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# Development of a Clamp-on Mechanism for an Ultrasonic Flow Meter

Utvikling av en clamp-on mekanisme for en ultralyd mengdemåler

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# PREFACE

This thesis concludes a five-year Master of Science in Mechanical Engineering, Process Technology and Product Development at the Norwegian University of Life Sciences. The thesis consists of 30 credits and was conducted through the spring semester of 2018.

The product development done in this thesis was undertaken in cooperation with Kroksjøen Waterworks, in order to help promising innovative technology from some of the worlds most renowned universities make its way onto the burgeoning clamp-on flow meter market. During my work on this thesis, I have learned a lot about water leakages and the challenges water utilities face, both nationally and internationally. Investigating the subject has been elucidating, and it is my hope that this thesis can accelerate the development of a much-needed tool to reduce water leakage worldwide.

I would like to thank my assistant supervisors Kristian Sørby Omberg, and Ola Sørby Omberg, for guidance and good ideas throughout the whole process. At Kroksjøen Waterworks, I would like to thank Ola Kristian Klanderud for providing me with useful material and arranging a tour of their water distribution network. I would like to thank Christopher Eek Mjelde for thorough proofreading. At last, I would like to thank my fellow students, friends and family for support, interesting conversations and discussions during the time of this thesis.

Ås, June 1st, 2018

Kevin Gaden Vesterås

# ABSTRACT

274 billion liters of clean, processed drinking water are lost from water distribution systems daily. In order to identify and locate leakages in water distribution networks, water utilities use time-consuming techniques and resource-demanding technology. This limits their ability to efficiently reduce and repair leakages, and as a result, much water is lost before it reaches the consumer. A network of clamp-on flow meters can be used to monitor entire water distribution networks remotely, greatly reducing the necessary resources and time it takes to identify leaks [1].

The scope of this thesis is to derive the critical specifications necessary for a clamp-on ultrasonic flow meter to provide a viable alternative to traditional leakage detection technologies. In order to achieve this, prototype models are developed to provide a "Proof of Concept" for different solutions and gather insight for further development through extensive testing.

To achieve the above, an extensive literature review was performed to provide the basis for understanding the limitations and challenges related to leakage management and methods. This was followed by a case-study of a Norwegian water utility, to determine suitable installation locations on a water distribution network, and gather more insight. As a result, multiple concepts on clamp-on mechanisms and different clamp-on enclosures were designed and evaluated, using product development methods. The selected concepts were then as developed and built as prototype models, to explore the different solutions in order to see the advantages and weaknesses of the individual concepts. By engaging the end-user early in the whole development process, valuable insight was gathered through dialogue and testing, and from this process the specifications were derived. The most critical specifications include; intuitive design, long lifetime, small size, durable materials, and low cost.

The activities performed throughout this thesis indicate that a clamp-on flow meter using industrial cable ties as a clamp-on mechanism is a viable option and should be developed further. In addition, a clamp-on flow meter capable of being welded to PE pipes with electrofusion welding, is of high interest. Two versions of these flow meters should be developed, as private and professional markets have different requirements regarding size, functionality and preferred clamp-on mechanism.

# SAMMENDRAG


274 milliarder liter med rent drikkevann går tapt fra vanndistribusjonsnett daglig. For å identifisere og lokalisere lekkasjer i vanndistribusjonsnett, bruker vannverk tid- og ressurskrevende teknikker og teknologi. Dette begrenser deres evne til å effektivt redusere og reparere lekkasjer, noe som fører til at store mengder vann går tapt før det noen gang når forbrukeren. Et nettverk av clamp-on vannmålere kan brukes til å overvåke hele vannforsyningsnettverket eksternt, samt kraftig redusere de nødvendige ressurser og tid det tar å identifisere lekkasjer [1].

Omfanget av denne oppgaven innebærer å utlede de kritiske spesifikasjonene som er nødvendig for at en clamp-on ultralyd vannmåler skal være et verdig alternativ til tradisjonelle lekkasjesøk-metoder. Fra dette utvikles og bygges Proof of Concept-modeller til testing for å samle inn innsikt for videre utvikling.

For å oppnå dette har en omfattende litteraturstudie blitt utført for å gi grunnlag for å forstå begrensningene og utfordringene knyttet til lekkasjehåndtering og dagens metoder. Dette ble etterfulgt av en case-studie av et norsk vannverk, for å fastslå egnede installasjonssteder på et vannforsyningsnett, og samle videre innsikt. Som et resultat ble flere konsepter på clamp-on mekanismer og forskjellige clamp-on konstruksjoner utformet og evaluert ved hjelp av produktutviklingsmetoder. De valgte konseptene ble så utviklet og bygget som prototypemodeller slik at fordeler og svakheter til de enkelte løsningene kunne utforskes. Ved å engasjere sluttbrukeren tidlig i utviklingsprosessen, ble verdifull innsikt samlet gjennom dialog og testing, og fra denne prosessen har spesifikasjoner blitt avledet. De mest kritiske spesifikasjonene inkluderer; intuitivt design, lang levetid, liten størrelse, slitesterkt materiale og lav pris.

Aktivitetene som har blitt utført gjennom denne oppgaven, indikerer at en clamp-on mekanisme som bruker industrielle strips som festemekanisme er en verdig løsning og burde videreutvikles. I tillegg viser funn gjennom oppgaven at en clamp-on mekanisme som kan sveises til PE-rør med elektrofusjons sveising, av høy interesse. To versjoner av disse clamp-on vannmålerne burde utvikles, da private og profesjonelle markeder har forskjellige krav til størrelse, funksjonalitet og foretrukket clamp-on mekanisme.

# Content

# ABBREVIATIONS

| | |
|---|---|
| ALC | Active Leakage Control |
| ELL | Economic Level of Leakage |
| SRELL | Short Run ELL |
| LRELL | Long Run ELL |
| NMBU | The Norwegian University of Life Sciences |
| IPD | Integrated Product Development |
| PDS | Product Design Specification |
| GRP | Glass fiber Reinforced Plastics |
| PVC | Polyvinyl Chloride |
| PE | Polyethylene |
| HDPE | High-density polyethylene |
| IWA | International water association |
| NRW | Non-revenue water |
| MNF | Minimum Night Flow |
| SIV | System Input Volume |
| CARL | Current Annual Real Losses |
| UARL | Unavoidable Annual Real Losses |
| PETG | Polyethylene terephthalate glycol-modified |
| PET | Polyethylene terephthalate |
| IP | Ingress Protection |
| IEC | International Electrotechnical Commission |
| POC | Proof of Concept |

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# 1. INTRODUCTION

Access to clean water, and enough of it, is a growing challenge facing the world. Climate change and population growth are adversely affecting both the supply and demand for clean water, and, making matters worse, large quantities of water are lost before ever reaching consumers' taps, due to both inefficient water management, and distribution systems prone to leaks. An estimated 274 billion liters of clean, processed drinking water are lost from water distribution systems daily [1].

Water produced in a network but lost before reaching the consumer, is referred to as Non-Revenue Water (NRW). Such losses might be due to leakages in aging water infrastructure lacking proper maintenance, metering inaccuracies, theft, or authorized, unmetered consumption, like water used from fire hydrants. Contrary to common misconceptions, these are not problems restricted to only the developing world – Montreal, for example, loses about 30% of all its produced water due to leaks, despite annually spending millions of dollars improvements and repair [2].

Management of leakages is becoming increasingly important and receiving more focus than ever before. Traditional methods of finding leakages are expensive, resulting in water utilities allowing high levels of NRW before they act. Budgetary constraints are a major obstacle for some water utilities, stopping them from investing in new solutions. Preventing leakages from the water network is also a health concern, as pollution enters the drinking water through leaks, spreading potentially harmful bacteria and parasites to a lot of people. Renewal and repair of pipelines is an important part of keeping the water distribution network in good condition. This has been neglected for a long time by water utilities in countries with good economy and easy access to clean water, but is said to receive more attention in the coming years [3].

The majority of NRW is lost through small leakages, which are hard to discover before they eventually develop and cause a noticeable problem to the surrounding area. Technological innovations offer hope for water utilities, as new clamp-on flow meter solutions are being developed to help identify leaks while they are still small. This thesis serves as the beginning of the development of a clamp-on enclosure and mechanism for a new type of ultrasonic transducer.

## 1.1 Project objectives

The purpose of this thesis is to design and build a clamp-on (attachment tool) for an ultrasonic flow meter that will attach a new transducer element to waterpipes of different diameters and materials (metal, PVC, PE and PP). In addition to developing a clamp-on solution for the current market, a more specified solution for the anticipated future market will also be researched.

Furthermore, this thesis will review the necessary groundwork and basic knowledge needed to successfully design and develop a clamp-on ultrasonic flow meter. In doing so, the theory and key concepts covered in **Section 4**, will go slightly beyond the bare minimum requirements for the undertaken product development.

## 1.2 Project overview and product Requirements

For a new clamp-on ultrasonic flow meter to become a viable market alternative, it must either be price competitive, or bring a new technological advancement to the industry. The technological innovation for this smart flow meter will largely be based on a new transducer element, being developed externally to this thesis. As there is little information about this new transducer element, its requirements, and its competitiveness in the current market, existing flow measurement principles will be reviewed to gain some insight to its potential. In addition, theory regarding water leaks and how water utilities manage them, is covered to create a foundation for further development once information about the new transducer becomes available.

To identify requirements for a clamp-on ultrasonic flow meter, it is important to review existing solutions. During this review, common strengths and weaknesses are considered, as well as possible improvements.

**Requirements for a smart flow meter:**

- Price competitive.
- Compact design.
- Easy assembly and installation.
- Rigid clamp-on mechanism preventing movement.
- Sufficient water- and dust resistance.
- Accurate and repeatable measurements.

## 1.3 Goals and objectives

**Main goal:**

Develop a prototype to demonstrate a "Proof of Concept" (POC) of a clamp-on mechanism for a ultrasonic flow meter, based on performed activities and derived initial specifications through an iterative development process and testing with end-user - in order provide insight for further development.

**Objectives:**

- Review theory associated with water leakage management.
  - Identify motives and market potential.
- Produce a specification list.
  - In cooperation with industrial partners.
- Conduct an end-user design study – Kroksjøen Waterworks.
  - Identify necessary requirements.
  - Identify suitable placement.
- Create a preliminary design.
  - Evaluate clamp mechanisms.
  - Evaluate enclosure designs.
  - Identify suitable materials and durable design.
- Build prototypes to serve as “Proof of Concept”
  - 3D-print.
- Validate and test of concepts.
  - With replica of transducer element.
  - Evaluate concepts strengths and weaknesses.
- Suggest further work.

## 1.4 Limitations

The new transducer element being developed is the main motivation for developing an entirely new smart water meter. There are several parties involved in the overall development, across Germany, USA and Norway, all with different task and resources. The Norwegian University of Life Sciences (NMBU) is involved through Eik ideverksted, an innovation workshop. As the development of the transducer is still in early stages, valuable information is held to a strictly need-to-know basis. This results in a range of limitations while developing a clamp-on solution, as the only essential information available is the actual size of the transducer element. Limitations caused by flow of information and time available, are listed below:

- Research about Norwegian water utilities and information obtained in cooperation with Kroksjøen Waterworks is assumed to be valid for most water utilities in similar situations.
- Information regarding the new transducer element and specifications as to how it works are based exclusively on conversations with project partners, and are not documented in this thesis. There will be no testing of the actual transducer element during this thesis.
- The solutions developed in this thesis are meant as guidelines only, and needs further work and testing when the transducer is available, such as relevant calculations and simulations relevant to design properties.
- Technical drawings of the developed solutions are not meant for professional use at this stage and are not up to industry standards, as the models are subject to constant iteration beyond the scope of this thesis.
- Ultrasound gel and coupling agents used to ensure transmission of ultrasonic waves through a material is outside the scope of this thesis and should be considered for further research.

# 2. BACKGROUND

## 2.1 Water leakage in Norway

In Norway, the challenge is not the access to enough water; heavy rainfall and, overflowing water reservoirs are becoming more frequent, cementing Norway as one of the countries with most freshwater per capita. Furthermore, Norway's water is often clean, requiring little work before making its way out to the consumer. Instead, the problem lies in the fact that this processed, clean water leaks out of the distribution system. In fact, of the 750 million $m^2$ of water sent out on the water distribution system in Norway in 2014, about one third was lost through leakages [4] [5].

In other parts of the world, however, clean water is rarely this abundant. In response, the European Union (EU) has put innovation within the water industry on the agenda through a "climate action, environment, resource efficiency and raw materials" challenge; a part of its Horizon 2020 initiative. The goal is to increase the EU's competitiveness, growth and workplaces within the water sector to make Europe a global market leader within water related innovation [6].

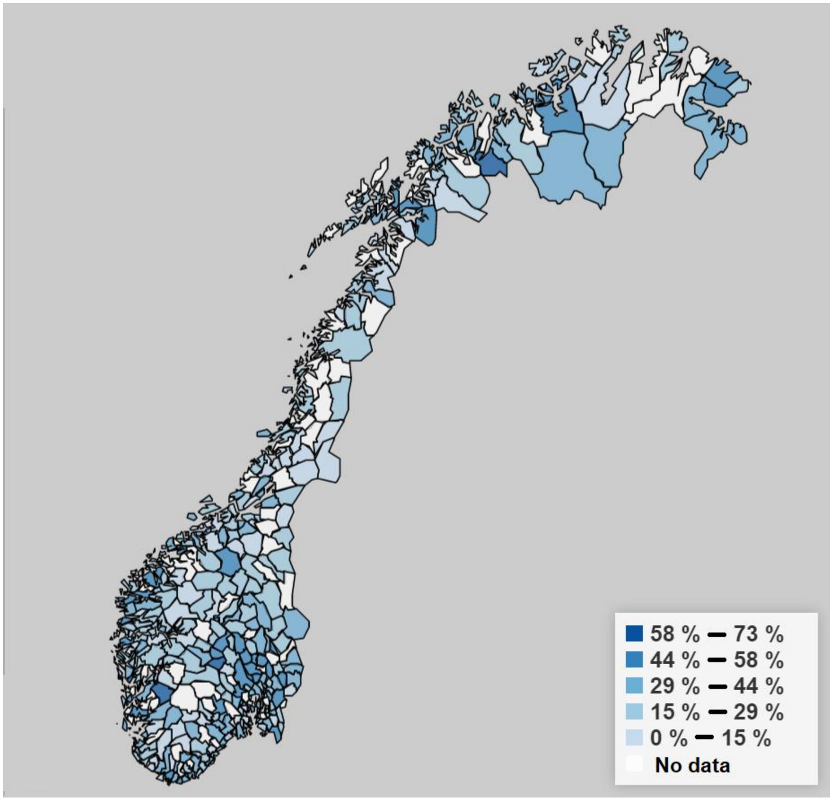



Figure 1: Leakage percentage in Norwegian municipalities. Adapted from [5].

## 2.2 Smart water technology

New water pipes are often made of thermoplastic materials, which does not possess the ability to carry sound and vibrations as well as older metal pipes. This is a problem because most of the traditional technology used to locate leaks, rely on sound and vibrations. New and smarter water metering technologies are being developed, offering hope for water utilities, and end-users, in gathering much needed data from the water distribution networks.

This new market, called Smart Water Technology, has huge potential to reduce global water losses, and increase water resource efficiency. Implementing a network of smart water sensors that can track water quality, temperature, pressure, consumption and more, will provide huge benefits in reduced water and energy consumption. These devices typically communicate directly with a water utility company, which uses software to analyze the data and return it to the consumer in an easy-to-understand format. Users can then see how their consumption compares to city averages, previous time-periods and more. Furthermore, suppliers can, depending on the density of sensors, locate leaks throughout their network with great accuracy. Smart water infrastructure replaces manpower and time-consuming tasks by enabling a continuous stream of information from a network of sensors [7].

The use of smart water infrastructure enables cities to better manage their water distribution networks in the face of climate disruption. Turning the existing static network of water pipes and pumps into adaptive and connected networks provides huge benefits in reduced water and energy consumption. The opportunity will benefit both operators and consumers, as the reliability of delivery will increase while water supply costs decrease.

Smart water meters often rely on ultrasonic technology, by mounting a set of transducers emitting ultrasonic waves into the pipe. This measuring principle has an advantage over traditional flow metering as it does not have to be intrusive or invasive to the flow. However, ultrasonic water meters can be fragile, as any movement of the transducer after it has been mounted can cause incorrect measurement. Ultrasonic flow meters can also be expensive, resulting in water utilities looking to other measuring principles.

A recent technological innovation has opened the possibility of ultrasonic flow measurement utilizing a new type of transducer. This transducer allows for easier, more reliable measurement and should be cheaper to produce. The Norwegian market is ideal to assist in developing a clamp-on solution for this new transducer, as Norwegian water utilities are motivated to reduce leakages and have the resources to do so. In this thesis, a clamp-on solution for a new ultrasonic flow meter will be developed. Relevant theory linked to water loss and management of water utilities will be covered.

## 2.3 Key economic data

### 2.3.1 COST – WATER LEAKAGES

Water loss can be expensive, especially if clean water resources are scarce. Although this is not the situation on Norway, water utilities are very aware of the cost tied to water leakages. A report published by Bergen municipality states that over 40% of its produced water is lost before reaching the consumer. **Table 1** shows an example of what a small leakage costs in Bergen, based on a pen sized hole in a water pipe [8].

Table 1: Cost of water leakage from a pen sized hole. Data from Bergen municipality [8].

| **Leakage** | $m^3$ | **Price for water** $[\frac{NOK}{m^3}]$ | **Cost** $[NOK]$ |
|---|---|---|---|
| **Hour** | 2,5 | 5,63 | 13,40 |
| **Day** | 60 | 5,63 | 322,00 |
| **Week** | 420 | 5,63 | 2251,00 |

A leakage of 2,5 $m^3/hour$ is considered a small leak, but it can be a huge cost for the water utility if it is not repaired. Small leaks can be difficult to find, and are often left undiscovered for a long time until they increase in size.

### 2.3.2 ECONOMIC LEVEL OF LEAKAGE

Managing a water utility efficiently and economically revolves heavily around managing leakages. However, this is not the same as combatting them exhaustively. Every water distribution system has a unique Economic Level of Leakage (ELL), corresponding to the intersection point between the cost of activities to reduce leakages, the benefits these accrue, and the law of diminishing returns associated with each additional activity. In other words, the EEL is the leakage percentage that remains when the marginal benefit of reducing it further is less than the cost. There is no method to accurately calculate the ELL alone, as it is a result of several activities connected to operating a water distribution network. The activities impacting water leakage can be divided into two categories, short run and long run [9].

**Short Run ELL (SRELL)**

SRELL mostly consists of active leakage control (ALC) to uncover new leakages, followed by some form of leak repair activity. The ALC activity is necessary to locate unreported leaks that might not surface or come to the water utilities attention otherwise. Finding unreported leaks requires teams of trained leakage detection staff to actively search along the water distribution system. By actively searching for unreported leaks, and repairing them, leakage can be maintained at a desired level. Water utilities need to consider the cost of conducting ALC in comparison to the cost of leaking water, as there is an economic leakage level where the total cost is the lowest. This is illustrated in **Figure 2** below.

