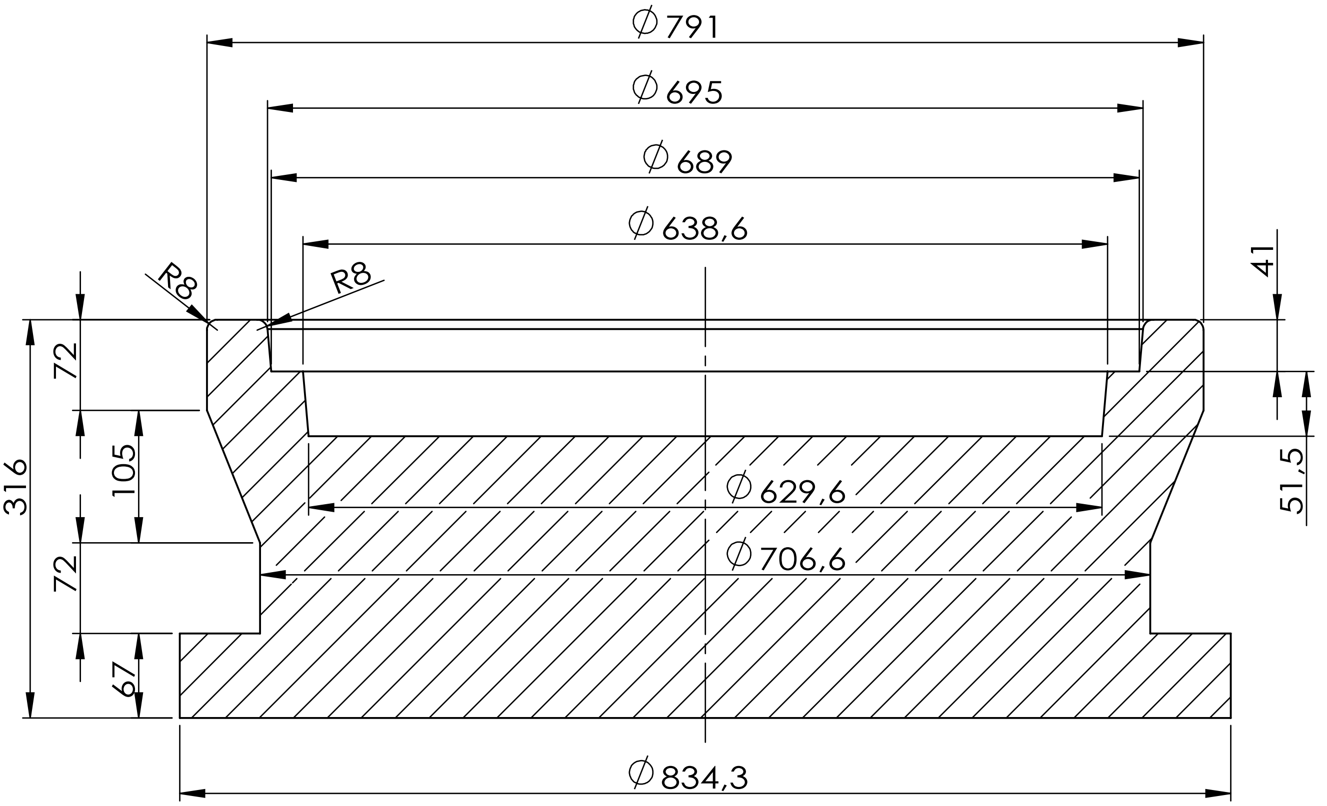
Technical drawings



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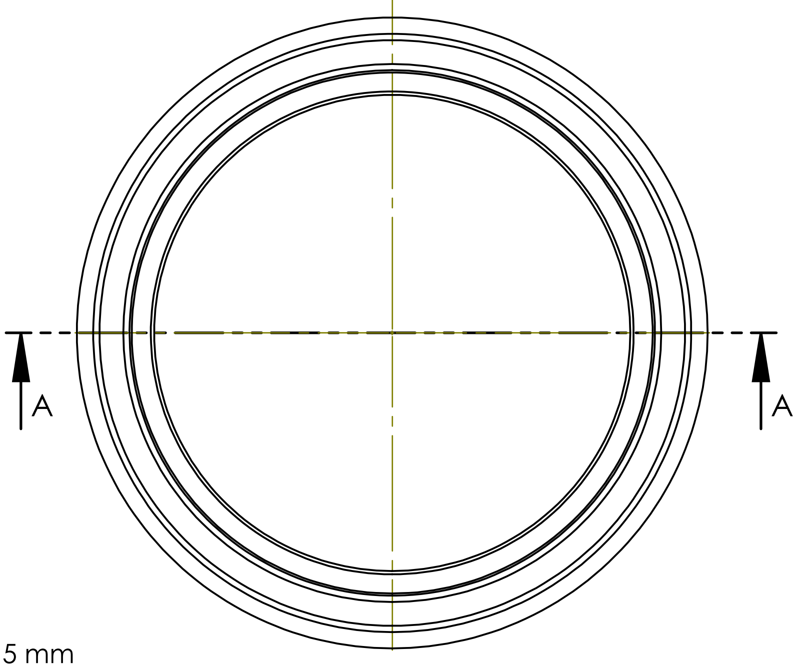