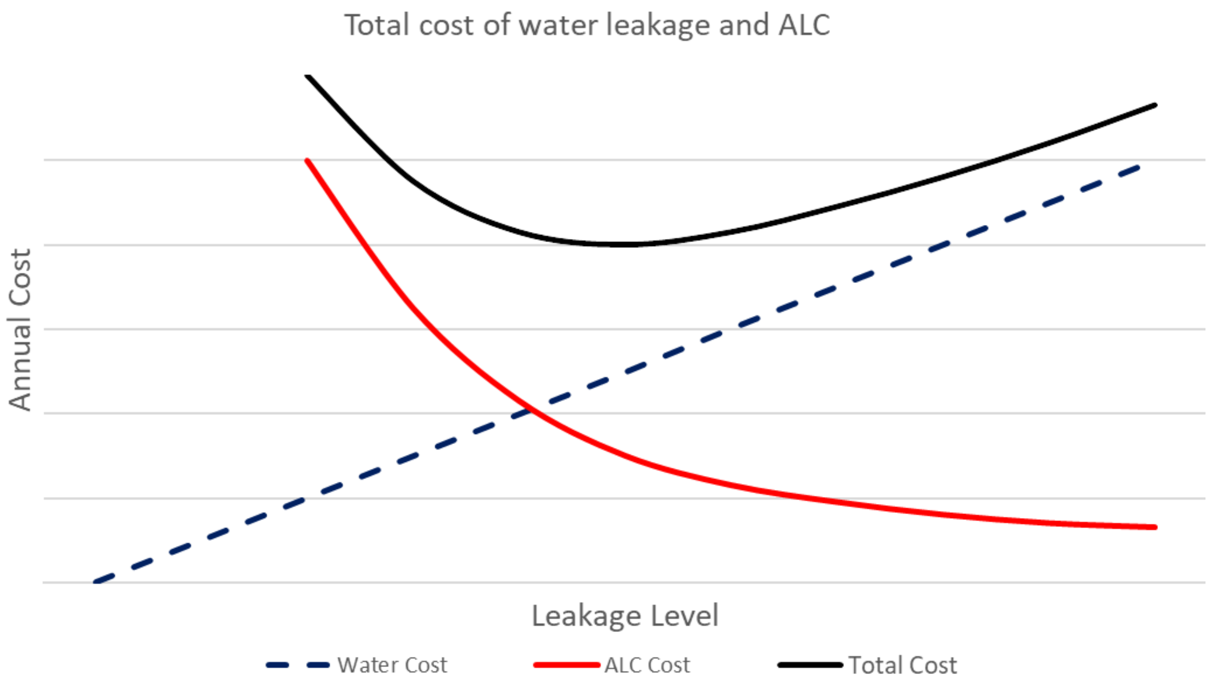



Figure 2: Total cost of water leakage and ALC, illustrating the economic balance between the them and when total cost is at its minimum [9].

**Long Run ELL (LRELL)**

In addition to SRELL, a water utility should perform activities affecting the amount of water leakages in the long run, called Long Run ELL. These activities can be considered investments, as the results of performing them are often only apparent after some time. Pressure management is one of the more important activities influencing water leakage levels. Not only does is affect the amount of water leaking at any given time, it also impacts the lifetime of a pipeline.

Rehabilitating the water distribution network will reduce the rate at which new leaks occur. Identifying pipes with high frequency of leaks and burst, and replacing these, will reduce the leakage level as well as costs associated to ALC.

To further increase their control and amount of available information, water utilities can divide their network into sectors and monitor the amount of water flowing in and out of these sectors. This is usually done with the help of flow meters at key points in the water distribution network. Data gathered from these flow meters help detect and identify leaks faster, resulting in less resources spent on ALC.

Water metering technology available on the market today, is intrusive, expensive and in many ways not practical for a widespread network installation. The new transducer technology provides the possibility for a cheaper and more applicable ultrasonic water meter. Developing a clamp-on mechanism for this transducer capable of reliable and efficient installation wherever the water utility wishes, is a much-needed tool to fight water leakage.

## 2.4 New transducer technology

Transducers are the main component in all ultrasonic technologies, including ultrasonic flow meters. Ultrasonic sound waves travel between a set of transducers, which is a device capable of transforming mechanical energy to electric energy, and opposite. This electromechanical effect is called piezoelectricity. The key element in a transducer capable of this operation, is called a piezoelectric crystal. Conventional ultrasonic transducers consist of various components illustrated in **Figure 3** below [10].

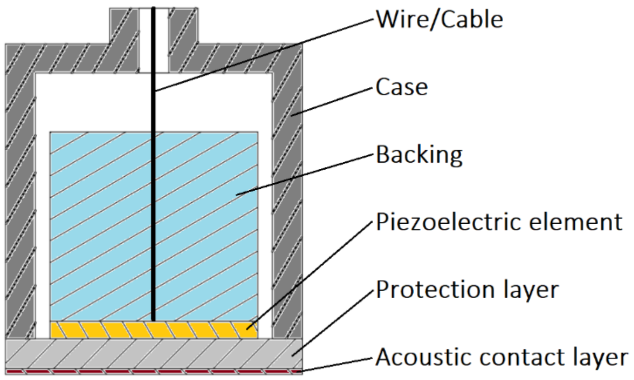



Figure 3: Conventional transducer with labeled components [11].

The new ultrasonic transducer element does not resemble the conventional transducer. Although little information about the transducer is known at the time of this thesis, the shape and dimensions are confirmed to be equal to a pen. To assist the development of the clamp-on mechanism, a copper replica has been made.

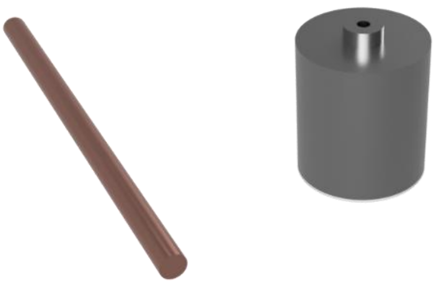


Figure 4: Visual comparison of new transducer element and conventional transducer.

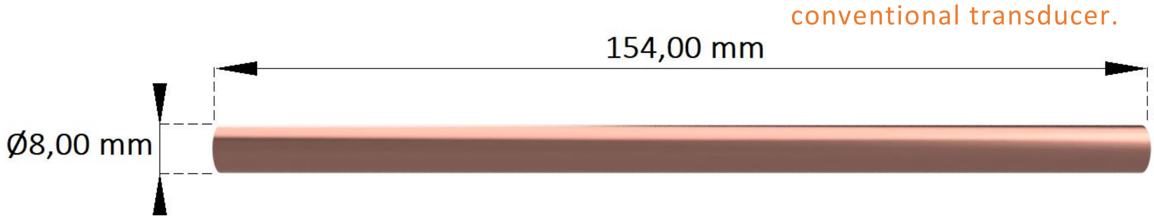



Figure 5: New ultrasonic transducer element with presumed measurements.

# 3. METHODOLOGY

## 3.1 Method

**Integrated Product Development (IPD)**

IPD is a philosophy centered around the inclusion of a wider field of studies and principles while conducting your project development. The method's ambition of is to increase efficiency by implementing knowledge from all stages of development from the beginning, instead of separating the design, build and test phases any more than absolutely necessary. Furthermore, IPD also promotes the engagement of customers and suppliers early on to identify their needs, determine their requirements, and understand the market. This method has been applied in this thesis by involving an end-user early in the product development [12].

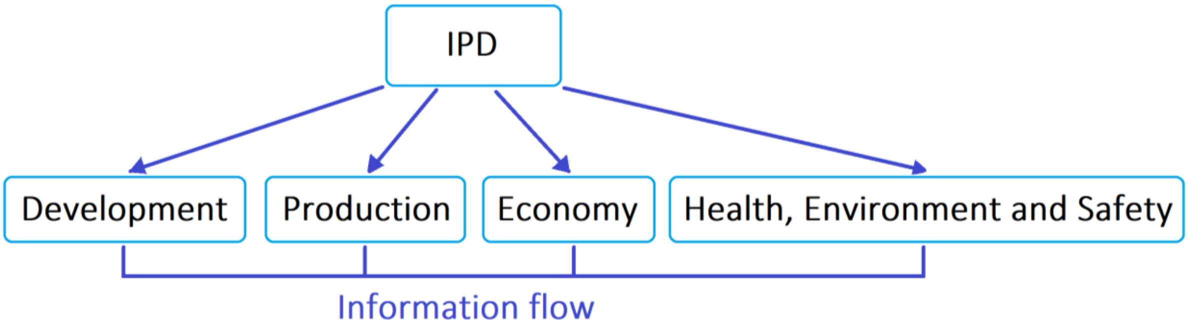



Figure 6: IPD methodology illustrating the flow of information between the main elements.

**Total Design methodology**

Total Design methodology invented by Stuart Pugh, builds on many of the same principles as the IPD method. Rather than individual processes of a product development being separate, Total Design advocates for the integration of technological and non-technological parts of development [13].

A Product Design Specification (PDS) must be formulated and kept central to the overall development. The PDS should evolve during the design process and act as a control for the total design activity. To select the most compatible concepts during the development process, the "Pugh method" is used. This method selects a baseline concept which other concepts are scored against in a decision matrix. The concept with the highest score is naturally the most compatible with the current PDS. Evaluation of designed concepts in **Sections 7.1** and **7.2** use this method to determine which is the most promising.

**SCAMPER**

SCAMPER is a creative thinking and problem-solving technique used to simplify the activity of brainstorming. It is meant to help innovative thinking and encourage new ideas by using any or all of seven perspectives included in its acronym. This has been applied to develop clamp-on mechanism concepts in this thesis [14].

**S**ubstitute – Substitute a part of the product.

**C**ombine – Combine one or more parts of the product.

**A**dapt – Adapt a part of the product to fulfill more tasks or multiple purposes.

**M**odify – Modify the shape or size of a part.

**P**urpose – Put a part to another use somewhere else in the product.

**E**liminate – Eliminate a part to see how it affects the product.

**R**everse – Reverse a process or interchange an element in the product.

## 3.2 Tools

**Programs used**

- Microsoft Word 2016 – Report writing.
- Microsoft Excel 2016 – Tables, plots and calculations.
- Autodesk Fusion 360 – CAD-modeling, renders and simulations.
- Microsoft Paint and Autodesk Fusion 360 – Sketching figures.

**3D printing**

Prototypes were manufactured with the use of two *Flashforge Guider II* 3D printers at Eik Ideverksted.

**Sources**

Written sources such as books or articles used in this thesis are either educational, made for professional or academic use. Web sources are used to investigate existing solutions available on the market, as well as researching the market development. Some theory is based on web sources only, and have been cross-checked with several web sources to ensure validity of material.

# 4. THEORY AND KEY CONCEPTS

## 4.1 Water pipes – materials and dimensions

Water supply network consists of long stretches of pipes of which the material and size, will depend on when it was placed, what soil surrounds it, and how much water needs to flow through it. Metal pipes have long been the preferred choice by water utilities, resulting in a water network largely made of iron. New pipes are almost exclusively made of thermoplastic materials such as polyvinyl chloride (PCV) and more recently polyethylene (PE).

Although the share of PE pipes is increasing, and will most likely continue to do so in the coming years, all the dominating pipe materials must be taken into consideration when developing a new clamp-on flow meter solution. The distribution of pipe materials in Norway can be seen in **Figure 7**.

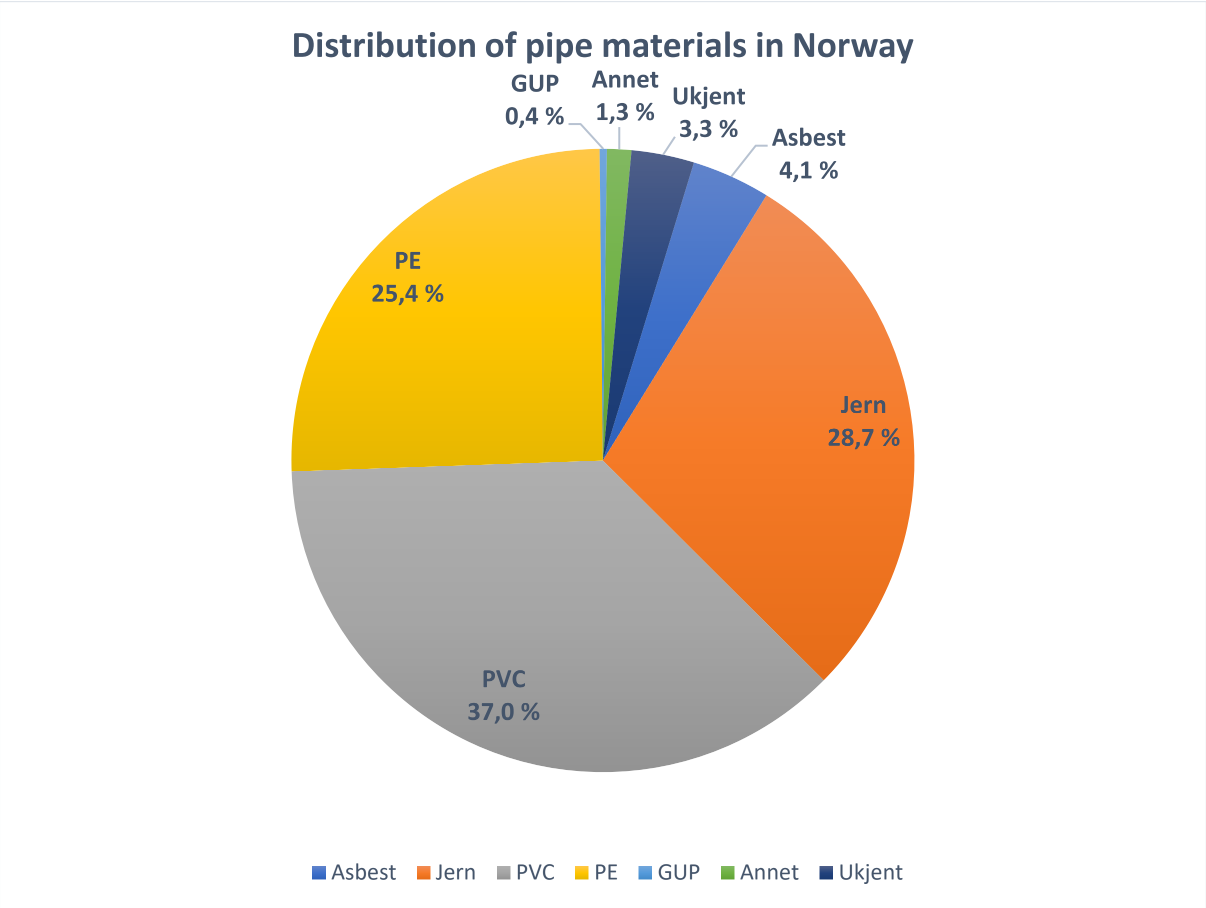



Figure 7: Distribution of pipe materials in Norway [15].

### 4.1.1 PE PIPES

High Density Polyethylene (HDPE) pipes is the new preferred choice by water utilities. It is durable, flexible, lightweight and often more cost-effective than other materials. As opposed to metal pipes, HDPE pipes does not rust, rot or corrode. Furthermore, it is resistant to biological growth. These properties greatly extend the service life of HDPE pipes compared to other options, with an estimated lifetime of 50 – 100 years, depending on use, installation and design.

Many types of leaks occur in pipe joints, increasing the possibility of a leak in large complex water distribution networks. An additional benefit of HDPE pipes lies in their ability to be welded together to form long, leak-free sections [16].

### 4.1.2 WELDING OF PE PIPES

Thermoplastic pipes like PE pipes can be joined together by either butt-fusion or electrofusion welding. Which method should be used depends on the size of the pipe's and accessibility.

Butt-fusion welding is used to join two pipes of the same diameter in order to extend a pipeline; the ends are trimmed, aligned, heated up and joined together by pressure. This technique is usually used on bigger pipe diameters and in easy-access situations [17].

Electrofusion welding utilizes a molded socket fitting, containing an embedded electrical resistive heating coil. Two pipe ends are inserted into the socket and fastened, before an electrical current is applied to heat up and join the parts together. This process is illustrated in **Figure 8** [18].

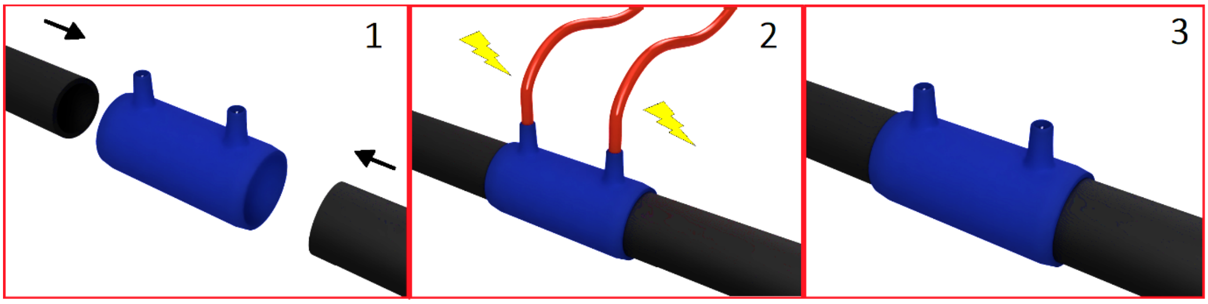



Figure 8: Electrofusion welding of two pipes with a socket fitting. The two pipes are inserted into the socket fitting (1) before and electrical current is applied (2), welding the pipes together (3).

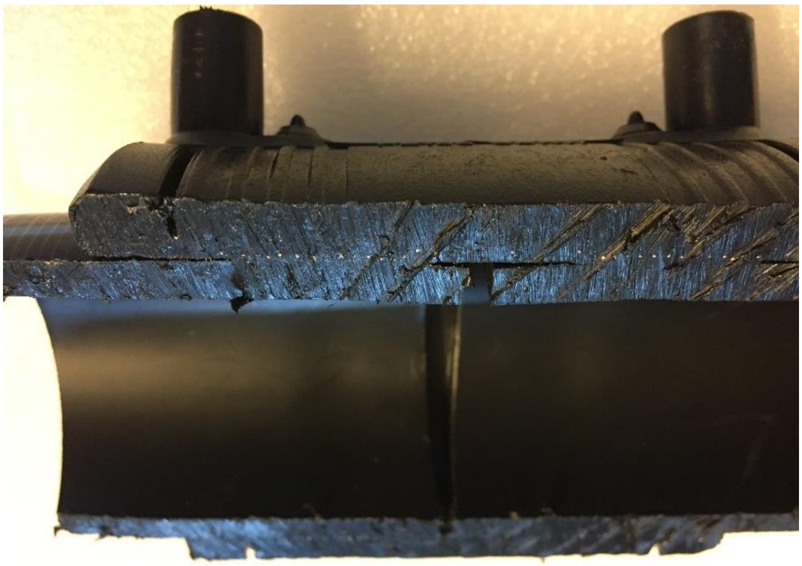


Figure 9: Socket fitting with two separate pipe ends welded together, cut in half to show how the material is melted together. The electrical resistive heating coil is also visible in the joint (Photo: Kevin Vesterås).

This method of joining parts together can be implemented into a clamp-on solution for an ultrasonic flow meter. Although the clamp-on will permanently become a part of the pipe, it provides a much stronger and safe enclosure than any other clamp-on methods available on the market today.

## 4.2 Non-revenue water calculation

Prior to any discussion related to water balance and leakage, all components and meaningful data must have clear definitions. While there are significant differences in the terminology used in different countries, the International Water Association (IWA) has proposed a standardized terminology. Use of this terminology is especially helpful when conducting international comparisons of water balance, but it is important to remember to first re-allocate the individual nations water balance into the components used in the IWA standard terminology. To keep track of water consumption and calculate the amount of NRW, International Water Association has formed two methods.

**Top-Down method**

The IWA 'best practice' terminology is shown in **table 2** and described below. This method is known as the "Top-Down" approach to calculating water loss, where the known volumes are entered in the appropriate columns in the table. Top-down water balance is subject to errors and uncertainty as water suppliers lack sufficient estimates and reliable data for real water losses [19].

**Table 2:** International Water Association standard terminology for Water Balance [20].

| | | | | |
|---|---|---|---|---|
| System Input Volume | Authorized Consumption | Billed Authorized Consumption | Billed Metered Consumption (including water exported) | Revenue Water |
| | | | Billed Unmetered Consumption | |
| | | Unbilled Authorized Consumption | Unbilled Metered Consumption | Non-Revenue Water |
| | | | Unbilled Unmetered Consumption | |
| | Water Losses | Apparent Losses | Unauthorized Consumption | |
| | | | Metering Inaccuracies | |
| | | Real Losses | Leakage on Transmission and/or Distribution Mains | |
| | | | Leakage and Overflows at Utility's Storage Tanks | |
| | | | Leakage on Service Connections up to point of Customer metering | |

The components of the water supply system according to IWA, are defined as:

- **System Input Volume (SIV)** is the measured volume of water supplied to a defined part of a water supply system.
- **Authorized Consumption** is the metered and/or unmetered volume of water consumed by authorized parties such as registered customers, the water supplier and others who are implicitly or explicitly authorized to do so. This part of the water balance also includes exported water and leaks and overflows after the point of customer metering. Authorized consumption may be billed or unbilled depending on the use and local practice. Water consumed from fire hydrants, public fountains and municipal buildings are examples of typically unbilled consumption.
- **Revenue Water** is the volume of metered water delivered to the customer, that can be billed and generate revenue for the water utility.
- **Water Losses** consist of Real and Apparent Losses. It is the volume of water lost between the water supplier and the customer meter. Real losses are the volume of water lost through leaks, overflows, bursts on mains, leakage from service connections and reservoirs.
- **Non-Revenue Water (NRW)** is the total volume of water that for any reason does not generate revenue for the water utility. This can be either lost water, metering inaccuracies, data handling errors or unauthorized consumption.

**Bottom-Up method**

The "Bottom-Up" method for managing water balance is more precise than top-down, but more time consuming, expensive, and complex. By measuring the Minimum Night Flow (MNF), i.e. the minimum water consumed at night within a defined network, it is possible to get an indication of the amount of potentially detectable losses by subtracting both the calculated background losses, and the customers' night-use. As the results from this method use data from a short period of time, it is not recommended to make leakage estimates over time. The "Bottom-Up" approach is best used in combination with the "Top-Down" method [21].

$$\begin{gathered} Potentially\ Detectable\ Losses = \\ \text{Minimum Night Flow (measured)} \\ \text{- Background Losses (calculated)} \\ \text{- Customer Night Use (measured)} \end{gathered} \quad (1)$$

Not only would a network of clamp-on ultrasonic flow meters throughout a water distribution network provide more reliable data to use in these methods, it would reduce the need for these methods entirely.

**Stages of a leak**

Leaks can be divided into four stages during its lifetime. If a leak remains undetected or unrepaired, it will become progressively worse, allowing more water to escape [22].

- Weep/Small loss – a small failure allowing less than 5 liters per minute to escape.
- Leak/Medium loss – a orifice allowing as much as 90 liters of water to escape per minute.
- Burst/Large loss – an orifice allowing as much as 315 liters of water to leave the pipe per minute.
- Catastrophic failure – a complete rupture of the pipeline

Table 3: Stages of leaks.

| Size of leak | $m^3/hour$ |
|---|---|
| Weep | < 0,27 |
| Leak | 0,27 - 11 |
| Burst | 11 - 27 |
| Catastrophic failure | >27 |

Small leaks are the most difficult to find, and are often left unnoticed until they develop. A network of clamp-on ultrasonic flow meters could help identify smaller leakages while they are still minimal, and they are cheaper to repair.

## 4.3 Water leakage management

Water utilities manage their water distribution network differently, depending on their economic situation and the availability of water. As infrastructure ages and become more prone to leaks, it might be more beneficial to exploit new resources rather than recovering some of the lost water. This is often the situation in countries with an abundance of natural water reservoirs, like Norway. Nevertheless, leaks will inevitably become worse, forcing repairs and replacements of mains and service connections.

Managing water losses in a water distribution network requires a good knowledge of the factors influencing leakage. The factors influencing the amount of leakage allowed in a system can be grouped under four policy categories, illustrated in **Figure 10** and listed explained below [23].

1. Resources

   The amount of resources available is crucial to the volume of leakage. Leakages might be tolerated where water resources are plentiful, as opposed to in areas with less water or even drought. Financial resources and available manpower greatly impacts how a water utility deal with leakages, regardless of the amount of water available.

2. Infrastructure condition

   Infrastructure deteriorates differently over time, depending on the quality of the material used, the laying technique and what type of soil surrounds the pipe. A company's overview of the water distribution network and their policy towards replacing and maintaining the pipes affect the amount of leakage.

3. Institutional attitude

   The perception of, and attitude towards leakages in an institution, is central in how they are managed. Water utilities are affected by the attitude, regulations and political influence of the government and its municipality.

4. Leakage control policy

   A water utilities leakage control policy determines the perception of, and all activities related to, the management of their water distribution network. This can range from only repairing visible leaks, to actively monitoring flow and leakage in different areas of the network. As a result, the volume of leakage is greatly influenced by the leakage control policy.


Figure 10: Key factors influencing leakage in a water utilities network. Efficient leakage management requires a good understanding of all factors [24].

## 4.4 Managing real losses

All water distribution networks will inevitably suffer from leakages. There are many elements to managing the real losses in a network. To simplify this, the management of real losses can be summed up with four primary methods:

- Pipeline and Assets Management
- Pressure Management
- Speed and quality of repairs
- Active Leakage Control

The Current Annual Real Losses (CARL) are the sum of all water loss in a water distribution system, **Figure 11** illustrates how the methods mentioned above are all used for leakage reduction.

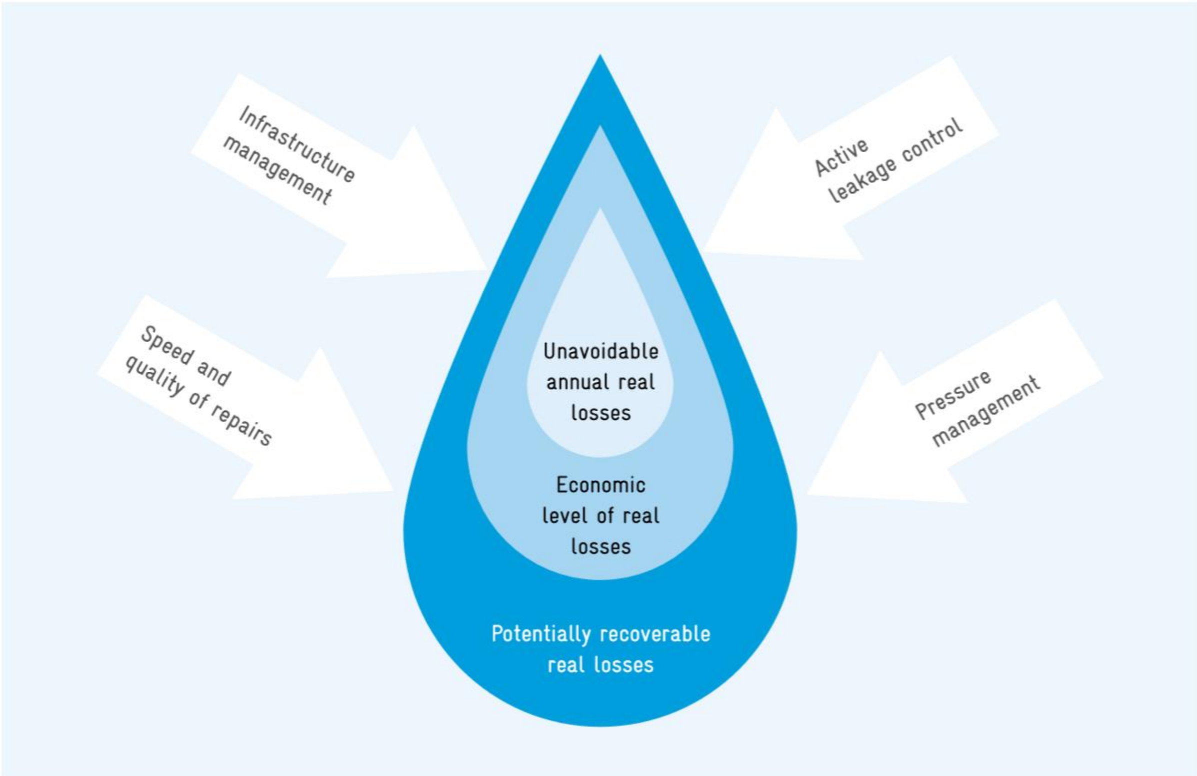



Figure 11: Leakage management activities that affect Current Annual Real Losses [24].

CARL can be calculated with the "Top-Down" method using IWA's water balance table. It is the goal of a water utility to reduce this as much as possible, given its economical and physical constraints. Indeed, a well-managed and well-maintained system always suffer from some leaks, as the annual volume of Real Losses cannot be eliminated entirely. This is the

Unavoidable Annual Real Losses (UARL), defined as the lowest technically achievable annual volume of Real Losses in a system. Attempting to eliminate the UARL is not economical.

The Infrastructure Leakage Index (ILI) is a non-dimension value used to compare the performance between different systems. With this value in mind, a water utility can determine the need for increased leakage reduction activity.

$$ILI = \frac{CARL}{UARL} \tag{2}$$

Table 4: ILI scale and water loss based on system pressure.

| Technical Performance Category | ILI | | Physical Losses [Liters/connection/day] (When the system is pressured) at an average pressure of: | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10m | 20m | 30m | 40m | 50m |
| Developed Countries | A | 1 – 2 | | < 50 | < 75 | < 100 | < 125 |
| | B | 2 – 4 | | 50 – 100 | 75 – 150 | 100 – 200 | 125 – 250 |
| | C | 4 – 8 | | 100 – 200 | 150 – 300 | 200 – 400 | 250 – 500 |
| | D | > 8 | | > 200 | > 300 | > 400 | > 500 |
| Developing Countries | A | 1 – 2 | < 50 | < 100 | < 150 | < 200 | < 250 |
| | B | 2 – 4 | 50 – 100 | 100 – 200 | 150 – 300 | 200 – 400 | 250 – 500 |
| | C | 4 – 8 | 100 – 200 | 200 – 400 | 300 – 600 | 400 – 800 | 500 – 1000 |
| | D | > 8 | > 200 | > 400 | > 600 | > 800 | > 1000 |

Pipeline and Assets Management covers the selection, installation, maintenance and renewal of pipes in a system. Hence, this is the primary influence on the number of new leaks emerging in said system. In addition, the frequency of new leaks is notably influenced by Pressure Management, as well as it directly impacts flow rates of leaks and bursts. Active Leakage Control effects how long unreported leaks remain unlocated, and the Speed and Quality of Repairs controls the average duration of a leak.

### 4.4.1 PRESSURE MANAGEMENT

Pressure management is the practice of managing system pressures to an ideal level, which ensures sufficient and efficient supply, while keeping wear and losses to a minimum. The positive effects of pressure management are many, and it is the only method to positively impact all three components of real water losses; reported, unreported and background leakage. Managing system pressure also decreases frequency of new leaks and pipe breaks [24].

### 4.4.2 LEAKAGE CONTROL

An important aspect to managing leaks is active leakage control, which is done by systematically searching for hidden leaks. This can be done in several different ways, most of which requires training. The alternative to active leakage control, in the case of a water utility only repairing reported or visible leaks, is called passive control. Even small leaks can cause major damage and water loss if it remains undiscovered for a long time, which makes passive control unpopular to practice.

Multiple techniques are usually deployed to locate leakages in a network. Some techniques are good for approximating the position of the leak, while others can find the exact location. To identify if there is a leak in an area of a network, it is normal to measure and monitor the amount of water flowing through it. If the water utility has flow meters placed between specified zones of their network, it is easy to monitor the waterflow and detect deviations. Alternatively, flow meters can be placed at each end of a stretch of pipe to measure if there is an unreported difference between the two points [22].

### 4.4.3 LEAK DETECTION TECHNOLOGIES

After a leakage has been confirmed in an area, further action is needed to pinpoint the exact location before repairs can be done. Depending on the pipe size, material and the general area of the leakage, different techniques are applied. As many techniques rely on acoustics to locate the leak (leaks create sounds and vibrations carried by the pipes), plastic pipes can be a challenge. Pipes made of PVC and PE do not propagate sound waves as well as the more rigid metal pipes. There are other acoustic principles applied to leakage detection, including resonance, attenuation and acoustic impedance, but these are generally still hard to take advantage of in plastic pipes.

**Gas injection method**

With the gas injection method, a lightweight tracer gas is injected into the pipe, and then searched for with gas detectors on the surface. This provides an accurate location for the leak, as the tracer gas should rise straight to the surface after leaking from the pipe. However, it is important to be aware that dense terrain can cause the gas to surface in a false location. The gas injection method can be used on all pipe materials and a range of different pipe diameters. Hydrogen has no effect on the water quality. As more gas is required on larger pipe diameters, this method is more used on service pipes and small leakages. Hydrogen is the most commonly used tracer gas due to its properties and low cost.

**Manual listening stick**

By using a listening stick, or stethoscope with an earpiece, a person listens for leaks on pipes and fittings from the surface. The stethoscope can be made of metal, wood or plastic. No electrical equipment is required, only the person’s ability to hear. Hence, its effectiveness heavily relies on the operators’ experience, and the amount of background noise. The ideal conditions for the use of this method, is on metallic pipes with a diameter between 75 mm and 250 mm, and with pressures above 1 bar. However, the type of soil around the pipe, and the type of surface material, greatly influences the effectiveness of this method. Some materials are poor conductors of the sound and vibrations caused by a leak, making pinpointing a leak difficult for inexperienced operators [26].

**Leak noise correlation**

This method is based on the comparison of detected noise at two different points on the pipeline. By measuring the time difference from when the two sensors detect the noise traveling from the leak, its position can be determined. If the leak is equidistant between the two sensors, the sensors will detect the noise at the same time. The noise will travel at a constant velocity in both directions from the leak, assuming consistent pipe material and diameter. Time delay between when the sensors detect the noise, the length of pipe between the sensors and velocity of the sound carried by the pipe can be entered an equation to pinpoint the leak. Leak noise correlation is normally done with one of two types of noise transducers, accelerometer or hydrophones.

### 4.4.4 WATER METERS

Automatic Meter Reading (AMR) is used to measure the volume of water consumed by the end-user. Readings from the meter is gathered by the water utility either by walk-by, drive-by or fixed network. This assures the customer is billed for the actual water usage, rather than an estimated monthly usage. Communication with the AMR system is one-way, which means the meter can only transmit data to the meter-reading device and not receive any commands in return. Today, AMR systems are present in most modern homes and businesses.

Advanced Metering Infrastructure (AMI) is an upgrade from AMR systems that enables two-way communication between the water meter and the water utility over a fixed network. AMI systems allow continuous monitoring of the whole distribution system by reading meters at hourly intervals. Not only does this allow a water utility to find evidence of leaks much sooner, it is also the foundation of a smart water grid with a surplus of useful information. New advanced smart water meters can gather information about flow, temperature, pressure, quality and uncover potential leaks. These sensors make up the AMI system. Data management software process and aggregate the collected data into easy-to-understand reports, that previously would require tedious, repetitive work.

Water utilities have an opportunity to improve their overall performance through AMI. The benefits of an AMI system potentially include;

- Greater bill accuracy
- Improved customer service
- Enhanced water management capabilities
- Reduced distribution losses and operational costs
- Customer usage pattern awareness

Customers will also benefit from the implementation of an AMI system through increased awareness of their water usage.  Most water utilities today base their pricing exclusively on the volume of water consumed by the customer. However, water usage, much like electricity, varies throughout the day, causing an uneven load on the network. Through the implementation on an AMI system, water utilities might consider dynamic pricing through the establishment of hourly rates for water consumption. Rates would increase during peak hours, and conversely decrease when the overall network usage is low.

## 4.5 Metering location

As water flows through the water distribution network, it can encounter several disturbances causing changes to how the water flows in the pipe. These changes in the flow profile impacts the accuracy of ultrasonic flow meters. To choose a good metering location, it is important to be aware of how each disturbance impacts the flow profile. Although different ultrasonic flow meters handle disturbances to the flow profile differently, typical recommended distances from a flow disturbance is shown in **Table 5** [10].

Table 5: Typical distances from flow disturbances [10].

| Disturbance | Downstream distance in number of pipe diameters | Upstream distance in number of pipe diameters |
|---|---|---|
| **Single elbow** | 10 | 5 |
| **Double elbow in plane** | 25 | 5 |
| **Double elbow out of plane** | 40 | 5 |
| **T-piece** | 50 | 10 |
| **Diffuser** | 30 | 5 |
| **Valve** | 40 | 10 |
| **Reducer** | 10 | 5 |
| **Pump** | 50 | - |

## 4.6 Water tight seal design

A clamp-on water meter must be designed to withstand harsh environments. The lifespan of the product is heavily dependent on the reliability of the gasket, a sheet or ring of water-resistant material sealing a joint, or space between two objects. It is therefore important to make good design choices early in the development to ensure the product meets the requirements. Environmental aspects to consider for the clamp-on includes dust, debris, temperature extremes, humidity exposure and potentially full submersion. These conditions might be occasional or constant, determining the performance requirements of the product [27].

The requirements result in a product that can be given a specific Ingress Protection (IP) rating, defined as a standard by the International Electrotechnical Commission (IEC) for international use. There is specified test any product with an IP rating must be able to withstand. The international standard IEC 60529 provides a detailed guide to determine an appropriate IP rating based on these tests, describing the protection against water and intrusion of foreign bodies. **Table 6** lists the protection levels that can be achieved, which when combined results in the two-digit IP rating [28].

Table 6: Ingress Protection rating chart [29].

| **Level** | **Intrusion protection** | **Moisture protection** |
|---|---|---|
| **1** | Objects greater than **50 mm.** | Vertically falling drops of water in upright position. |
| **2** | Objects greater than **12,5 mm.** | Water drops when tilted at up to 15˚ angle. |
| **3** | Objects greater than **2,5 mm.** | Water spray at up to 60˚ angle from vertical. |
| **4** | Objects greater than **1 mm.** | Water splash from any angle. |
| **5** | Dust protected.<br>Some protection from dust, but not large quantities. | Water jets from any angle. |
| **6** | Dust tight. | Powerful water jets from any angle. |
| **7** | - | Temporary submersion of up to 1-meter depth. |
| **8** | - | Continuous submersion for longer periods. (conditions vary for each product, but must be more severe than moisture protection level 7) |

Products meant to be used near water or in areas with high moisture often have a high IP rating. This can be due to safety requirements, such as for fittings used in bathrooms, or simply to ensure a longer product life. Clamp-on smart water meters available on the market today often have an IP68 rating, meaning they are completely dust and water tight.

# 5. TECHNICAL REVIEW

## 5.1 Fluid dynamics - Measuring principles

Accurate measurement of the volume of water flowing in a water distribution network is essential for successful operation. This can be done by installing flow meters at key locations throughout the network. Without this information, it is not possible to determine how much water is produced, or delivered to a customer. There are many different types of flowmeters, which all have their own advantages and disadvantages. Flow meters can be used to measure volumetric or mass flow rate in a gas or liquid with a linear or non-linear flow. Some of these are intrusive, and require direct contact with the fluid, while others are simply attached to the outside of a pipe wall. The most common flowmeters used in industrial applications are as following:

- Differential Pressure
- Positive Displacement
- Coriolis
- Vortex
- Turbine
- Electromagnetic
- Thermal
- Ultrasonic

**Differential Pressure Flow Measuring Principle (Orifice-Nozzle-Venturi-Rotameter)**

Pressure at both sides of an orifice or nozzle in the pipe is measured, and with the help of Bernoulli's equation and known dimensions of the pipe, the flow rate can be determined.

**Positive Displacement principle**

This principle adapts a mechanical solution where the fluid forces an object to move. Flow rate is then measured by how much the object is moved in a certain amount of time. A good example is measuring the time it would take to fill a bucket of a known volume,

**Coriolis Flow Measuring Principle**

A vibration is applied to the pipe by a set of sensors, when fluid flows through the pipe the vibration will shift along the pipe resulting in a measurable flow rate.

**Vortex Flow Measuring Principle**

An obstruction in the pipe creates vortices in the flowing fluid. The time difference and spacing between the vortices is measured by a sensor, allowing accurate measurement of the flow rate.

**Turbine measuring principle**

Turbine flow meters are relatively simple, as flow rate is measured by fluid forcing a turbine located in the pipe to move.

**Electromagnetic Flow Measuring Principle**

Conductive fluid flowing through a magnetic field creates a voltage measured by electrodes placed on pipe wall.

**Thermal Flow Measuring Principle**

Two temperature sensors (one heated, one not heated), measure the temperature drop when a fluid flows past them, as well as the energy needed to maintain a specific temperature difference. Consequently, comparing them allows for measurement of the flow rate.

**Ultrasonic Flow Measuring Principle**

*Transit time method*

Ultrasonic flow measurement uses soundwaves to determine the flow rate of a fluid. A set of transducers are mounted on the pipe wall, emitting and receiving sound signals from each other through the medium flowing in the pipe. Soundwaves travelling with the direction of flow travels faster than soundwaves travelling against the flow. If the fluid travels faster or slower, the time difference will increase or decrease. This time difference combined with the known area inside the pipe, allows for accurate measurement of the volume of fluid flowing in the pipe. The soundwaves are inaudible to the human ear, as they have higher frequency than humans are capable of hearing. **Figure 12** illustrates this method.