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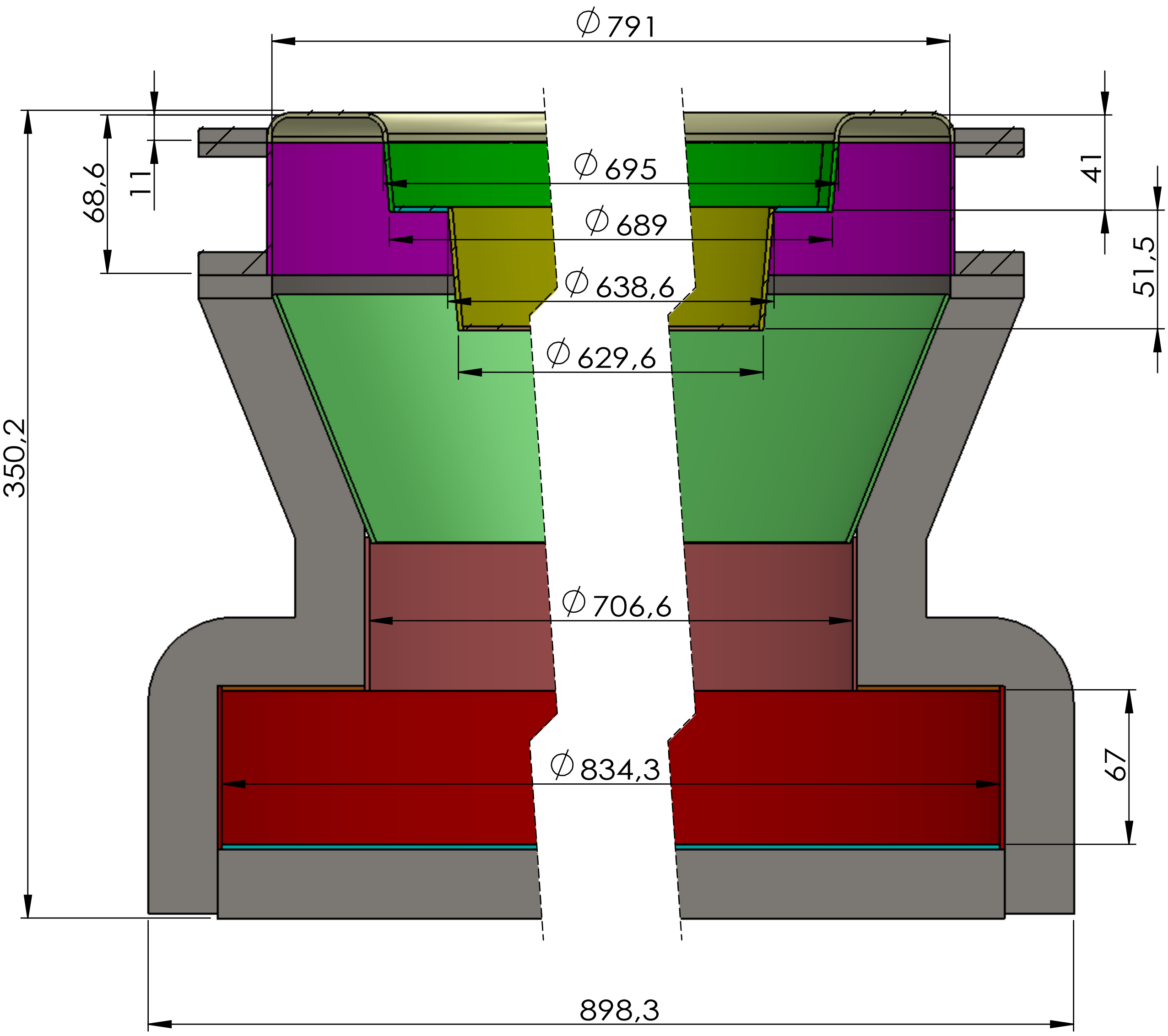

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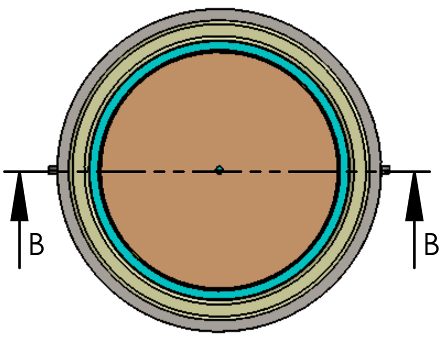

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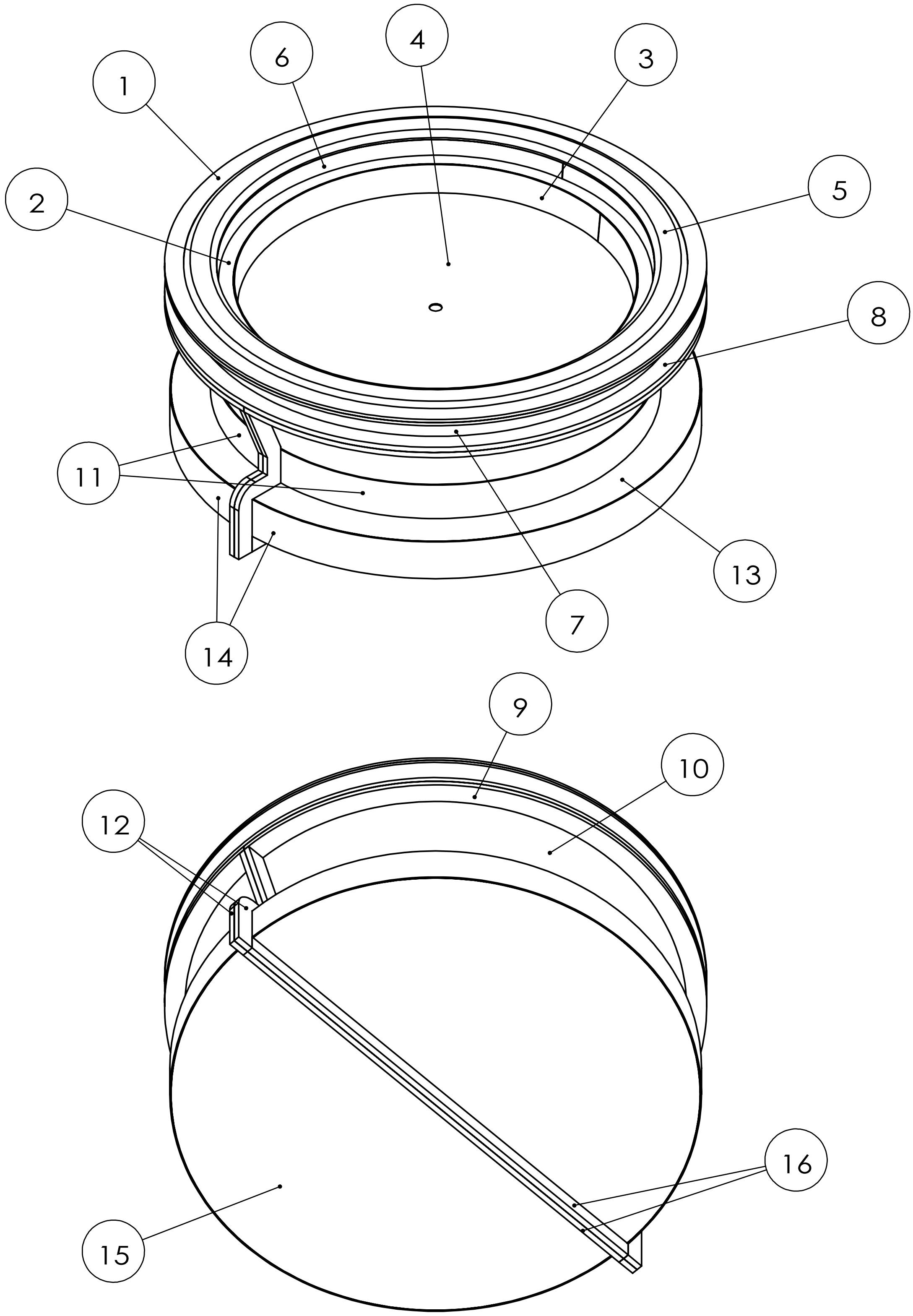