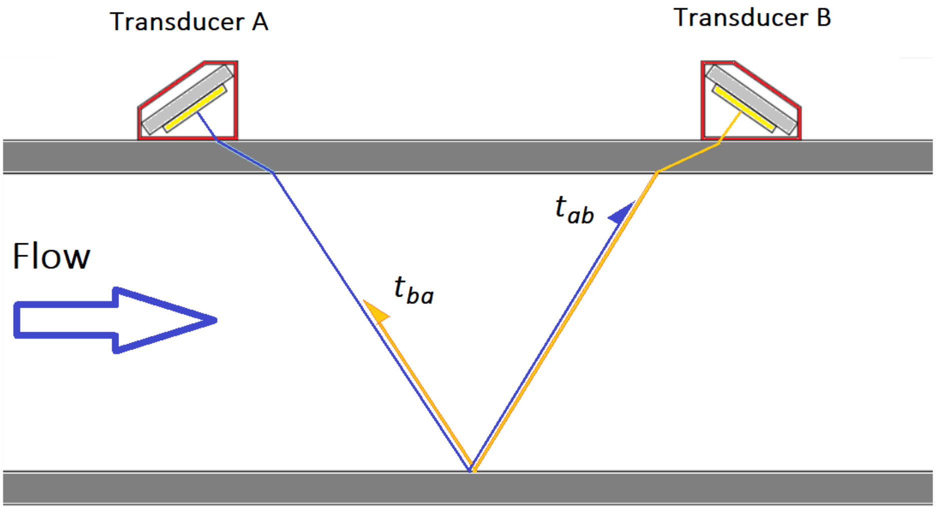



Figure 12: Transit time method. Ultrasonic waves travels faster downstream ($t_{ab}$) than upstream ($t_{ba}$), resulting in a measurable time difference.

*Doppler method*

Another method using ultrasonic soundwaves may be used for fluids containing a certain number of particles or bubbles. This method applies the Doppler Effect. Ultrasonic sound is transmitted into the fluid, and reflected to the sensor from particles or bubbles. When the fluid is in motion, the frequency of reflected waves will increase or decrease relative to the sensor. This method can be seen in **Figure 13.**

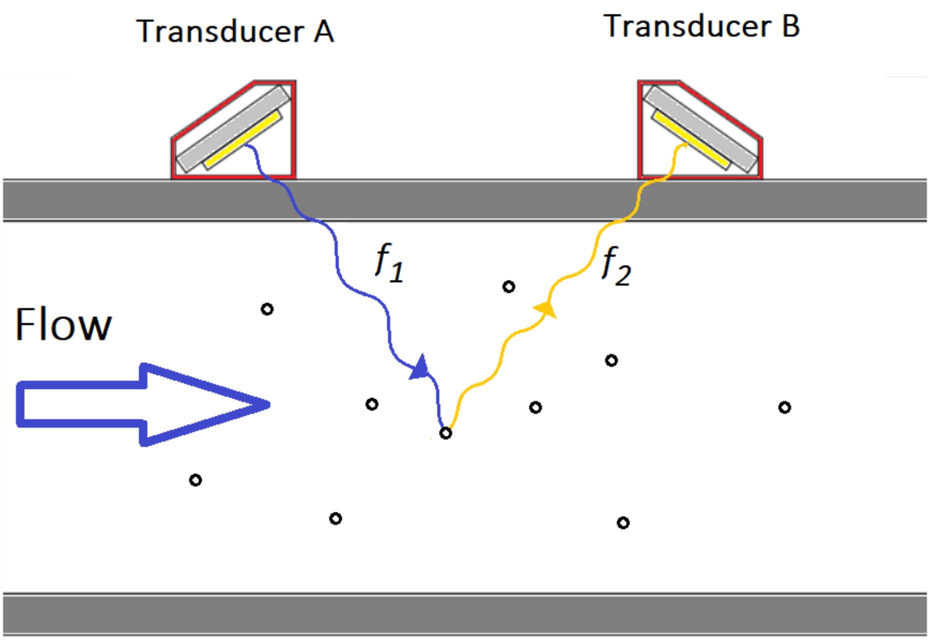



Figure 13: Doppler method. Ultrasonic waves shift frequencies when reflected from particles flowing in the pipe. The frequency shift between the transmitted frequency ($f_1$) and received frequency ($f_2$) is used to measure volume flow.

### 5.1.1 ULTRASONIC WAVES - MODES OF ACOUSTIC WAVE PROPAGATION

Ultrasonic waves are sound waves with higher frequency than those distinguishable by the human ear. The human audible range is frequencies from 20 Hz to 20 kHz, while ultrasonic waves consists of frequencies higher than 20 kHz. Ultrasonic waves possess many of the same properties as light; they can be focused, reflected and refracted by objects. These waves are also transmitted through air, water and many other materials by causing high-frequency particle vibrations. This makes ultrasonic waves useful for a wide range of applications and industries. Ultrasonic transducers generate and detect ultrasonic waves with the piezoelectric effect, where pressure produces an electric voltage in a capable material.

There are two different types of ultrasonic wave sensors used for clamp-on flow meters, with different modes of acoustic wave propagation: shear mode and Lamb wave [30].

**Shear wave**

Shear mode sensors injects a narrow, focused beam of acoustic signals through the pipe and into the opposing sensor (**Figure 14**). Sound absorption in the pipe wall is negligible with shear waves, meaning the pipe wall thickness is not a restriction. Shear wave sensors are easier and cheaper to apply than Lamb wave sensors, but at the cost of high sensitivity to particles or bubbles in the fluid, which can lead to poor performance if the concentration is too high.

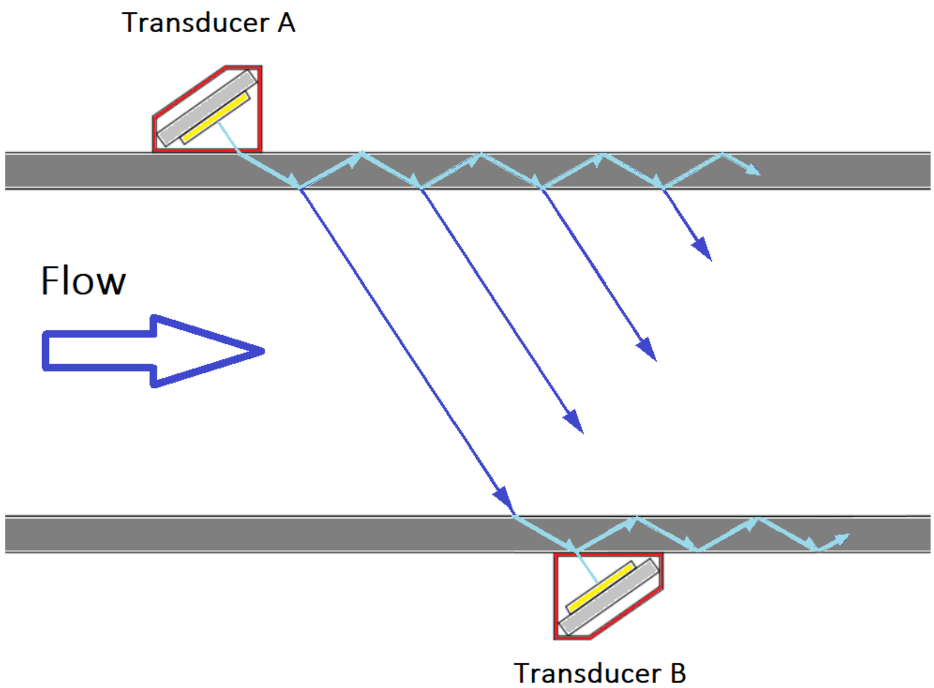



Figure 14: Shear wave sensors producing narrow ultrasonic beams. Adapted from [31].

**Lamb wave**

Lamb wave sensors emit an acoustic signal into the pipe wall, travelling in parallel with the pipe. This creates a wide sound beam in the fluid with higher signal amplitude than shear mode waves (**Figure 14**). In addition, concentration of particles and bubbles can be much higher before it disturbs the beams. For lamb waves to be effective, the frequency of the acoustic signal needs to be matched with the resonant frequency of the pipe wall. Hence, this mode is more susceptible to errors and bad measurements if the incorrect frequency is used for a specific pipe thickness, material or density [32]. Metal pipes are better suited for this method as they have better acoustic properties, allowing a stronger signal to be carried by the pipe wall.

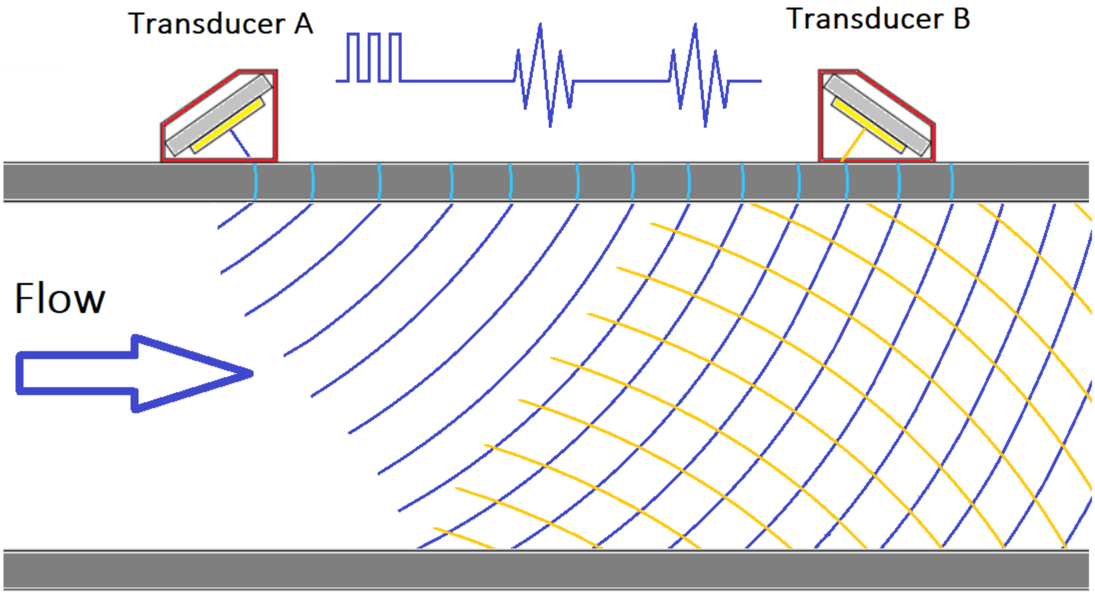



Figure 15: Lamb wave sensors producing a wide ultrasonic beam. Adapted from [31].

## 5.2 Existing Flow Sensor Technologies

There are many existing solutions on the current market supplying ultrasonic flow meters. In this section, the most similar and competitive ultrasonic flow meters will be presented as a reference point for further developing a feasible flow sensor.

### 5.2.1 KAMSTRUP

MULTICAL and flowIQ are smart water meters based on ultrasonic technology, designed for residential and industrial use, respectively. These smart water meters are intrusive and must be installed as a part of the pipe network. Kamstrup utilizes the transit-time measurement principle in their meters, resulting in accurate flow measurements [33].

In a statement in 2016, Kamstrup said it will provide 6,000 units of its MULTICAL 21 smart water meters. Many municipalities in Norway are currently replacing old water meters with new smart water meters, such as the Kamstrup MULTICAL® 21, in hope of establishing an AMI system. Kamstrup said the smart water meter is equipped with radio technology, wireless data communication and sensitive leak detectors allowing quick detection of even the slightest amount of water [35].


Figure 16: Kamstrup MULTICAL® 21 [34] [36].

Key specifications for the Kamstrup MULTICAL® 21 and flowIQ® 2101/..02/..03 are listed below in **Table 7**.

Table 7: Kamstrup MULTICAL® 21 and flowIQ® 2101/..02/..03 key specifications.

| | |
|---|---|
| **Installation method** | Intrusive, pipe specific dimension |
| **Ultrasonic measuring principle** | Transit-time |
| **Price** | ~300 USD |
| **Pipe diameters** | 26 to 33 mm |
| **Flow rate range**<br>(Meter specific) | Nominal: $1{,}6\ to\ 4{,}0\ m^3/h$<br>Maximum: $4{,}6\ to\ 8{,}5\ m^3/h$ |
| **Accuracy** | $\pm 2\%$ of reading |

### 5.2.2 GENERAL ELECTRICS

GE's AquaTrans AT600 is a simple clamp-on ultrasonic flow meter for liquids. It is easy to install and can be applied on a variety of pipe types of different sizes, if there is room. Aquatrans AT600 is designed to be reliable and cost around 2600 USD. It measures flow based on the ultrasonic transit-time principle. Even though it can be applied to a variety of different pipe sizes, a pair of transducers needs to manually be perfectly distanced for correct flow measurement [38] [39].

Figure 17: AquaTrans AT600 mounted on a metal pipe, with its control unit to the right on a separate pipe [39].

Key specifications for the AquaTrans AT600 is listed in **Table 8**.

Table 8: AquaTrans AT600 Key data.

| | |
|---|---|
| **Clamp-on method** | Hose clamp |
| **Ultrasonic measuring principle** | Transit-time |
| **Price** | ~2600 USD |
| **Pipe diameters** | 15 to 7600 mm |
| **Flow rate range** | -12.19 to 12.19 m/s |
| **Accuracy** | ±1% of reading for ≥50 mm pipe<br>±2% of reading for <50 mm pipe |

## 5.3 New Flow sensor technologies

New water meters focus on the implementation of smart technology, sharing data obtained about the flow real-time to other devices. These smart water meters gather more information through advanced data gathering and interpretation.

### 5.3.1 STREAMLABS SMARTHOME WATER MONITOR

A recently announced smart water meter is the Streamlabs SmartHome Water Monitor. It is an affordable wireless device aimed at both the private and industry customers with a price of 199 USD. Streamlabs have developed their own mobile application for easy and understandable viewing of the water consumption data. The Streamlabs monitor can only be installed on a small selection of pipes. Because of this, it is easily installed with the help of two cable ties [40] [42].


Figure 18: Streamlabs SmartHome Water Monitor [41].

Key specifications for the Streamlabs SmartHome Water Monitor is listed below in **Table 9**.

Table 9: Streamlabs SmartHome Water Monitor key specifications.

| | |
|---|---|
| **Clamp-on method** | Cable tie |
| **Ultrasonic measuring principle** | Transit-time |
| **Price** | 199 USD |
| **Pipe diameters** | 19 to 25 mm |
| **Flow range** | - |
| **Accuracy** | - |

### 5.3.2 PULSAR FLOW PULSE

Flow Pulse from Pulsar measure flow using the Doppler principle. This principle is uncommon as a measuring principle alone, as it is often used in combination with a sensor utilizing the transit-time principle. For the sensor to be accurate, the fluid must contain a certain number of particles, with a minimum concentration of total dissolved solids of 200 ppm. Hence, Flow Pulse works best on dirty liquids, but depending on the country and location could also be used for drinking water as the maximum desirable TDS is 500 ppm [43] [44] [46].


Figure 19: PULSAR FLOW PULSE [45].

Key specifications for the Streamlabs SmartHome Water Monitor is listed below in **Table 10**.

Table 10: Flow Pulse key specifications.

| | |
|---|---|
| **Clamp-on method** | Hose clamp |
| **Ultrasonic measuring principle** | Doppler |
| **Price** | - |
| **Pipe diameters** | 30 to 350 mm (version 1)<br>30 to 1250 mm (version 2) |
| **Flow rate range** | 0,3 to 4 m/s |
| **Repeatability** | ±5% of reading |

### 5.3.3 FLUID SMART WATER METER

Fluid is a smart water meter made for the private consumer, and similarly to Streamlabs SmartHome Water Monitor, it only fits a few pipe sizes. It helps the consumer understand when, where and how much water is being consumed in their household. By creating water use signatures for each fixture and appliance in a home, it knows how much a specific appliance uses. The meter is controlled through a smartphone application, providing all useful information in an understandable format [47].


Figure 20: Fluid learning water meter [48].

Key specifications for the Fluid smart water meter is listed below in **Table 11**.

Table 11: Fluid key specifications.

| | |
|---|---|
| **Clamp-on method** | Clamp-feature part of enclosure |
| **Ultrasonic measuring principle** | Transit-time |
| **Price** | 299 USD |
| **Pipe diameters** | 19 mm |
| **Flow rate range** | - |
| **Repeatability** | - |

## 5.4 Flow sensor technology – summary

Flow measurement using ultrasonic technology is a not a new concept in the water industry. Ultrasonic flow meters are becoming more accurate, cheaper and smaller as new innovations push the technology even further. Additionally, these sensors do not contain any moving parts, resulting in a low maintenance product. As water leakage and consumption is becoming a growing concern around the world, several newly established start-up companies are attempting to bring breakthrough smart flow meters to the market. These smart flow meters, while a viable alternative for private home usage, often lack the versatility and accuracy to be applied by industry water suppliers.

For the establishment of a widespread AMI system to become a reality, water utilities require a smart flow meter that can make the change worthwhile. The AquaTrans AT600 flow meter is versatile and has the accuracy required for professional use, but it is in an entirely different price range than the other reviewed clamp-on flow meters. An affordable clamp-on flow meter with the necessary specifications for professional use, is likely to be a success. The reviewed solutions are briefly summarized in **Table 12** below.

Table 12: Summary of ultrasound smart water meters.

| **Name** | **Ultrasound measurement principle** | **Clamp-on method** | **Size** (Length x Width x Height) [mm] | **Price** [USD] |
|---|---|---|---|---|
| **MULTICAL® 21 and flowIQ® 2101/..02/..03** | Transit-time | Not clamp-on (intrusive) | 110-190* x 66 x 92 | ~300 |
| **AquaTrans AT600** | Transit-time | Hose clamp | 168 x 61 x 128 | 2600 |
| **Streamlabs SmartHome Water Monitor** | Transit-time | Cable tie | 127 x 91 x 61 | 199 |
| **Flow Pulse** | Doppler | Hose clamp | 120 x 65 x 65 | - |
| **Fluid** | Transit-time | Integrated clamp | 203 x 57 x 108 | 299 |
| | | | **Varies with pipe* | |

# 6. CASE STUDY – KROKSJØEN WATERWORKS

To develop a clamp-on mechanism for an ultrasonic flow meter that is supposed to be used by water utilities, it is necessary to involve the end-user to some degree. A water utility will have invaluable input to the development that could greatly impact the success of the product.

Kroksjøen Waterworks is a water utility located in Eidskog municipality in Norway, supplying 4500 people with clean water every day. Their water supply system consists of two pumping stations and one water tower to maintain pressure and act as a buffer during peak demand hours. Kroksjøen Waterworks is a good example of how a water distribution system is managed in Norway, in the way that they have very little information about the water flowing throughout their system. The total volume of water supplied to the network by the two pumping stations, and the volume of water in the water tower, is the only information gathered by the water utility itself. Water meters measuring the individual customers use is the only other source of data gathered. It is therefore challenging to uncover small leaks without manual inspection [49] [50].

Water utilities could benefit greatly from the implementation of a network of sensors spread throughout their water distribution network in the future, when water cost inevitably will rise. Currently the situation is not threatening enough in countries like Norway, where it is often more economical to accept a higher percentage of water loss and simply increase the supplied volume. Nonetheless, even with a surplus of available water resources, water utilities in Norway are interested in a way to monitor the water flow and direction of flow in their pipes if it is economical.

Water utilities in Norway are a good market to study when developing a new clamp-on solution, as the renewal of pipes have been a focus in recent years. Norwegian water distribution networks mainly consist of pipes made of PVC and iron, but new pipes are often made of PE [3].

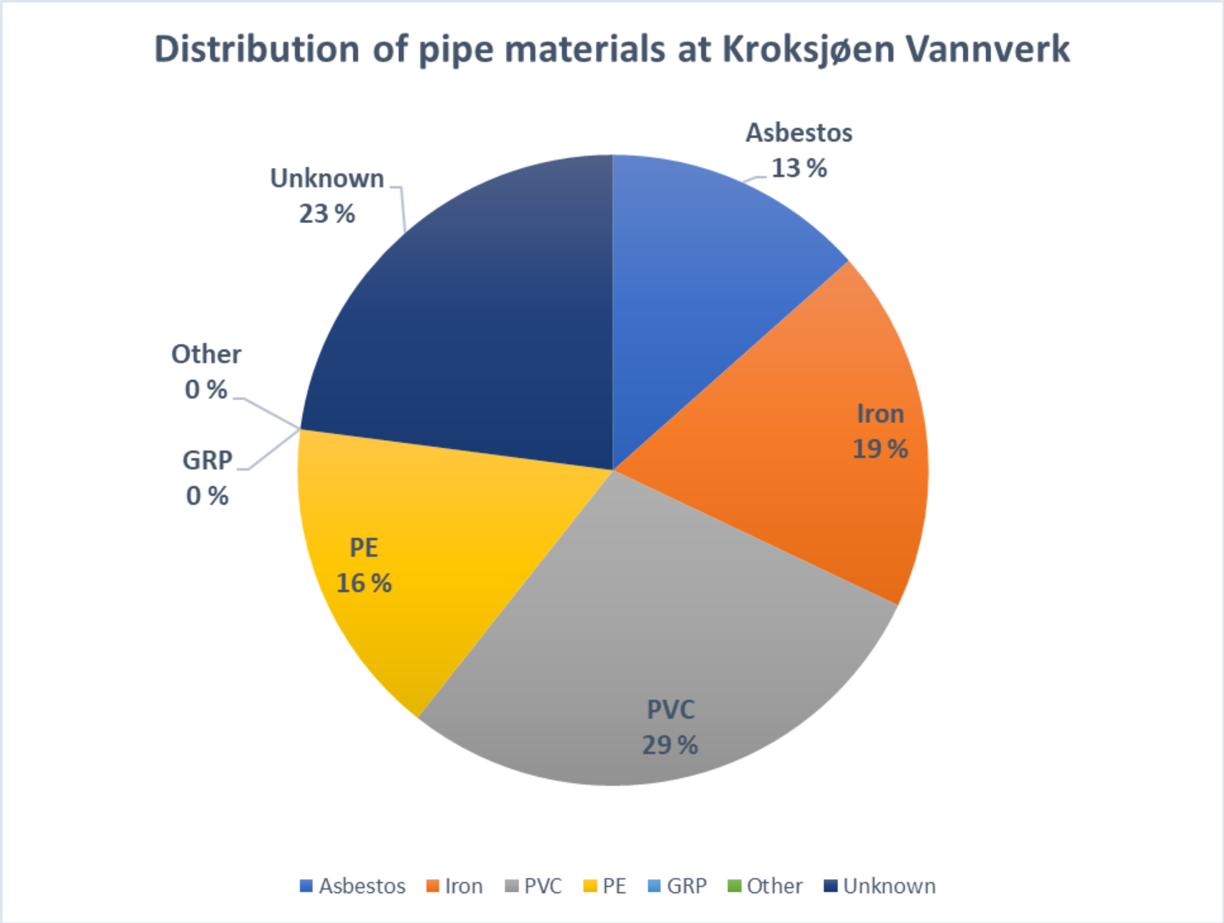



Figure 21: Distribution of pipe materials at Kroksjøen Waterworks [15].

**Table 13** lists the pipe dimensions and materials commonly used by Kroksjøen Waterworks for renewal and extension of their water distribution system. To further assist with the development of the clamp-on, Kroksjøen Waterworks provided the project with meter-length samples of each pipe size and material.

Figure 22: Meter-length pipe samples of PE and PVC pipes used at Kroksjøen Waterworks.

Table 13: Pipe diameters and materials currently used when installing new, or renewing old pipes by Kroksjøen Waterworks.

| Type | | Material | Diameter [mm] | Wall thickness [mm] |
|---|---|---|---|---|
| **Service pipe** | | PE | 32 | 3,0 |
| **Main** | | PE | 50 | 4,6 |
| | *Common* | PE | 63 | 5,8 |
| | | PE | 75 | 6,8 |
| | | PE | 90 | 8,2 |
| | *Common* | PE | 110 | 10,0 |
| | *Common* | PE | 225 | 20,5 |
| | | PVC | 110 | 5,3 |
| | | PVC | 160 | 7,7 |
| | | PVC | 225 | 10,8 |

In cooperation with Kroksjøen Waterworks suitable placement of the clamp-on ultrasonic flow meter was found during a visit on 22.02.2018. Manholes are the primary area of interest for Norwegian water distribution networks, as these utility holes often have short stretches of exposed pipe where the flow meter can be installed. This option is preferable to installing the flow meter on buried pipes for several reasons; easier installment, less risk of damage from environment and easy access for service and maintenance.

Two manholes of different age and condition were inspected while visiting Kroksjøen Waterworks. The first manhole was older and had become dirty with mud and corrosion of metal parts. Inspection of this manhole proved the importance of a water and dust tight enclosure, even if the clamp-on water meter is installed in a relatively closed of area. A stretch of PVC pipe where the flow meter could be installed is shown in **Figure 23**.

Figure 23: Inspection of the first manhole revealed a suitable placement of a flow meter, although in a dirty environment (Photo: Kevin Vesterås).

The second manhole was newer and in much better condition. This manhole contained a similar stretch of PVC pipe as the first manhole, as well as two service pipes leading to individual consumers. All these pipes are suitable for clamp-on water meter installation and can be seen in **Figure 24**.

Figure 24: Inspection of second manhole revealed multiple places a clamp-on flow meter could be installed (Photo: Kevin Vesterås).

Before the possibly suitable locations in these manholes can be considered, the new ultrasonic transducer element needs to be tested regarding how much it is affected by disturbances in the flow profile. Manholes usually serve as utility access points to the distribution network, and contain elements disturbing the flow profile. Although there are room for installing a clamp-on flow meter, the water flowing in the pipe might be too affected by a disturbance nearby for the flow meter to get accurate measurements.

Based on surveys done at Kroksjøen Waterworks on 22.02.2018, a clamp-on based on industrial cable tie or pipe clamp will be sufficient to cover most areas of interest during the future market launch.

Figure 25: Cable tie (left), clamp-on sensor using cable ties (middle) and sensor fastened with hose clamp (right).

# 7. PRODUCT DESIGN SPECIFICATION

For a new clamp-on solution to be better than the existing solutions, it must offer the same strengths while being more applicable and preferably easier to install. While it can be challenging to develop an innovative and better solution for the market as it is today, a solution that meets the future demands of the market is of high interest. However, a new clamp-on flow meter solution should possess the following specifications:

- Small size with dimensions not exceeding 250 x 100 x 100 mm (length x width x height).
- Can be installed on all pipes of commonly used materials currently in use.
- Clamp-on mechanism must properly secure the flow meter, preventing movement after installation.
- Easy to install by one person.
- Can be installed in tight areas with limited access to pipe.
- Design should consider ease of production, to keep overall cost as low as possible.
- Material used in clamp-on should be durable to ensure long lifetime.
-

## 7.1 Early clamp-on mechanism evaluation

Clamp-on mechanisms are developed and used for many markets and products, such as cameras, portable lights, hair clamps, industrial equipment and more. As there are several mechanisms used for clamp-on flow meter technology on the current clamp-on flow meter market, it is necessary to evaluate both new and existing mechanisms before proceeding with concept generation. The selection of a clamp-on mechanism is done by comparing the mechanisms with a selected reference mechanism, based on the specifications mentioned above.

The mechanisms mentioned on the next page are the most promising mechanism currently used on clamp-on flow meter market, as well as adapted mechanisms from other clamp-on products. These mechanisms are evaluated in **Table 14** according to the “Pugh method”.

«Butterfly» clamp mechanism.

- Can be installed by one person.
- Complicated design.
- Can be installed with limited access to pipe.
- Difficult to achieve high clamp-force.
- Specialized design increases total cost of the clamp on flow meter.

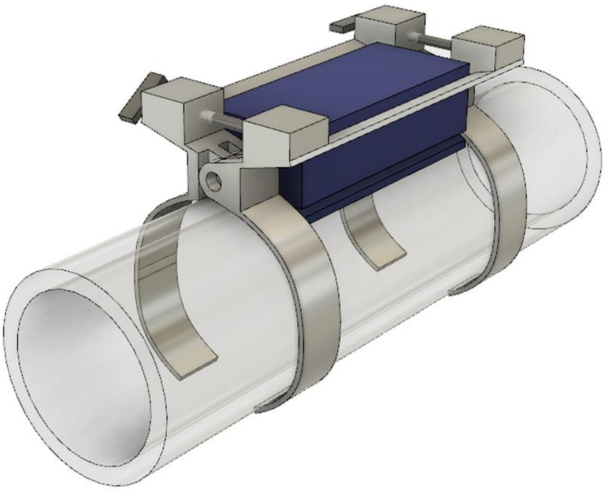


Figure 26: “Butterfly” clamp mechanism.

Joint clamp mechanism.

- Can be installed by one person.
- Simple design, easy to operate.
- Must have access around entire pipe circumference.
- Can achieve high clamp-force.
- Specialized design increases total cost of the clamp on flow meter.

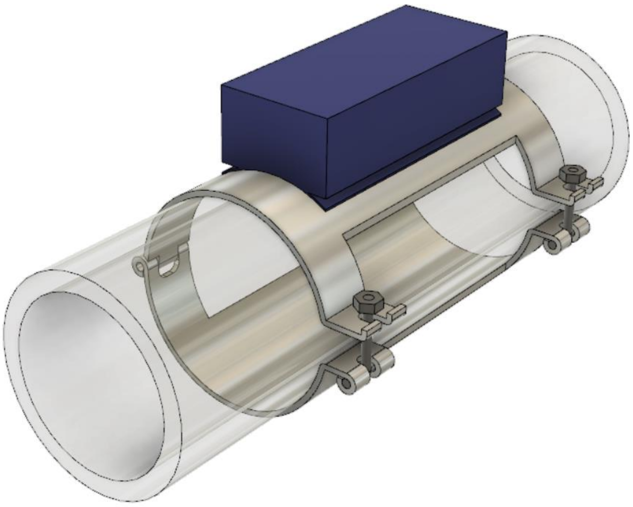


Figure 27: Joint clamp mechanism.

Hose clamp/Cable tie mechanism.

- Can be installed by one person.
- Simple design, but requires intricate work when tightening hose clamps.
- Must have access around entire pipe circumference.
- Can achieve high clamp-force.
- Uses existing standardized parts.

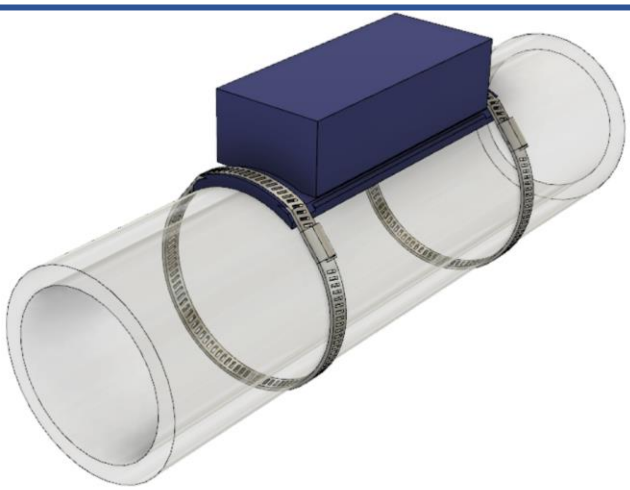


Figure 28: Hose clamp/cable tie mechanism.

Table 14: Early concept selection of clamp on mechanism.

| Criteria | "Butterfly" clamp | Joint clamp | Hose clamp/ Cable tie |
|---|---|---|---|
| **Size** | - | - | R |
| **Complexity** | - | 0 | e |
| **Weight** | - | - | f |
| **Easy installation** | - | + | e |
| **Production cost** | - | - | r |
| **Applicable with limited pipe access** | + | 0 | e |
| **Clamp-force** | - | 0 | n |
| **Adaptability for multiple pipe diameters** | - | - | c |
| **Reliability of mechanism** | - | 0 | e |
| **Score** | -7 | -3 | 0 |

The result of the early concept screening suggests that the hose clamp/cable tie mechanism is a better option than the two other concepts. Although this mechanism is widely used cannot be considered innovative in the flow meter clamp-on market, it looks to be the safest choice.

To ease the implementation of the new clamp-on flow meter into the market, it can be beneficial to utilize an already established clamp-on mechanism. Following the implementation of a simple hose clamp/cable tie solution, a more specialized solution utilizing the electrofusion welding principle suggested in **Section 4.1.2** should be investigated. Electrofusion welding will only be applicable for PE pipes, but if the future market develops as predicted, it could have much potential.

## 7.2 Early clamp-on enclosure body evaluation

After selecting the clamp-on mechanism, a concept for the enclosure body needs to be determined. Ultrasonic clamp-on flow meters reviewed in **Section 0** have varied enclosure solutions, depending on the system design and electric components involved. An enclosure for the new type of transducer element will require a different design than the reviewed solutions, but it is useful for inspiration. Apart from the clamp-on transducer enclosure, it is possible to design a separate enclosure for necessary electronic components. The separate enclosure can be installed in a more accessible location, resulting in easier service and maintenance. Selection of an enclosure solution is executed in the same manner as the clamp-on mechanism, and evaluated in **Table 15**.

**Small curved base enclosure.**

- Curved base providing high friction for stability.
- Small transducer enclosure requiring a separate enclosure.
- Easy service and maintenance of electronics.
- Only compatible with one pipe diameter.

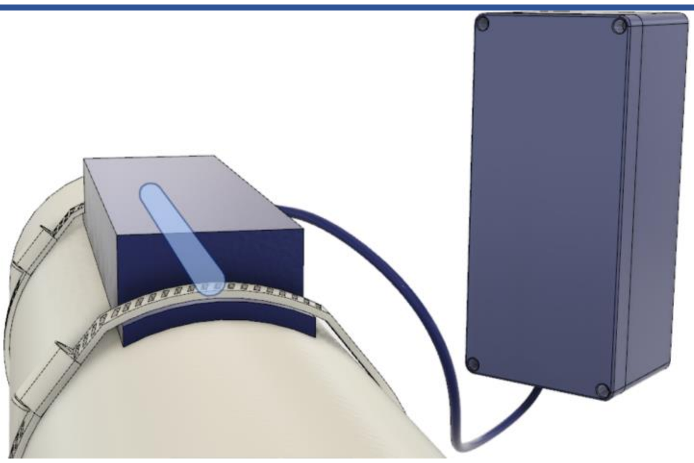


Figure 29: Small curved base enclosure, transducer highlighted in light blue.

**Large curved base enclosure.**

- Curved base providing high friction for stability.
- Large with room for all electronics.
- Few parts reducing risk of failure.
- Only compatible with one pipe diameter.
- Large enclosure demanding more space.

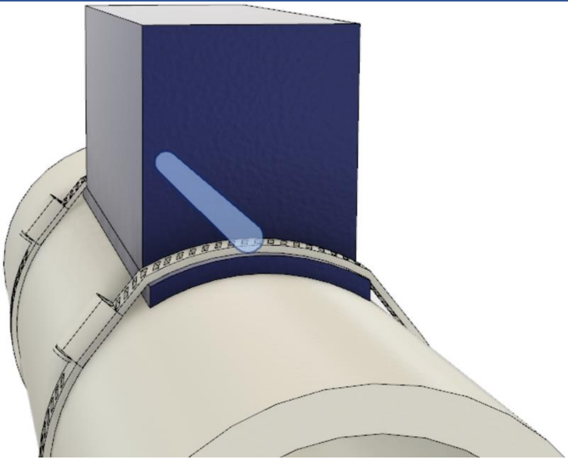


Figure 30: Large curved base enclosure, transducer highlighted in light blue.

Minimalistic flat base enclosure.

- Small transducer enclosure requiring a separate enclosure.
- Easier service and maintenance.
- Compatible with multiple pipe diameters.
- Less contact surface with pipe resulting in lower friction.

Figure 31: Minimalistic flat base enclosure, transducer highlighted in light blue.

Table 15: Early concept selection of enclosure solution.

| Criteria | Small curved base enclosure. | Large curved base enclosure. | Minimalistic flat base enclosure. |
|---|---|---|---|
| **Size** | - | - | R |
| **Complexity** | 0 | + | e |
| **Weight** | - | - | f |
| **Easy installation** | 0 | + | e |
| **Production cost** | 0 | + | r |
| **Service and maintenance** | + | - | e |
| **Friction with pipe** | + | + | n |
| **Adaptability for multiple pipe diameters** | - | - | c |
| **Chance of failure** | 0 | + | e |
| **Score** | -1 | +1 | 0 |

The result from the early concept selection of an enclosure solution is even. Although the large transducer enclosure with a curved base comes out of the comparison slightly ahead of the other concepts, it is not possible determine if it is the best solution.  A comparison with weighted criteria might have provided a different result, but would still have a high degree of uncertainty. To make an informed decision, all three concepts will be built as prototypes rto be tested and serve as POC models before a new comparison can be done.

## 7.3 Suggested specifications for a clamp-on mechanism

Important requirements and products specifications are summarized in **Table 16**.

Table 16: Product specifications for a clamp-on flow meter utilizing a hose clamp mechanism.

| | **Requirement** | **Comment** |
|---|---|---|
| **Price** | ~250 USD | In order to be price competitive, the clamp-on flow meter should not cost more than 250 USD |
| **Installation/ maintenance.** | Easy, no training required. | Easy to install and require little maintenance. |
| | | |
| **Physical** | | |
| Dimensions (Length x Width x Height) | 250 x 100 x 100 mm | Which pipe dimensions the clamp-on flow meter is design for can be influential. Preferably as small as possible. |

Table 16 continues:

| | | |
|---|---|---|
| Weight | **~ 0,5 kg** | **Equivalent to reviewed flow sensors.** |
| Enclosure material | HDPE | Durable material, in addition to the fact that an enclosure made from HDPE could be welded to HDPE pipes, with proper design. |
| | | |
| **Environmental** | | |
| IP rating | IP68 | Highest ingress protection. No ingress of dust and protected against continuous submersion for long periods. |
| Certification | Measuring instruments directive (MID) | According to relevant CE approvals [37]. |
| Temperature | $-20°C$ to $+70°C$ | Max. & min. temperature apply most for the electronics. |
| | | |
| **Performance** | | |
| Flow accuracy | $\pm 1\%$ of reading | Must have high accuracy for professional use. |
| Repeatability | $\pm 0,5\%$ of reading | Flow meter must be able to reproduce reading accurately and reliably. |
| Flow velocity range (Bidirectional) | $\pm 12\ m/s$<br>Minimum 0,3 $m/s$ | Flow meter must work at a wide range of flow rates. Should also be able to determine direction of flow. |
| Liquid types | Most clean liquids and liquids containing small amounts of gas bubbles or solids. | |
| Lifetime | 100 years | With proper inspection and maintenance, the flow meter must have a long lifetime to be a viable option |
| Pipe diameters | 32 to 1500 mm | Must be applicable to service pipes and the most common diameters used in a water distribution network. |
| Pipe materials | All metals and plastics | Testing is needed for concrete and composite materials. |
| Power supply | Built in battery with lifetime of ~2 years | The flow meter should be powered by battery, with a lifetime of approximately 2 years to ease need for maintenance. |

# 8. DEVELOPMENT OF CLAMP-ON DESIGN

## 8.1 Preliminary design development

The clamp-on should be designed with the current and future market in mind. A clamp-on flow meter using a hose clamp mechanism will accomplish this, but a more specialized solution could be better for a future market.

The current market consists of water pipelines made of a variety of different materials and diameters. A clamp-on flow meter should be possible to install on all commonly used pipes. Hence, a simple clamp-on solution like existing alternatives may be preferable for an easier market launch. Utilizing a common hose clamp or cable tie is by no means a new or innovative solution in the clamp-on meter market, however, it is the easiest functional solution.

As the use of PE pipes increases by water utilities, and is the preferred option in the foreseeable future, a solution specified for these pipes is favorable in the long run. To take advantage of this, a clamp-on solution compatible with electrofusion welding should be developed. The tools to install a clamp-on with electrofusion welding mechanism is already developed and taken into use by many water utilities, making it an accessible option. When replacing old pipes or installing new PE pipes, the water utility would be able to effortlessly install a water meter where desirable.