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6	M93020	2 mm DC01	1	16
7	M93002	2 mm DC01	1	14
8	M93022	10 mm S235/355	1	8
9	M93023	10 mm S235/355	2	7
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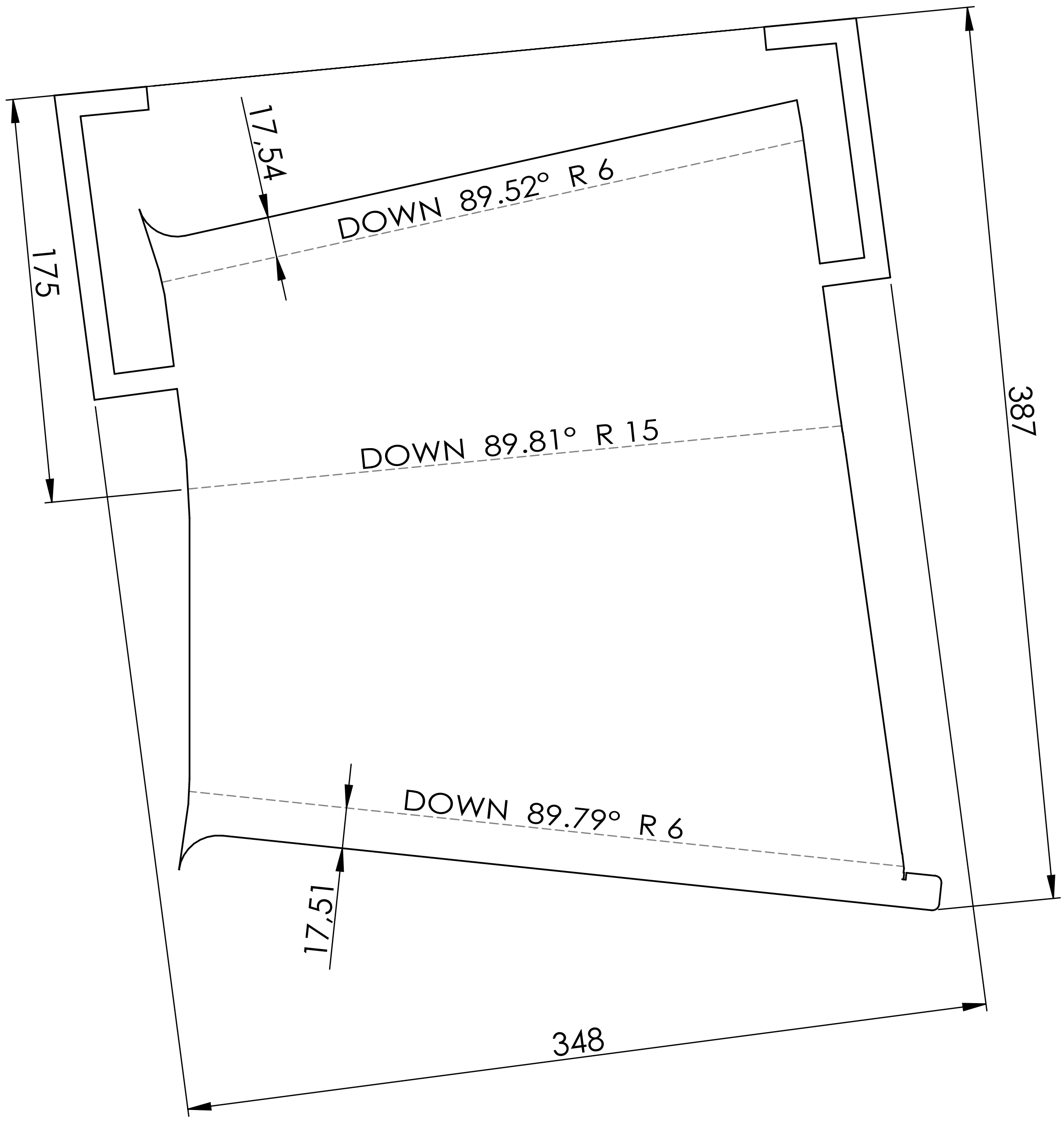

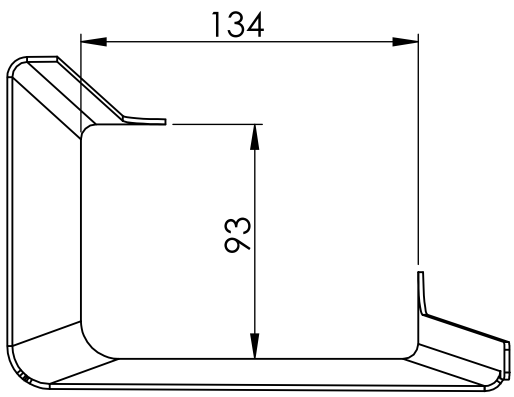

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Bounding Box Area-Blank: 88735.59mm^2
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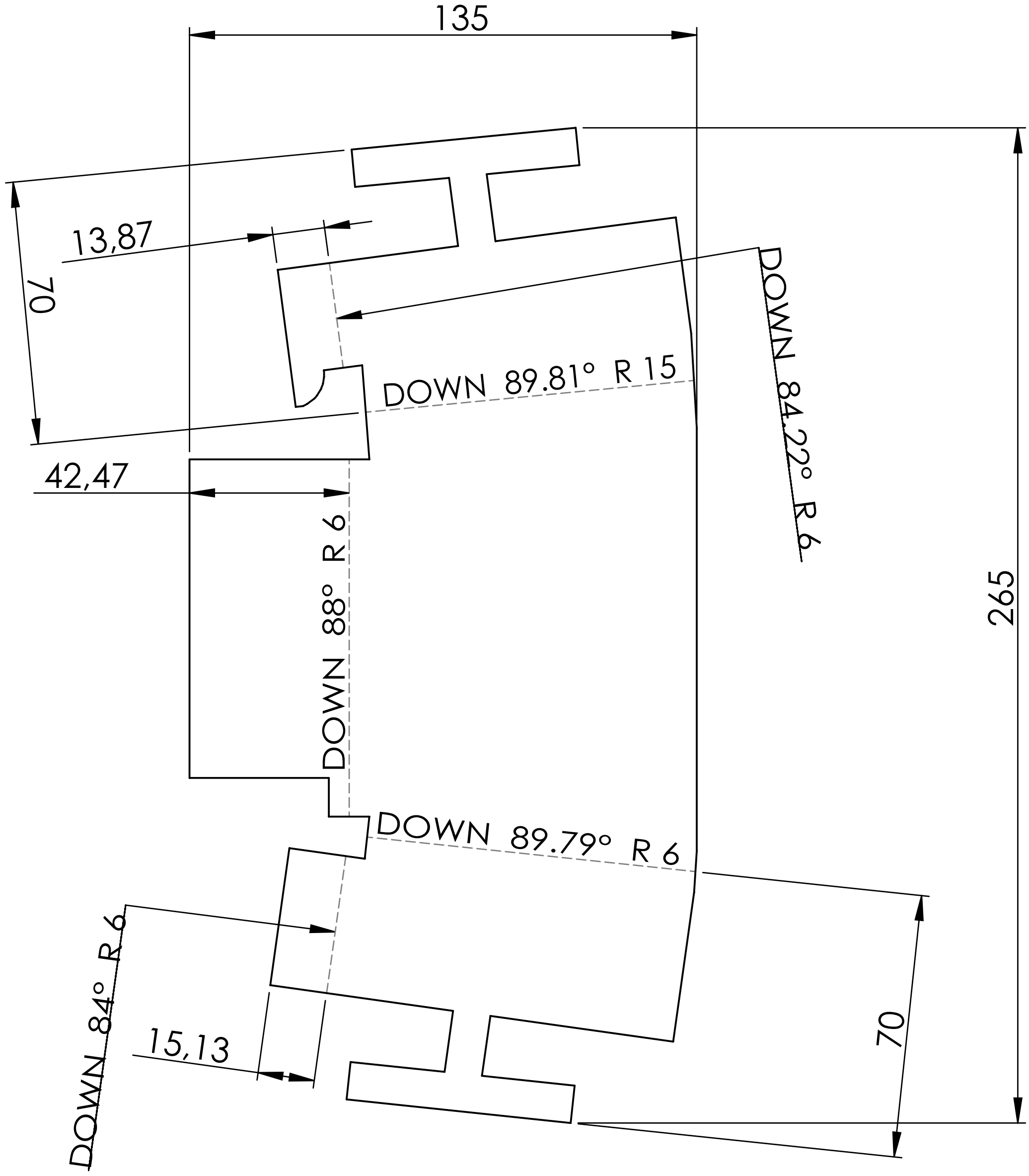

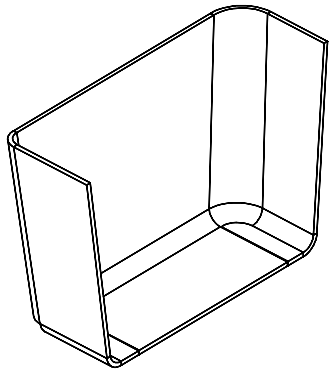

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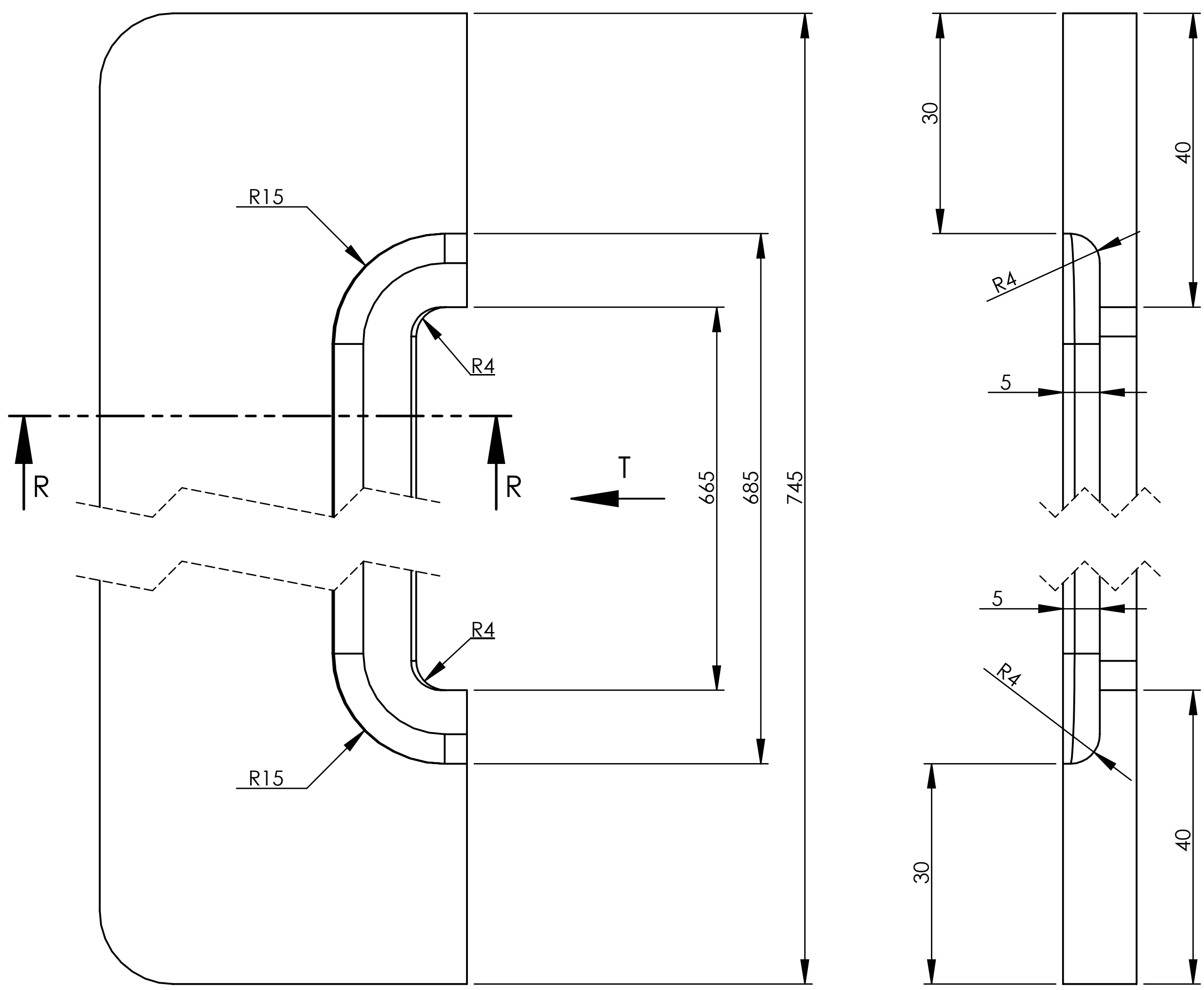
Kogus: 2 tk + 2 tk painded vastu pidi
Materjal: 2 mm DC01