Electrofusion welding results in a homogenous joint, as the material of the two parts are melted together. This fastens the clamp-on to the pipe in a stronger and more secure way than utilizing a hose clamp or cable tie. It is very important that the transducer does not move in relative to the surface of the pipe after it is mounted, as any movement can cause wear and damage to the transducer surface resulting in incorrect measurement. A welded joint makes movement of the transducer very unlikely.

The two design solutions mentioned above is meant for water utilities and larger industrial businesses. As the previously mentioned clamp-on flow meters suggests, there is a market in developing smart flow meters to the private consumer as well. Modern homes are becoming increasingly technological, and information regarding water use is no exception. A third version of the clamp-on flow meter should be developed for this market. The three versions mentioned are listed and summarized in **Table 17**.

Table 17: Overview of suggested clamp-on solutions.

| Suggested solutions | Clamp-on mechanism | Description |
|---|---|---|
| **Water utility/industry, current market** | Hose clamp | Clamp-on solution designed with the purpose of a quick and easy market launch, suitable for installation in existing pipe networks. |
| **Water utility/industry, future market** | Electrofusion welding | A solution designed with current market developments in mind, with the goal of providing a superior clamp-on for the presumed future market. |
| **Private consumer** | Cable tie | A smart water meter with focus on modern and elegant design, rather than durability. Appealing to the private consumer. |

## 8.2 Design challenges

The main challenges with designing the clamp-on flow meter is making sure the design is compact, strong and waterproof, while still providing enough room to house all electronic components. Accomplishing these challenges in an efficient and balanced manner, can be difficult to achieve.

Information regarding the electronics are not yet made available to this development, resulting in a loose design as to how much room the electronics demand and how it is fastened inside the enclosure. However, this should be relatively easy to adjust for at a later stage in the development. The key focus areas are therefore making the design strong and completely water tight.

In order make the design strong, some important design choices have been made. The walls of the main body are thin to save material cost and reduce weight. This unfortunately makes the side walls a weak spot as they will easily bend under pressure. To strengthen these walls without increasing the thickness, vertical ribs are added along the inside of the enclosure. This strengthens the walls as well as it provides a place for screw holes to secure the lid to the enclosure body. **Figure 32** shows the ribs on the inside of the larger enclosure concept with room for electronics.

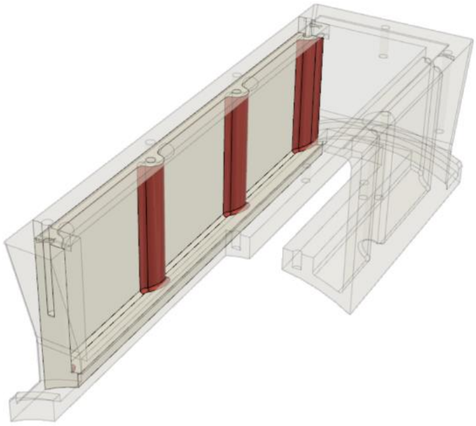


Figure 32: Ribs illustrated in red, strengthen the side wall and provide a place for screw holes.

The short sides of the enclosures have ends where the cable tie or hose clamp are meant to be fastened, illustrated in **Figure 33**. These clamp surfaces are also thin, but cannot be strengthened in the same manner as the walls. The two concepts with a curved base are naturally strengthened by the shape of the design. A curved surface makes the design more resistant to bending, as well as allowing for more surface area between the clamp-on and the pipe wall. This is an advantage when it comes to ensuring the design is water tight as well, as the silicon pad gasket can be large.

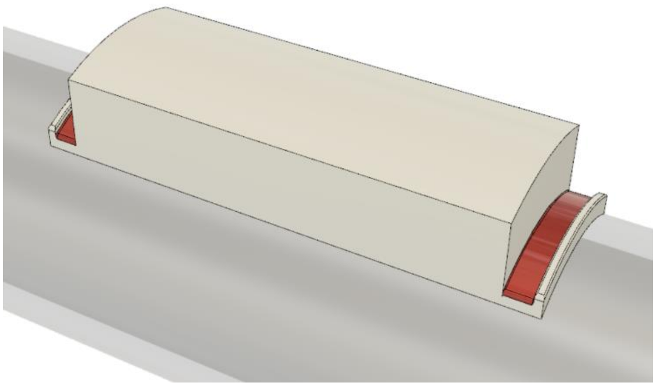


Figure 33: Clamp surfaces illustrated in red.

Choosing the right seal is key to a water tight design. O-rings are the most common and widely known, as they are simple and applicable for a broad range of uses. For a final and mass-produced product, O-rings are most likely the best alternative for sealing the lid, but for rapid prototyping reasons it has not been considered during the early development.

## 8.3 Material selection

Choosing the right material for a product can be pivotal for the products' overall quality. The type of environment and forces the product is exposed to, as well as the desired lifetime, are important factors to take into consideration when selecting the material. A clamp-on flow meter needs to endure harsh environments, as well as varying moisture levels. Even though it should remain static while installed to a water pipe, it can be exposed to various external forces depending on the location. Temperatures are relatively stable underground where the pipes are buried, but the design must be able to handle temperatures as if it were above ground. Durable design is a must, but without the right material it has little effect.

Metal, such as iron and aluminum are good alternatives as they are strong and durable, but offer few advantages other than the hardness of the material. In addition, metal, even stainless steel, has the tendency to corrode after long enough exposure to the certain environments. As mentioned above, the clamp-on flow meter needs to endure environments where metal components are prone to fail. Thermoplastic materials can with the right design and treatment, be a better and more suitable choice. Based on the increasing use of PE pipes, its properties and low material cost, PE is a good material choice for a clamp-on solution.

For testing, polyethylene terephthalate glycol-modified (PETG) is used to 3D-print the designs. PETG is a modified polyethylene terephthalate (PET) with lower melting temperature, making it ideal for production methods such as 3D-printing. PET is widely used in containers for liquids and food, as it is durable and easy to thermoform. Although HDPE is preferable for the final product, PETG can be used as a good alternative during early testing, as it possesses a lot of the same properties [51].

The effectiveness of a gasket which is the is determined by selecting the right material and have pressure provided by the enclosure to compress the gasket. Material should be selected based on the environment the product is to be used in, and in some cases, the material of the product itself. As the clamp-on flow meter will most likely remain hidden from direct sunlight and not encounter any harmful chemicals, temperature is the most deciding factor. Silicone or Ethylene-Propylene are both good material options as they have few limitations and work well in use with water applications [52].

## 8.4 Clamp-on enclosure CAD models

The three versions of the hose clamp concepts compared in **Section 7.2** have been designed in *Fusion 360* for testing, simulation and visualization. In addition to the concept differences described earlier, some additional design differences have been added for further testing. These additional differences mainly focus on design solutions for the sealing of the enclosure, such as the design of the individual lids for each concept. Preliminary technical drawings can be found in **Appendix C**.

### 8.4.1 VERSION 1 - SMALL CURVED BASE ENCLOSURE

Version 1 has a thinner enclosure, a curved lid and shorter clamp surfaces primarily made for cable tie fastening. This version is designed to only house the transducer and requires a separate enclosure housing other necessary electronics such as a battery.

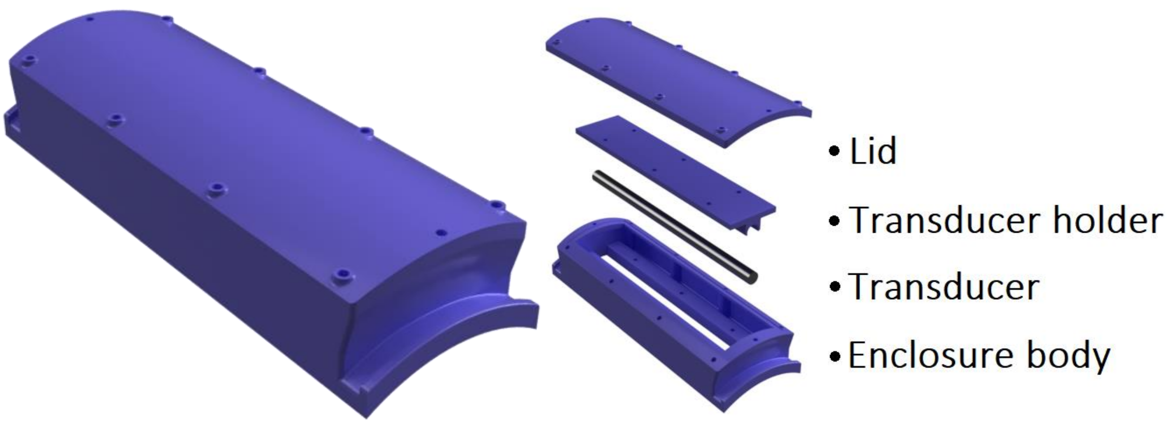



Figure 34: Version 1 of clamp-on designed for cable tie mounting. Exploded view on the right with named components.

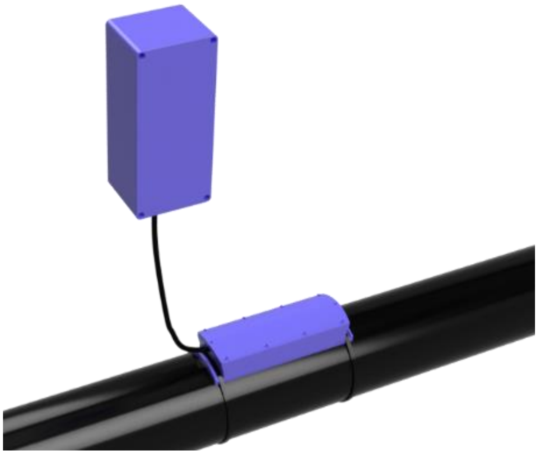


Figure 35: Version 1 connected to separate enclosure.

Separating the transducer element in its own enclosure allows the clamp-on to be more compact, which can be an advantage in some situations. In addition, the separate enclosure with necessary electronics can be placed in a more accessible location, making service and maintenance easier.

### 8.4.2 VERSION 2 - LARGE CURVED BASE ENCLOSURE.

The second version has a taller enclosure with room for all necessary electronics. In addition, the lid is flat with edges that extend around the top of the enclosure body. This results in a tight fit, which more efficiently secures the clamp-on from ingress of dust and water. It also has wider clamp surfaces made for hose clamp fastening.

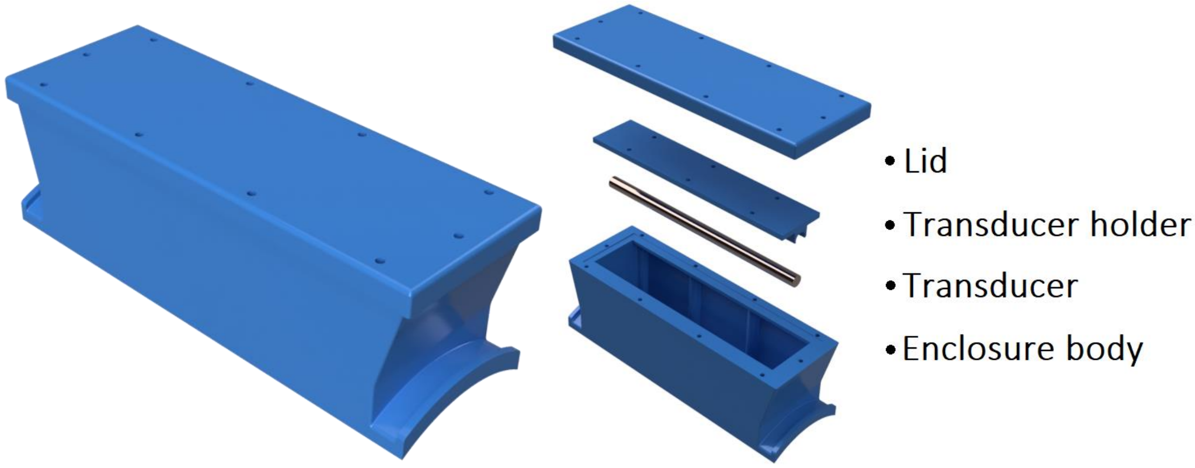



Figure 36: Version 2 of clamp-on designed for hose clamp mounting. Features a taller enclosure than version 1, with room for electronics.

Both version 1 and 2, as they are illustrated above, have been designed to fit a pipe with a diameter of 110 mm. This is one of the more common pipe diameters in preferred metering locations. However, the design is easy to adjust for other pipe diameters by simply changing the curvature of the base, illustrated in **Figure 37**.

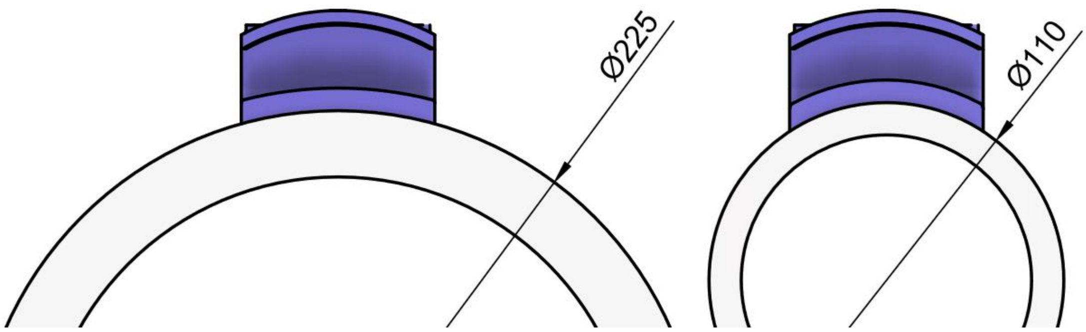



Figure 37: Clamp-on designed for pipe with a diameter of 225 mm (left) and for 110 mm (right).

### 8.4.3 VERSION 3 - MINIMALISTIC FLAT BASE ENCLOSURE.

The third version differs from the previously suggested designs. It can be used on multiple different pipe diameters, as it features a flat base surface. In addition, the transducer element is no longer in direct contact with the pipe surface. This assumes the transducer can measure accurately even if it is fully enclosed, with additional material separating it from the pipe wall. Sealing of the lid also has a different design in this version, a gasket mounted in the lid is pressed against a raised edge on the main body. When assembled, the two enclosure parts are in a flush position.

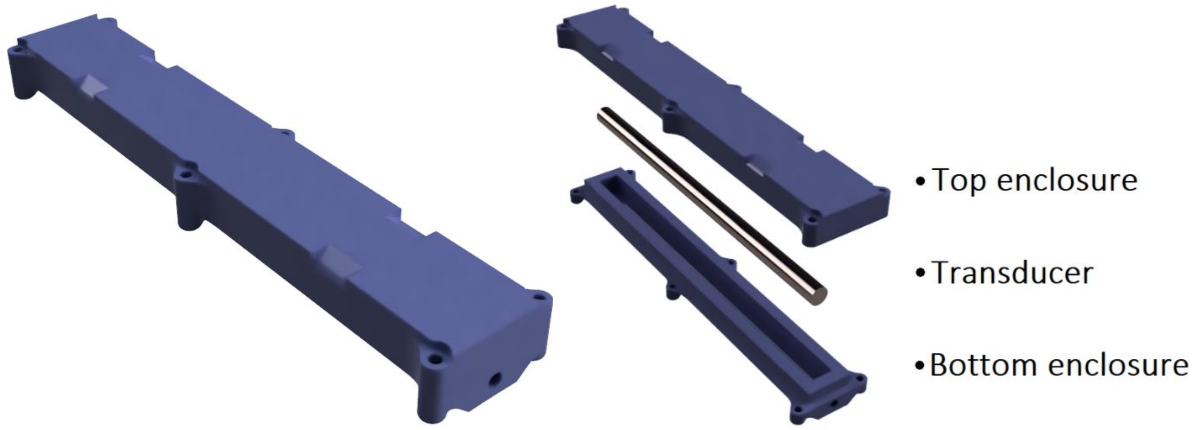



Figure 38: Version 3 of clamp-on with a more compact design.

Like version 1, this design only houses the transducer element and requires a separate enclosure for all other necessary electronics. The transducer enclosure is small and compact, making it ideal for the smaller 32 mm diameter service pipes. A clamp on solution for the private market can utilize this compact transducer enclosure, connected to a separate enclosure with an elegant design and integrated screen.

### 8.4.4 VERSION 4 - FUTURE CLAMP-ON CONCEPT - ELECTROFUSION WELDING

The clamp-on designed for electrofusion welding mounting has many of the same design elements as version 1. The broad surface base has copper wires built in, formed in an ellipse shape around the transducer opening. To make sure the clamp-on is securely fastened while it is being welded to the pipe, it can be fastened with hose clamps in the same manner as the previous versions. For the electrofusion weld to be successful, the base of the clamp on needs to have the same curve as the outside radius of the pipe, resulting in specialized designs for each individual pipe diameter.

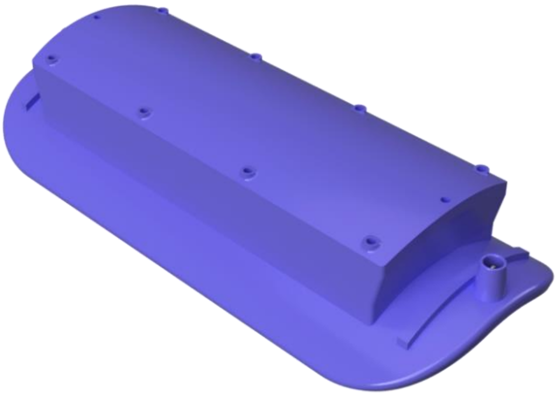


Figure 39: Clamp-on with similar design as version 1 for the current market, but with broader base with copper wires for electrofusion welding.

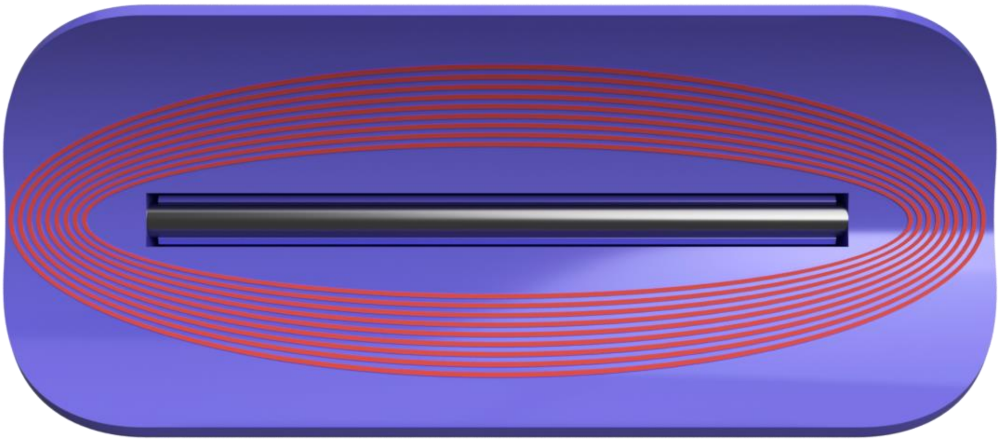


Figure 40: Copper wires are integrated into the base, in an ellipse shape around transducer element. Securing the clamp-on to the pipe as well as sealing the base of the enclosure.

Even though this concept requires more advanced tools and technology to install than the hose clamp mechanism, it is tools that most water utilities already have. As the percentage of HDPE pipes increase in water distribution systems, this clamp-on mechanism becomes more and more applicable.

## 8.5 Building of protoypes

All versions of the clamp-on enclosure made for the current market suggested in **Section 7.2** have been built by 3D printing as proof of concepts. Building a physical model of the enclosures allows for inspection and testing of the design, which can provide valuable results and information for further development of a finished product.

Although 3D printing is very useful for rapid prototyping, the printed models often have minor flaws resulting in varying degrees of weaknesses in the structure. It is important to be aware of these weaknesses when testing a 3D printed model. When printing certain models, support structure should be included to ensure the model is printed as accurately as possible. The curved base of version 1 and 2 was printed with the help of support structure, and needed to be worked before a seal could be installed.