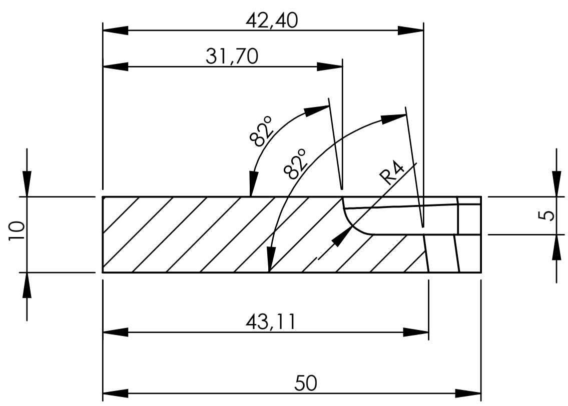
Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell Ytjämnhet, Ra	Vyplacering	Skala
V. Tamm		10.09.2013	SS-ISO 2768-1			1:2

Ägare	Titel/Benämning		
CIPAX	103000 150L liivatuskast		
	Ritningsnummer	Utgåva	Blad
	M103010		4(18)

Ändrings Nr	Ändringens art / Ändringsmeddelande	Godkänd av	Datum



VIEW T
SCALE 1 : 1



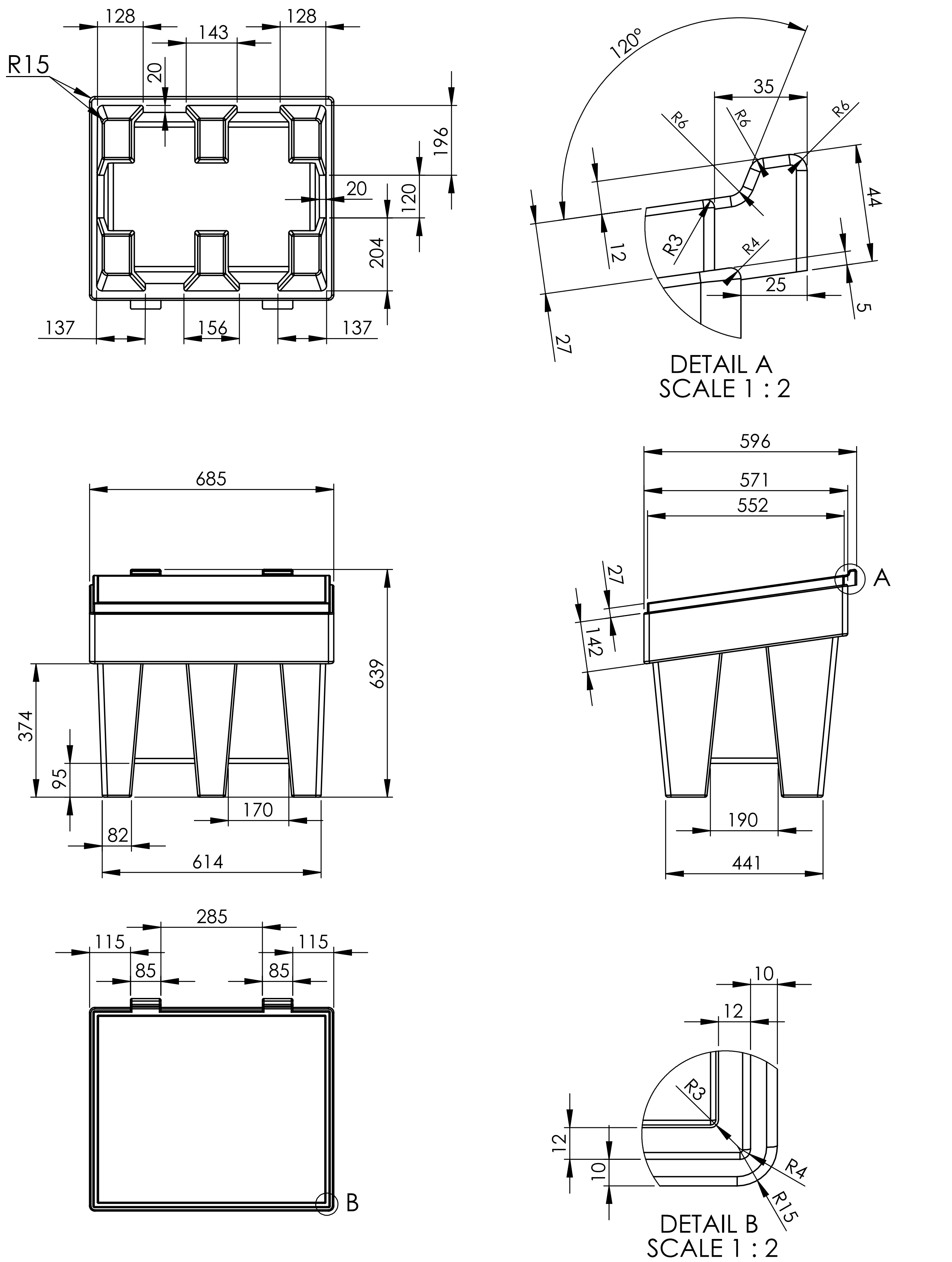
SECTION R-R
SCALE 1 : 1

Märkimata raadiused 10 mm
Materjal: 10 mm S235/355
Kogus: 1 tk

Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell Ytjämnhet, Ra	Vyplacering	Skala
V. Tamm		10.04.2013	SS-ISO 2768-1			1:1

Ägare	Titel/Benämning		
CIPAX	85000 150L liivatuskast		
	Ritningsnummer: M85006	Utgåva:	Blad: 11(26)

Ändrings Nr	Ändringens art / Ändringsmeddelande	Godkänd av	Datum

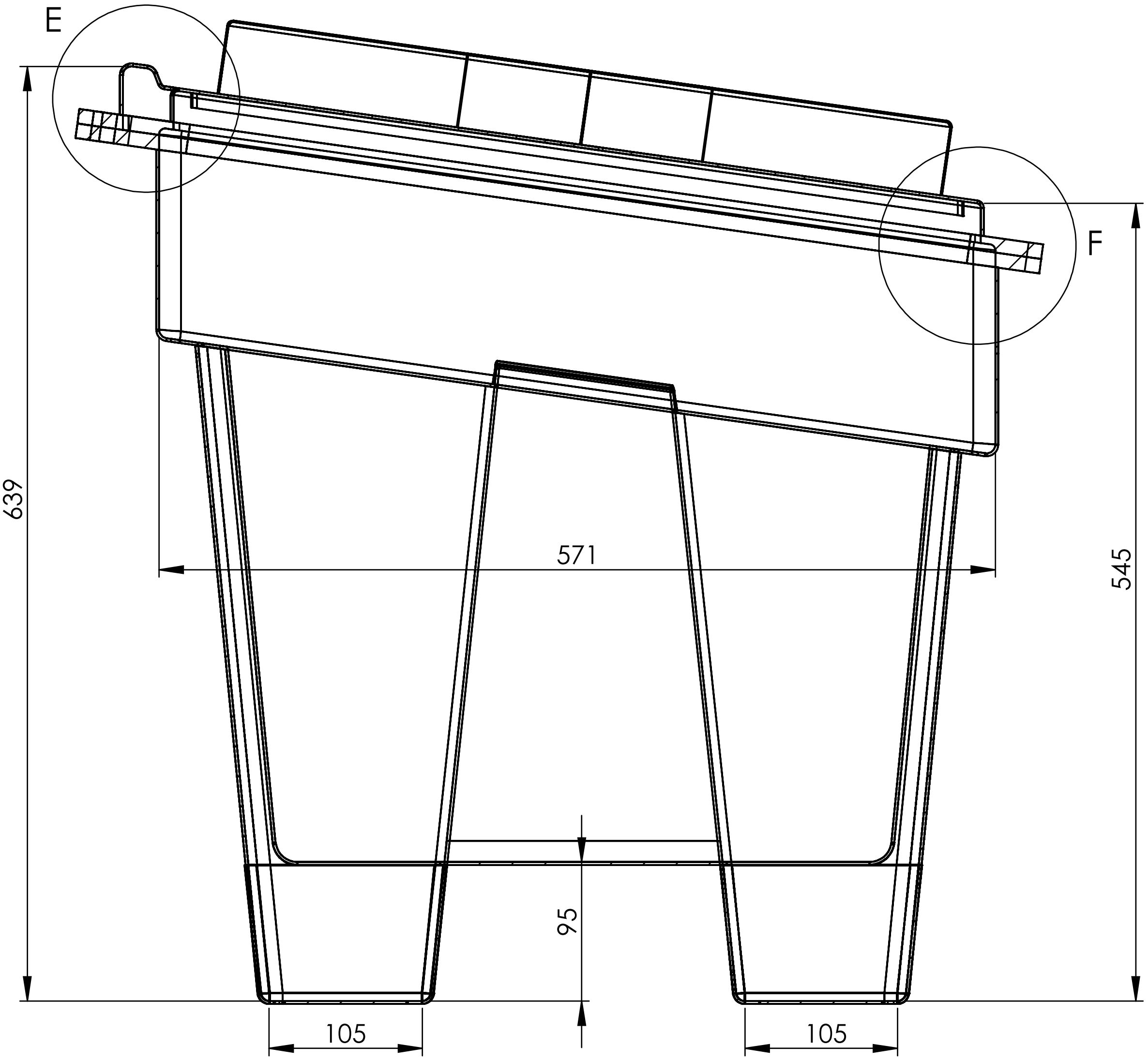


1. Märkimata raadiused 6 mm

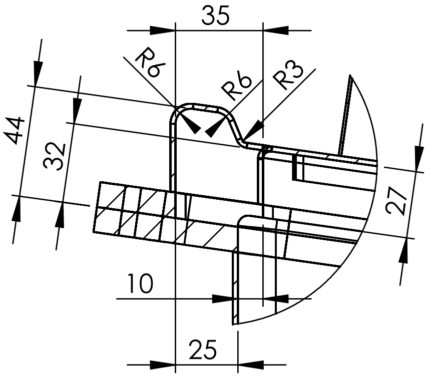
Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell Ytjämnhet, Ra	Vyplacering	Skala
V. Tamm		13.09.2013	SS-ISO 2768-1			1:15

Ägare	Titel/Benämning		
CIPAX	103000 150L liivakast		
	Ritningsnummer: 103000 vormi sisepind	Utgåva	Blad: 1(5)

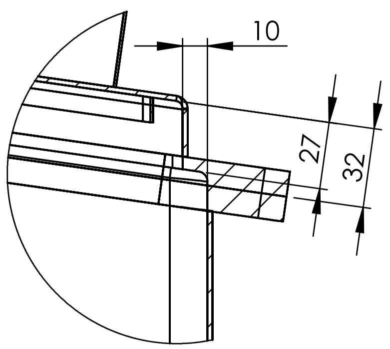
Ändrings Nr	Ändringens art / Ändringsmeddelande	Godkänd av	Datum