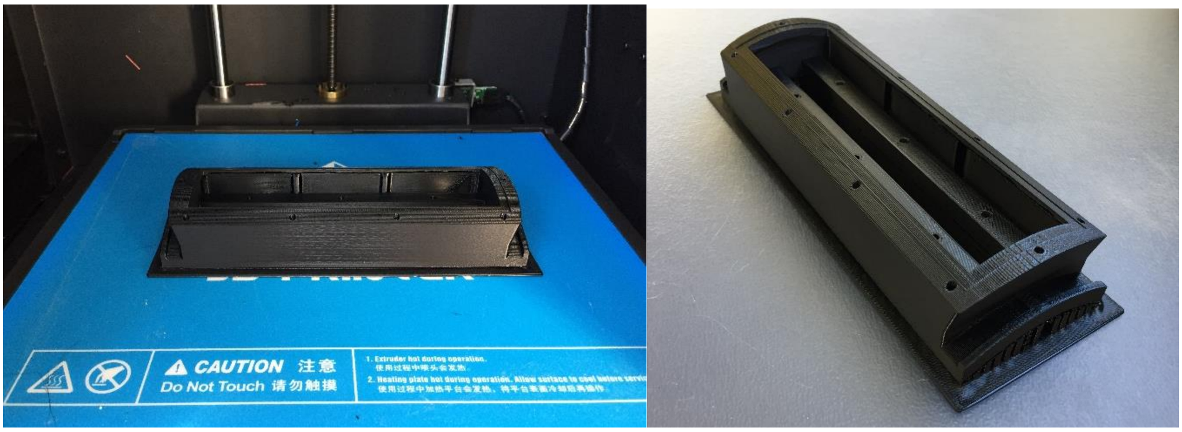



Figure 41: 3D printed model of version 1 enclosure body.

The screw holes in the prototypes does not have any threads, limiting the possibility of compressing the gasket in the lid when installing the lid to the enclosure. In addition, the 3D printed models are not printed with 100% infill, meaning the construction contains pockets of air. As the walls of the material may have flaws and weaknesses, water can leak through the construction, filling the pockets of air and possibly leaking all the way through. This unfortunately complicates even simplified ingress protection tests, limiting the technical tests of the prototypes. Either way, installing gaskets to the lids and bases of the models may provide useful observations.

Before applying silicone gaskets to the bases and lids of the printed models, the surfaces needed to be smoothened by sanding (**Figure 43**). After sanding, a modified silicone polymer adhesive sealant mixture is applied to glue silicone gaskets into place (**Figure 42**). The sealant mixture is not an ideal adherent to use with gaskets made of silicone, but it is sufficient for a prototype.

Figure 43: Sanded base of version 1 before applying sealant and gasket.

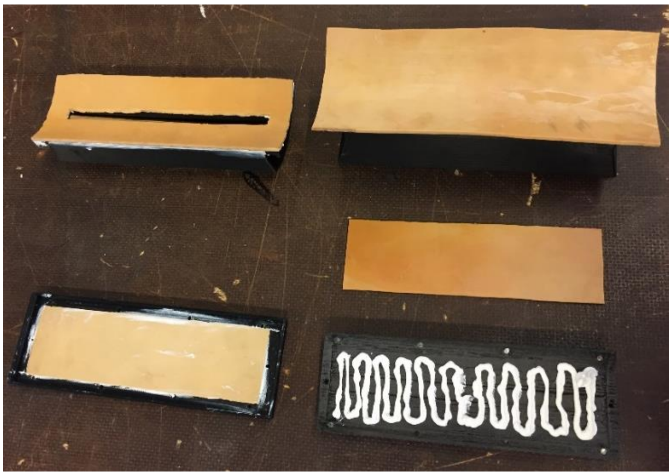


Figure 42: Gaskets being installed on curved base and lids of version 1 and 2.

The prototypes can be seen in their fully assembled state in **Figure 44**, **Figure 45** and **Figure 46**.

Figure 44: Version 1 prototype.

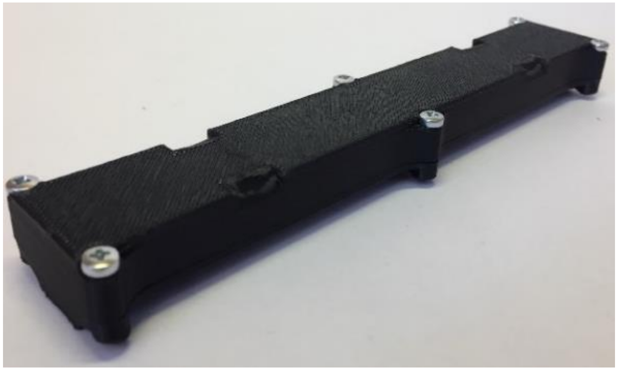


Figure 45: Version 3 prototype.

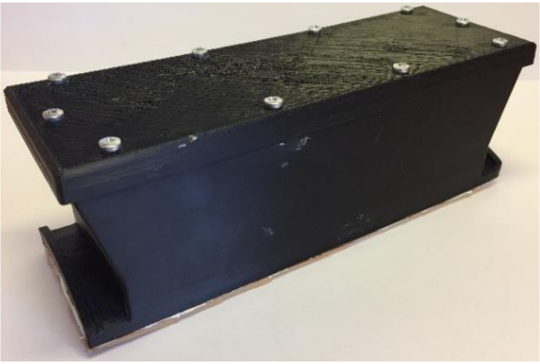


Figure 46: Version 2 prototype.

# 9. TESTING OF PROTOTYPES

As the 3D printed models have flaws resulting in weaknesses that would not be present in a final production line product, testing can only give an indication of the design qualities. Consequently, stress tests and simplified ingress protection test cannot give reliable results at this time. However, assembly of the enclosure, and installation on a pipe section, will come close to that of a final product.

The following tests are to be conducted on the models:

- Assembly of clamp-on enclosure concepts with transducer replica, and installation on pipe with cable tie and/or hose clamp.
- Assembly and installation by end-user, with the help of an instruction manual.
- Installation of version 3 on several different pipe diameters.

The goal of these test is to identify positive and negative design aspects of the individual concepts. There is much to learn by personally assembling and installing the enclosure concepts, and making notes of possible improvements. Furthermore, observing an end-user attempt to do the same thing by following an instruction manual can be even more informative. These tests will inform design improvements that can be undertaken in further work. Assembly and installation tests of clamp-on mechanism are executed alone by one person.

## 9.1 Assembly and installation of prototypes

***Version 1 assembly and installation***

As version 1 of the clamp-on mechanism also is the first iteration to be built and tested, it is expected to have the most design flaws. The silicon gasket used to seal the enclosure was harder than expected, and was not compressed when fastening the lid to the enclosure body. This created an unwanted gap between the lid and main body (**Figure 47**), exposing the silicone gasket and some threads on the screws.

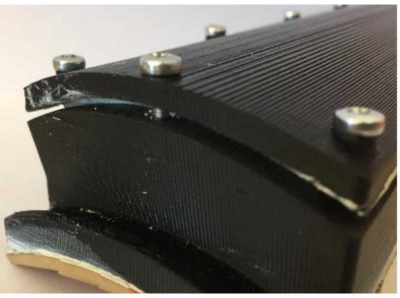


Figure 47: Gap between lid and enclosure body.

At some point during the modelling of version 1, the size of the main opening for the enclosure body was reduced in favor of additional area to compress the gasket in the lid. This resulted in a slightly too small opening for the transducer to easily be mounted when installed on the transducer holder.

Version 1 is designed to be fastened with cable ties, given its relatively thin clamp surface. While installing the clamp-on mechanism on a 110mm diameter pipe, several cable ties broke during tightening. This issue persisted with several different cable ties. As a result, the clamp-on could not be fastened sufficiently enough to prevent movement of the clamp-on after installation.

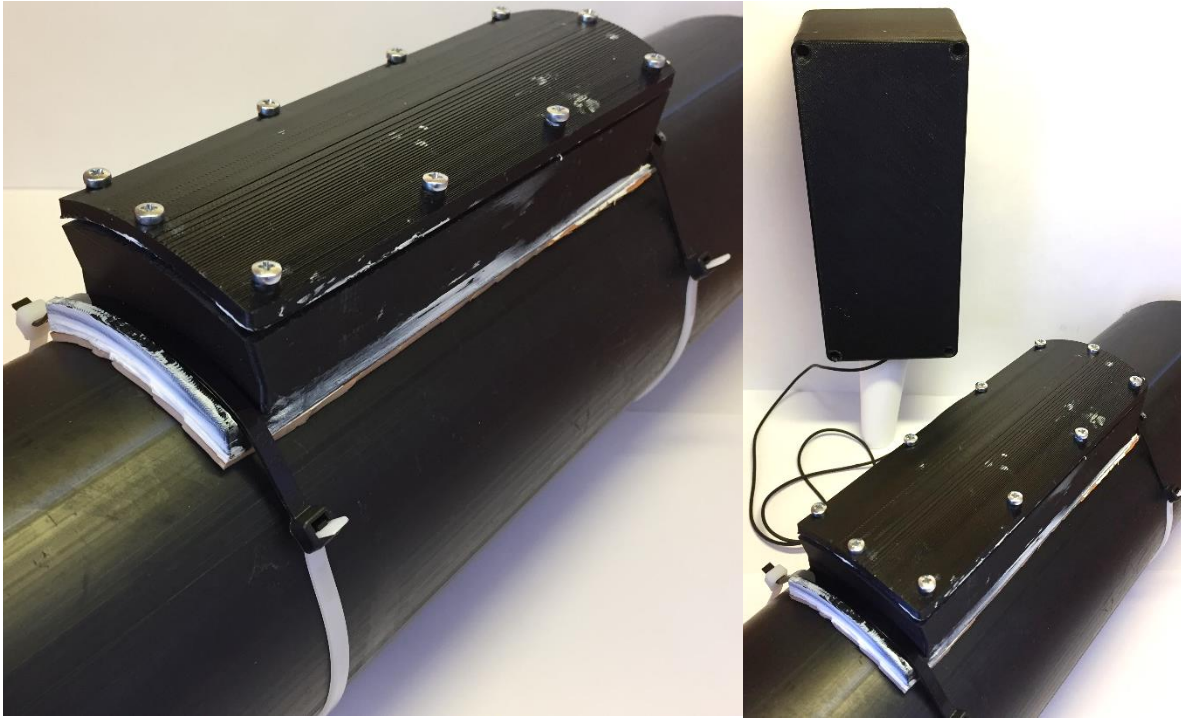


Figure 48: Version 1 assembled and installed on 110 mm diameter pipe (left). Connected to a separate enclosure that can be installed in a more accessible location (right).

***Version 2 assembly and installation***

The lid designed for version 2 has edges that extend around the enclosure body, solving the problem of a gap being created after the installation of a gasket. Transducer installation was also relatively easier as the enclosure has a slightly wider opening than version 1. Other than the high number of screws required to efficiently secure the lid (10 in version 1 and 2, compared to 6 in version 3), as well as gasket compression being tedious work, the assembly of version 2 shows promise.

The pipeline installation utilized hose clamps, which was easy to execute. The clamp-on mechanism is securely fastened as designed, and prevents movement of the enclosure after installation. Although tightening the hose clamps resulted in a crack on the enclosure body in the transition to one of the clamp surfaces, it is safe to assume this weakness is caused by warping (tension causing the model to bend) of the 3D printed model (**Figure 49**). Warping was also somewhat evident in the 3D printed lid, but not enough to cause further problems with the assembly.

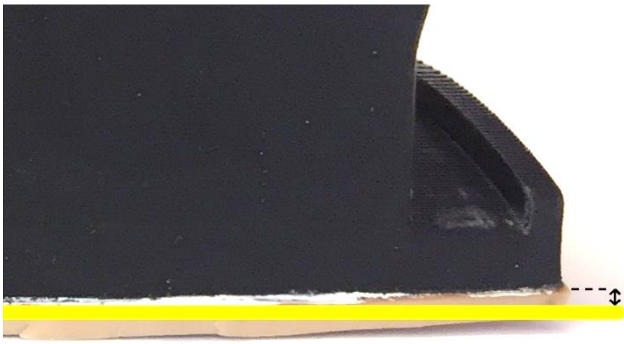


Figure 49: Warping of the enclosure body, causing the clamp surface to bend upward.

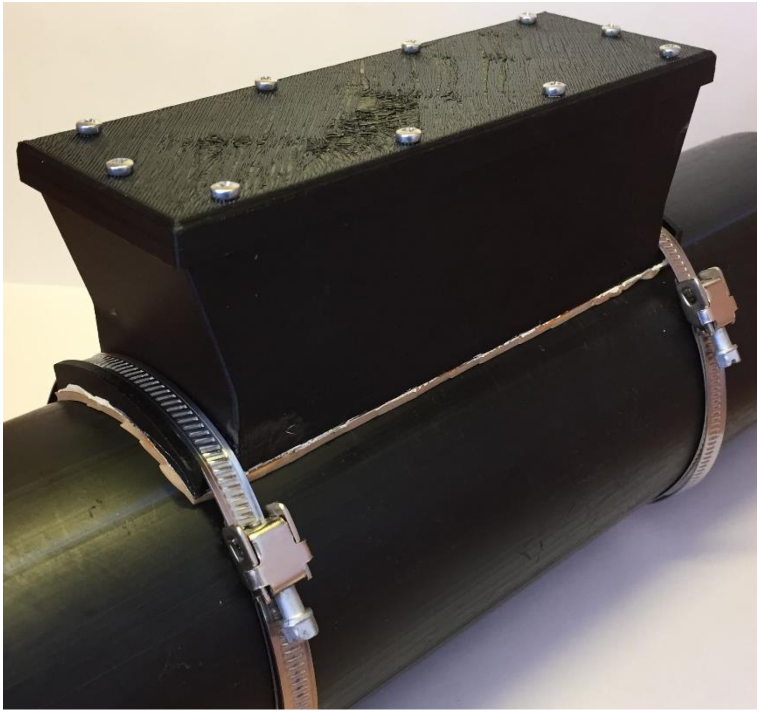


Figure 50: Version 2 assembled and installed on 110 mm diameter pipe.

***Version 3 assembly and installation***

Version 3 requires less work to assemble, as the design is smaller and consists only of a top and bottom enclosure. The transducer snaps into a slot in the bottom enclosure, keeping it firmly in place without the need of a transducer holder. When assembled, the two enclosure parts rests in a flush position, resulting in a better-looking product, with possibly lower risk of dust intrusion.

Installing the enclosure on pipes of several different pipe diameters is no challenge, and the clamp-on is securely fastened when the hose clamp are tightened sufficiently. Clamp surfaces integrated into the top enclosure works well with the compact design.

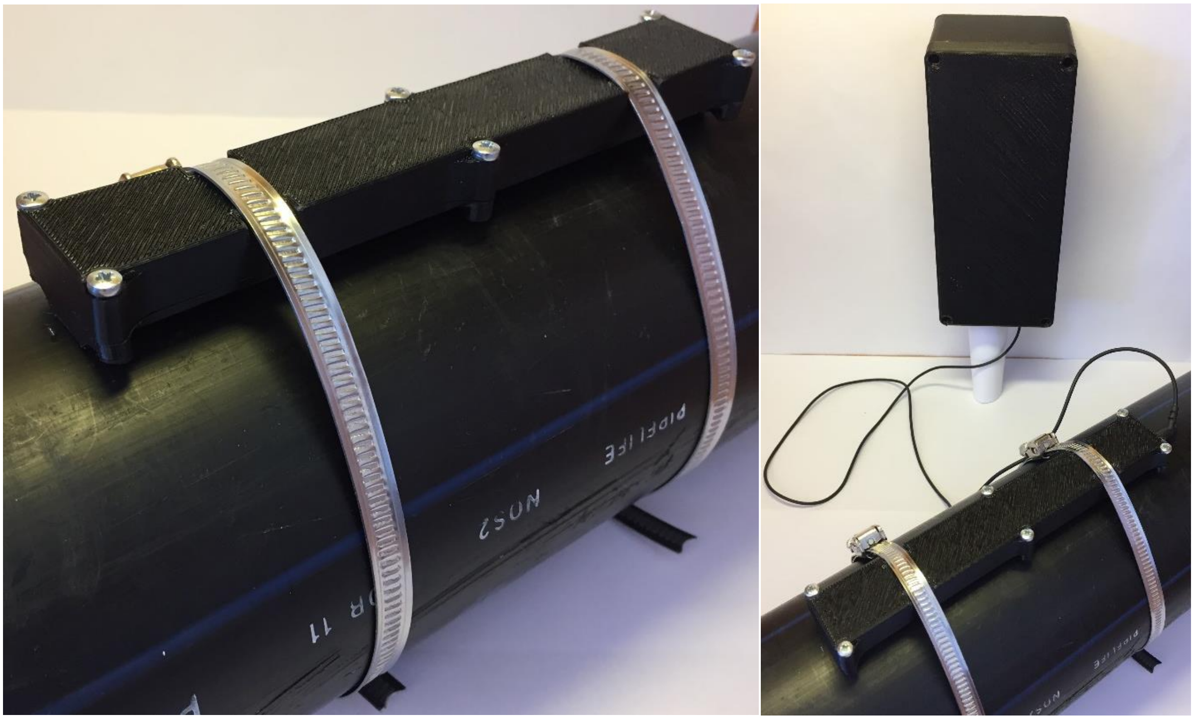


Figure 51: Version 3 assembled and installed on 110 mm diameter pipe (left). Connected to a separate enclosure that can be installed in a more accessible location (right).

## 9.2 End-user assembly and installation

A representative from Kroksjøen Waterworks was asked to perform assembly and installation of all three enclosure concepts on a length of pipe, with the help of an instruction manual. Comments made by the representative was noted while observing the test, to gather as much input for further development and improvement as possible.

A test scene was prepared with three pipes of different diameters mounted to a table (**Figure 52**). The representative was given the clamp-on enclosures, tools and an instruction manual (**Appendix A**), explaining how to assemble and install the enclosures.

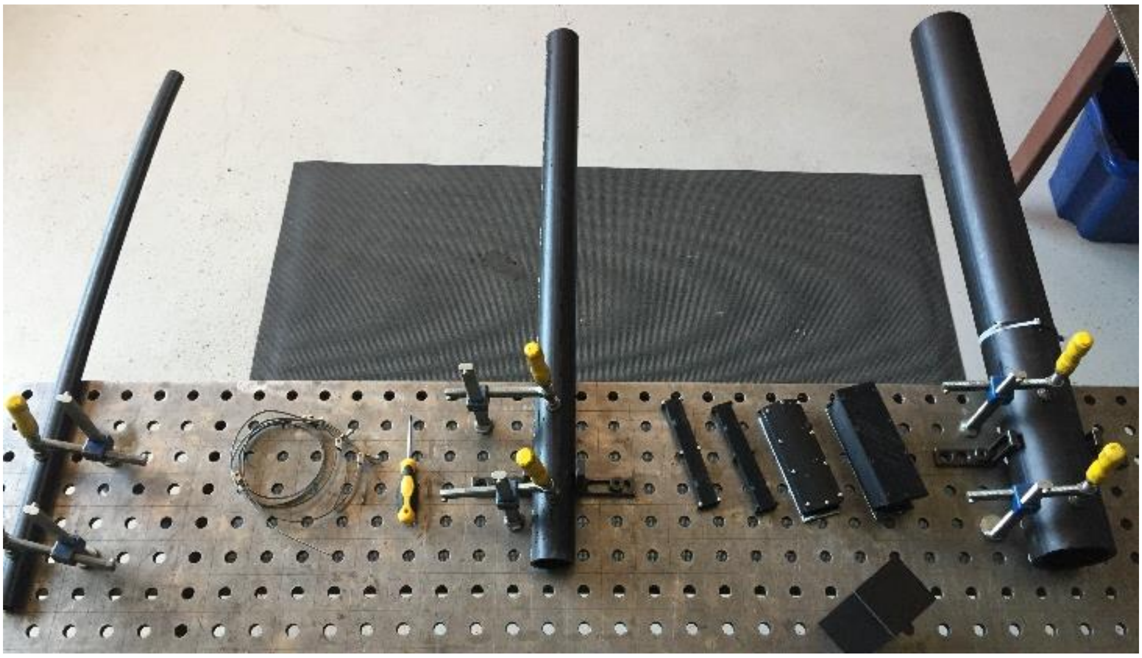


Figure 52: Setup for end-user test. Pipes of 32mm, 64mm and 110mm (left to right), were mounted to a table with easy access (Photo: Kevin Vesterås).