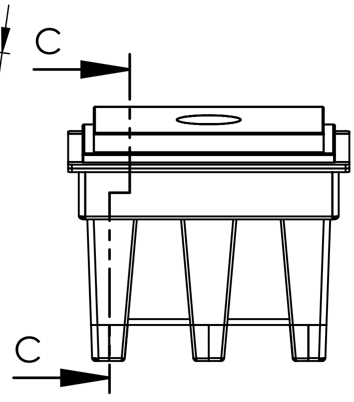
SECTION C-C
SCALE 1 : 5



DETAIL E
SCALE 1 : 3



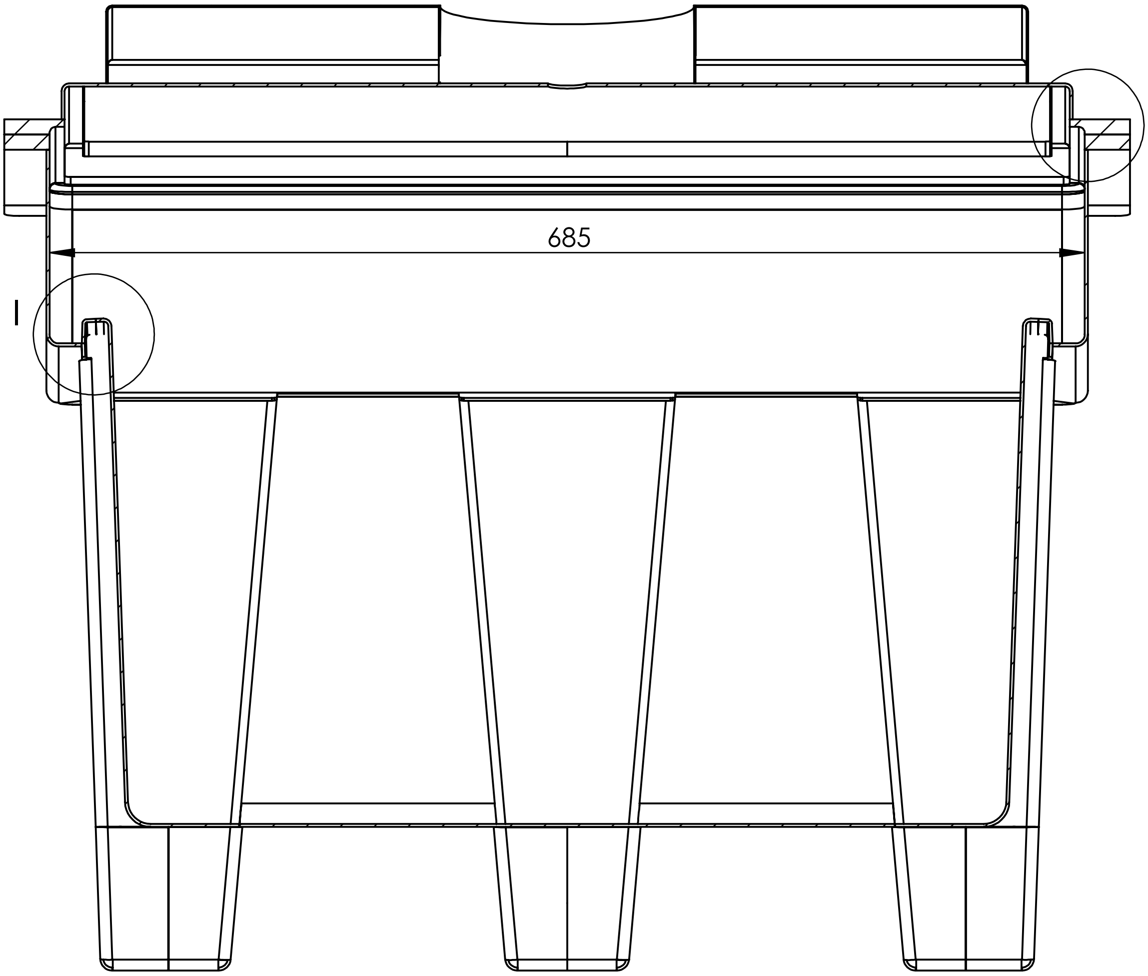
DETAIL F
SCALE 1 : 3



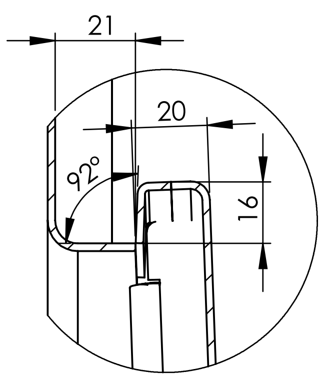
Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell	Vyplacering	Skala
V. Tamm		13.09.2013	SS-ISO 2768-1	Ytjämnhet, Ra		1:20

Ägare	Titel/Benämning		
CIPAX	103000 150L liivakast		
	Ritningsnummer: 103000 vormi koost	Utgåva	Blad: 2(5)

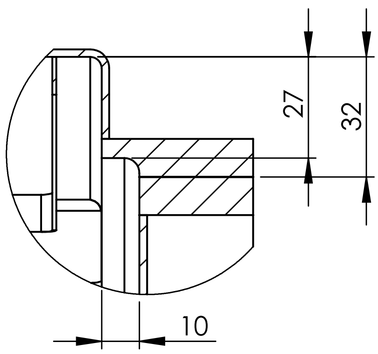
Ändrings Nr	Ändringens art / Ändringsmeddelande	Godkänd av	Datum



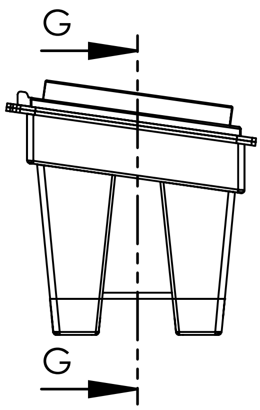
SECTION G-G
SCALE 1 : 5



DETAIL I
SCALE 1 : 2



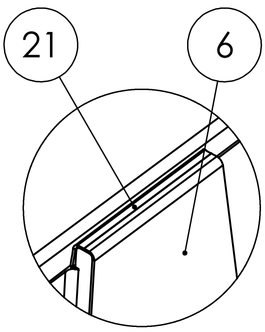
DETAIL J
SCALE 1 : 2



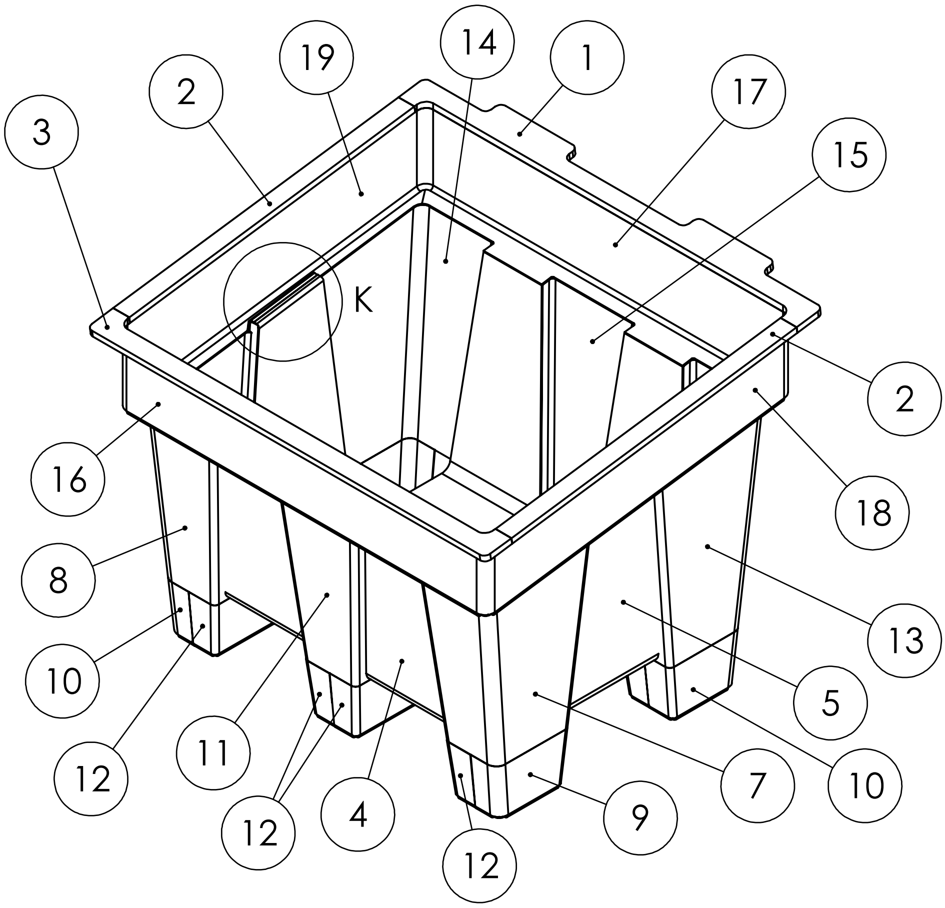
Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell Ytjämnhet, Ra	Vyplacering	Skala
V. Tamm		13.09.2013	SS-ISO 2768-1			1:20

Ägare	Titel/Benämning		
CIPAX	103000 150L liivakast		
	Ritningsnummer: 103000 vormi koost	Utgåva:	Blad: 3(5)

Ändrings Nr	Ändringens art / Ändringsmeddelande	Godkänd av	Datum



DETAIL K
SCALE 1 : 5



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M103001	10 mm S235/355	1
2	M103002	10 mm S235/355	2
3	M103003	10 mm S235/355	1
4	M103007	2 mm DC01	1
5	M103008	2 mm DC01	1
6	M103008b	2 mm DC01	1
7	M103009	2 mm DC01	1
8	M103009b	2 mm DC01	1
9	M103010	2 mm DC01	2
10	M103010b	2 mm DC01	2
11	M103011	2 mm DC01	1
12	M103012	2 mm DC01	8
13	M103013	2 mm DC01	1
14	M103013b	2 mm DC01	1
15	M103014	2 mm DC01	1
16	M103015	2 mm DC01	1
17	M103016	2 mm DC01	1
18	M103017	2 mm DC01	1
19	M103017b	2 mm DC01	1
20	M103024	2 mm DC01	1
21	M103024b	2 mm DC01	1

Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell	Vyplacering	Skala
V. Tamm		13.09.2013	SS-ISO 2768-1	Ytjämnhet, Ra		1:10

Ägare: CIPAX

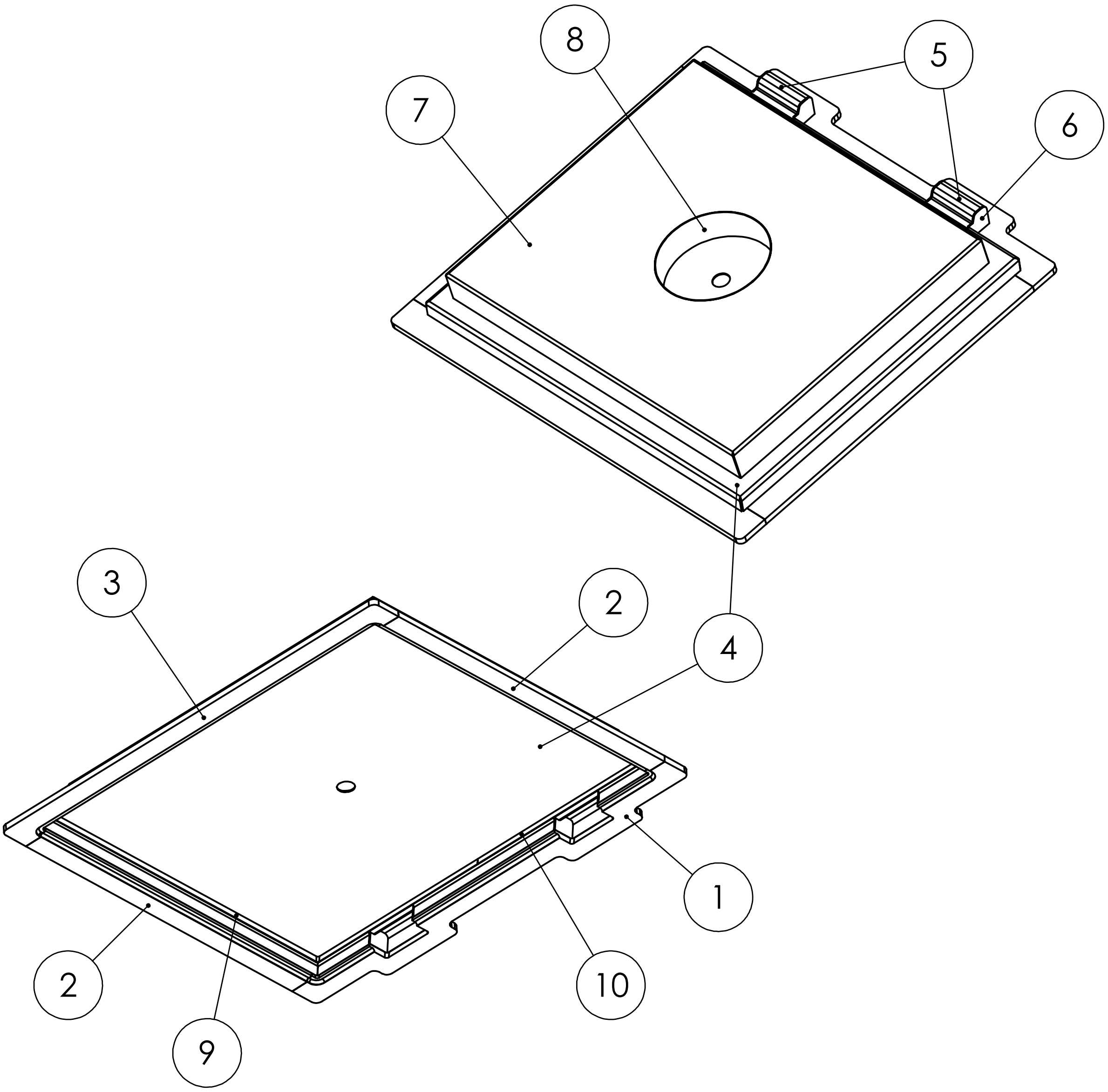
Titel/Benämning: 103000 150L liivakast

Ritningsnummer: 103000 vormi koost

Utgåva:

Blad: 4(5)

Ändrings Nr	Ändringens art / Ändringsmeddelande	Godkänd av	Datum



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M103004	10 mm S235/355	1
2	M103005	10 mm S235/355	2
3	M103006	10 mm S235/355	1
4	M103018	2 mm DC01	1
5	M103019	2 mm DC01	2
6	M103020	2 mm DC01	4
7	M103021	1 mm DC01	1
8	M103022	1 mm DC01	1
9	M103023	1 mm DC01	1
10	M103023b	1 mm DC01	1

Konstruerad av	Granskad av	Godkänd av - datum	Generell tolerans	Generell Ytjämnhet, Ra	Vyplacering	Skala
V. Tamm		13.09.2013	SS-ISO 2768-1			1:20

Ägare: CIPAX

Titel/Benämning: 103000 150L liivakast

Ritningsnummer: 103000 vormi koost

Utgåva:

Blad: 5(5)