The end-user assembled and installed version 2 and 3 of the clamp-on enclosures with ease, and expressed his thoughts about the unique concepts. In addition, the concept utilizing electrofusion wielding was discussed. **Figure 53** shows the result of the end-user test, with version 2 and 3 of the clamp-on concepts firmly installed on their individual pipes.

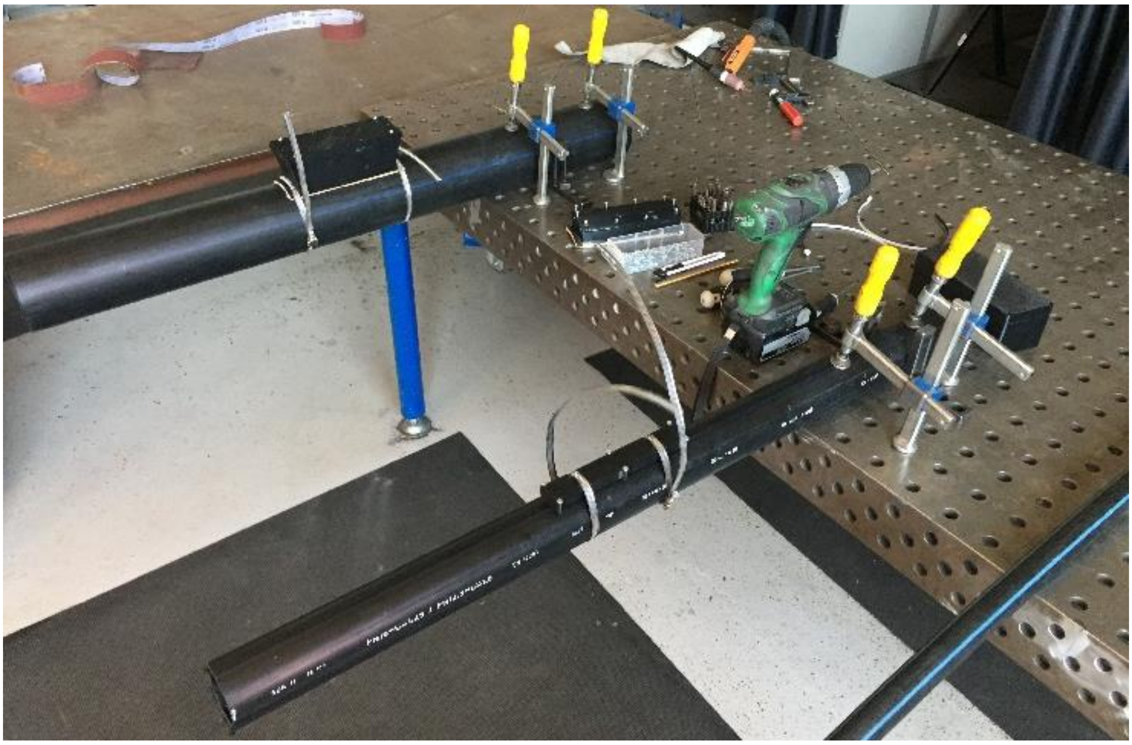


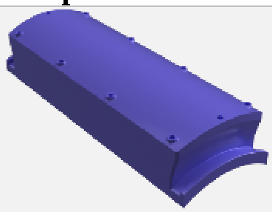
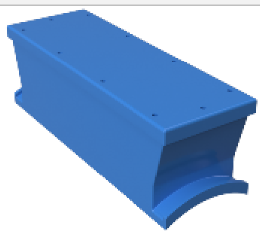
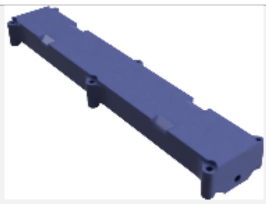
Figure 53: End-user assembled and installed version 2 and 3 to the 110mm and 64mm diameter pipes respectively (Photo: Kevin Vesterås).

Some concern was expressed regarding material of the screws and hose clamps, in the sense that it needs to be extremely corrosion resistant to be able to endure harsh environments. Stainless steel, as the screws and hose clamps are made of, is supposed to be resistant to corrosion. However, it can, and most likely will, suffer from corrosion at some point. The end-user suggested utilizing industrial cable ties, something that Kroksjøen Waterworks already have taken into use.

While the concepts were easy to install, they require some assembly of electrical components (such as the transducer) at this stage of development. The end-user expressed concern about this also, as the water utility preferably would like to have a ready-to-use product with no assembly required other than the installation on the pipe itself.

Furthermore, the concepts were compared with each other in terms of ideal areas of use, where all concepts (including the electrofusion welding concept) could be preferable in a certain situation. Results are listed further in **Table 18**.

Table 18: Comments and notes from end-user test.

| Concept | Comments and notes |
|---|---|
|  **Version 1** | • Good design, easy to handle.<br>• Was not installed on pipe due to the shorter clamp-surfaces only working with cable ties.<br>• Concept requires a separate enclosure for electronics, the clamp-on enclosure should be more compact.<br>• Ideal for use on pipe sizes above 64mm diameter and made from other material than PE. |
|  **Version 2** | • Curved base with a silicon gasket/pad provides strong grip to pipe, preventing movement when installed.<br>• Less practical with electronics (especially battery) in clamp-on enclosure, but there are exceptions.<br>• Ideal for use on pipe sizes above 64mm diameter and made from other material than PE. |
|  **Version 3** | • Ideal size for service pipes (32mm diameter)<br>• End-user very happy with size of version 3.<br>• Preferable if the enclosure comes fully sealed with transducer element inside. No need to open the enclosure. Only connect wire to external enclosure. |
|  **Version 4** | • Absolutely best solution for PE pipes, end-user very positive to this concept.<br>• The enclosure could be made smaller as it only houses the transducer, reducing the size some.<br>• Could be sufficiently fastened with only hose clamps or cable ties, negating the need for version 1 & 2. |

## 9.3 Results and evaluation

The assembly and installation test revealed various needs for improvement and changes across all the unique concepts. General notes from the tests and comments noted from the end-user test is summarized in the list below.

**General notes and comments:**

- Enclosure- and clamp mechanism material must be durable and very corrosion resistant. End-user is skeptical to the use of stainless steel, and would preferably have all plastic materials.
- Use plastic industrial cable ties instead of metal hose clamps, increasing the expected lifetime of the product.
- The clamp-on enclosure should require as little assembly as possible, in order to reduce required work by the installer and minimize number of components.
- All versions are ideal for their own specific scenario;
    - Version 3 is the best solution for smaller pipe diameters, such as the 32 mm diameter service pipes.
    - Version 1, 2 and 3 are ideal for use on the more common larger pipe diameters used in the water distribution network.
- The water utility is used to ordering and handling pipe diameter-specific parts when using electrofusion welding.
- End-user did not use the provided instruction manual when assembling and installing the enclosures, proving the need for an intuitive and simple design.

While most of the results from the test can be implemented into the design at the current stage, some changes require further information about the new transducer element and electrical components. Reducing the need for assembly of the clamp-on enclosure by the end-user, by producing a more complete product, can solve many of the suggested improvement potentials.

## 9.4 Further testing

When a functional prototype of the ultrasonic clamp-on flow meter can be produced, an experimental test rig should be built. The test rig should be a small-scale replica of a water distribution network, with a similar setup as Kroksjøen Waterworks. A suggested setup of this test rig can be seen in **Figure 54**. It consists of pipes of all the most used materials; PE, PVC and iron, connected to a water tower, allowing water flow in both directions. Taps should be placed along the pipeline, to simulate consumption and leaks. Ultrasonic clamp-on flow meters can then be installed between the taps, measuring the volume flow of water throughout the setup.

The test should have the following goals:

- Determine accuracy of reading.
- Determine repeatability of reading.
- Determine effectiveness on different pipe materials.
- Determine if flow meter can reliably determine direction of flow.
- Determine effectiveness of clamp-on mechanism

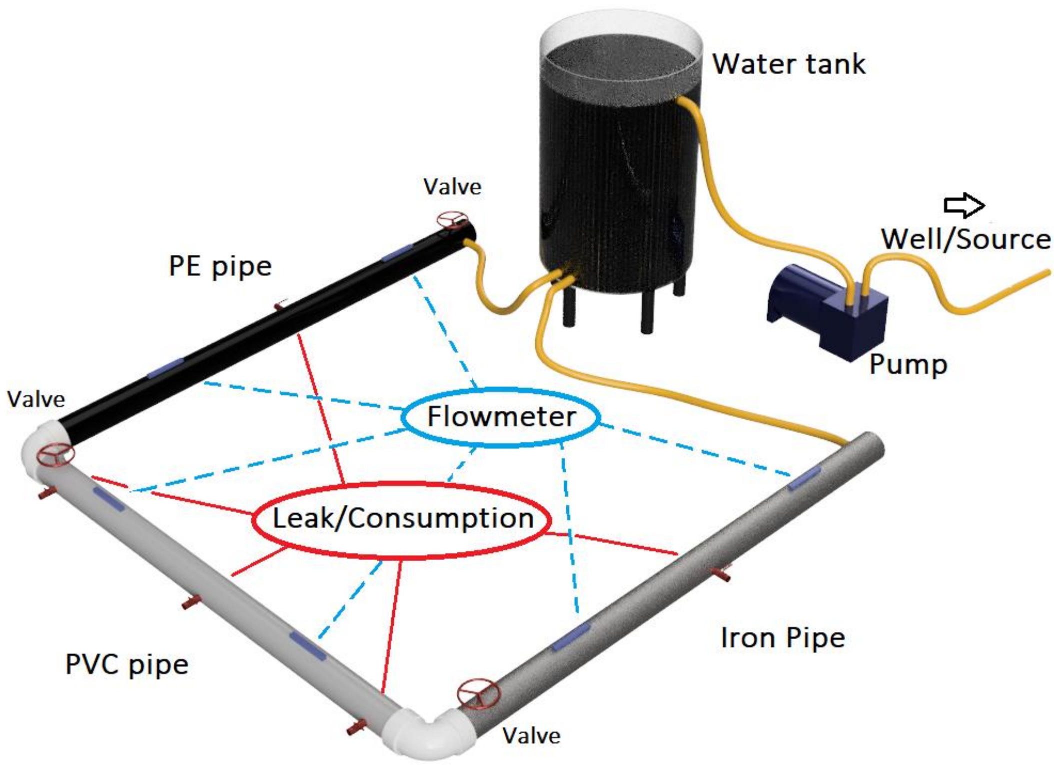



Figure 54: Test rig setup. A small-scale water distribution network with adjustable leaks/consumption and flowmeters spread throughout the system.

# 10. DISCUSSION

## 10.1 Process evaluation

The main goal of this thesis was to define initial specifications for a clamp-on flow meter based on an investigation of theory, and then subsequently test the prototypes for further development. As a result, the following activities was performed in order to derive a set of specifications:

1. Theory review – Research on water utilities, water leakage management, leakage detection techniques, flow meter technology and flow measuring principles.
2. Visit to Kroksjøen Waterworks – Determine suitable installation locations and important requirements by involving an end-user.
3. Concept design and evaluation – Design and selection of clamp-on enclosure and mechanism concepts.
4. Testing of concepts – Assembly of clamp-on enclosures and installation on sections of pipe.

Execution of these activities resulted in important insight for further development. **Table 19** lists the specifications derived from the process, critical for success.

Table 19: Summary of specifications for a clamp-on flow meter derived from performed activities.

| **Specifications** | **Insight** |
|---|---|
| **Small size** | The clamp-on flow meter should be as small as possible in order to fit in tight spots and hard to reach areas. |
| **Durable material** | Material must endure harsh environments. Research suggests that the clamp-on should preferably be made entirely of plastic as this is affected the least by the environment. |
| **Long lifetime** | Much influenced by material choice and clamp-on mechanism, the clamp-on flow meter should have a reliably long lifetime to make it a viable option. |
| **Intuitive design** | Water utility employees should not require special training or instructions to be able to install the clamp-on flow meter, necessitating an intuitive design. |
| **Low cost** | Clamp-on flow meters must have a low cost to make it a better option than traditional flow monitoring and leakage detection methods. The clamp-on flow meters available on the market are either above the costumers' willingness to pay, or lack the sufficient specifications. |

Table 19 continues:

| Other important results | |
|---|---|
| **Multiple versions** | Findings from this thesis indicates that multiple versions of the clamp-on flow meter for different areas of use could be beneficial, as some pipe diameters and materials are more significant depending on the costumer. |
| **Market development** | The clamp-on flow meter market has evolved slowly in terms of mechanical solutions. Current clamp-on flow meters are all fitted with relatively simple and basic mechanisms. A more secure clamp-on mechanism made to fit the evolving market has much potential. Electrofusion welding as a clamp-on mechanism, combined with smart functionality, can lead to a lucrative flow meter. |

1. **Theory review**

   The aim of this study was to present an overview of what is considered 'state-of-the-art' in terms of flow meters. The study combines theory of working principles of different measuring principles with commercially available flow meters. The goal was to outline the limitations of existing technologies and to give the reader a basis for understanding both the technology and the extent of challenges related to water leakage. Together with an extensive review of the problem in the Norwegian water network, the theory review provides a solid foundation for further and new developments in the industry.

   Reviewed theory, market predictions and motives are based on numerous credible sources, such as the IWA, the Strategic Alliance for Water Loss Reduction and other globally operating associations and technological companies. To further increase the credibility of the theory review, more clamp-on flow meter solutions, both existing and currently under development, should be reviewed. This will provide a better picture of what the competition is and what the finished product must compete with in terms of price and performance.

2. **Visit to Kroksjøen Waterworks**

   As mentioned in the methodology section, it can be an advantage to product development to involve several stages of development early in the process. In case of this thesis, an end-user was involved by visiting Kroksjøen Waterworks and getting a tour of their water distribution network.  This was very helpful to determine requirements that would not only ensure functionality of the clamp-on flow meter, but develop a product that would be easy for the end-user to use. By physically inspecting the suitable locations the flow meter could be installed, provided a deeper understanding of the required specifications.

   Small size is an undeniable advantage for a clamp-on flow meter, as the space available in suitable installation locations often is limited. Knowing how these installation locations look and possible complications related to installation of the clamp-on flow meter, is an advantage when designing and selecting concepts for development.

Ideally, more water utilities should have been visited, to cross-check the findings at Kroksjøen Wateworks, and possibly uncover new insight. Particularly a water utility with water distribution systems in larger cities, such as Oslo.

**3. Concept design and evaluation**

After the theory review and end-user study, initial specifications were set. In order to develop the best possible product, multiple concepts were designed and compared to determine which had the most chance of success.

Evaluation of the clamp-on mechanisms in **Section 7.1** provided a clear result. Although the evaluation only included 3 different mechanisms, they were the result of a broader investigation. Ideally, the individual mechanisms should have been tested, to increase the credibility of the criteria comparison result in **Table 14**. On the other hand, after the electrofusion welding method was discussed at Kroksjøen Waterworks, electrofusion welding is believed to be the best solution for a future clamp-on flow meter on PE pipes. A clamp-on flow meter with this clamp-on mechanism would be able to be permanently and homogenously welded to the pipe wall, with tools already in use by most water utilities. However, as electrofusion welding only is applicable on PE pipes, the hose clamp mechanism selected in the mechanism evaluation, is necessary to be able to fit clamp-on flow meters on the rest of the water distribution network.

The evaluation of the enclosure concepts in **Section 7.2** did not provide a clear result, which suggests that either the comparison criteria were wrong, or that it is simply not possible to determine an optimal concept without further testing. While moving forward with all enclosure concepts to the test phase slowed the overall progression of the development, it produced valuable insight. All the suggested enclosure concepts have their individual advantages and weaknesses, depending on the area of use and type of customer. In order to be able to select a single enclosure concept, it would be necessary to only focus on a specific section of the market.

Production methods must be kept in mind when ensuring the necessary specifications of the clamp-on flow meter. Limiting material choices to plastic, and simplifying the design to make it intuitive, can lead to standardized low-cost production, if designed carefully. Furthermore, by limiting the development to versions of the clamp-on flow meter, as the results suggests, the individual concepts can be simplified as much as possible.

4. **Testing of concepts**

   The end-user assembly and installation test of the concepts proved that all the suggested enclosures have some potential, hence not providing a clear result - similar to the concept evaluation in **Table 15**. The end-user confirmed that each of the suggested concepts are advantageous for different uses in the market and must be evaluated as such. As it is impractical to continue the development process further with all enclosure concepts, the challenge is to combine as many of the desired strengths into fewer concepts. Ideally two versions of the clamp-on flow meter should be able to cover the market needs. One version with a minimalistic flat base enclosure suitable for smaller pipe diameters, and one with a curved base with the option of electrofusion welding.

   Regarding the material choice, Kroksjøen Waterworks would prefer if the entire clamp-on flow meter were made of PE. Screws and other metal parts on the exposed sections of the enclosure, introduces the risk of corrosion and product failure. As the water utilities would prefer that no assembly was required, removing the need for screws entirely could be a possibility. If all electronics other than the transducer element are kept in a separate enclosure, the clamp-on enclosure could be permanently sealed in an all plastic enclosure. This could potentially increase the lifetime of the product. However, it would need to be developed further after more information about the transducer element becomes available.

   As revealed by the end-user assembly test, an intuitive design is absolutely essential. The clamp-on flow meter should require no explanation to be installed correctly. While still an obvious product requirement, just how critical it can be for the product to serve as a viable option for water utilities, should not be underrated. This should clearly be tested with more water utilities, but even if intuitive design is less essential to others, its need has already been established by Kroksjøen Waterworks.

   Assembly test should have been executed with more test subjects, preferably someone with production or manufacturing experience, to get more relevant feedback, as well as more water utilities. As the end-user test clarified, water utilities want little to do with the assembly of the product, and would prefer if it came ready to be installed.

## 10.2 Process changes

Initially, the objectives of the thesis included a more extensive development and testing phase, with ambitions of performing stress tests and simplified ingress protection tests. However, this had to be adjusted, as building functional prototypes capable of providing any meaningful data for such tests, proved too difficult and came with too much uncertainty; information regarding electrical components was simply too. Instead, more focus was applied to laying a solid foundation for future development, by thoroughly reviewing relevant theory in hope of identifying solutions with a clear market potential.

The use of 3D printing has been a huge help to the development and testing of concepts. Rapid prototyping enables the designer to make improvements much faster and easier, by being able to physically inspect the design. Nonetheless, it is important to be aware of the weaknesses of 3D printed models, as these can limit the usefulness of certain tests. As mentioned, the thesis objectives initially included a simplified ingress protection test of the 3D printed concepts, by using a humidity sensor connected to a microcontroller. As it turned out however, sealing the prototypes proved too much of a challenge for the tests' effective execution. The models did show promise though, and they would most likely only need minor adjustments to become completely water and dust tight.

As the project objectives was adjusted when the 3D models could not be used as intended, the focus on executing calculations and simulations regarding structural strengths and weaknesses, was forgone. Compressive force exerted by the hose clamps on the clamp surfaces, and other minor acting forces were calculated to some degree, but were discarded as it does not add value to the development at the current stage. Rather, the focus was shifted to identifying suitable concepts and specific areas of use.

# 11. CONCLUSION

## 11.1 Achievement of objectives

Based on the performed activities and resulting specifications, prototypes were built and tested with end-user. From this development process the conclusion is that a flow meter using industrial cable ties as a clamp-on mechanism is a viable option based on the derived specifications. In addition, a version capable of electrofusion welding should also be considered in order to meet the demands from the growing market for PE-pipes.

In order to meet the needs of the different market segments (private households, industry etc.), two versions of these flow meters should be developed; one minimalistic flat base enclosure for smaller pipe diameters, and one curved base enclosure with option of electrofusion welding.

## 11.2 Future work

As mentioned in the objectives, part of the goal of this thesis is to serve as a foundation for future development. To achieve this, some of the reviewed theory and performed activities are only preliminary, and requires further work.

To begin with, the clamp-on enclosure concepts should be improved according to the results and data gathered from the assembly and installation tests. This will hopefully improve the concepts to such an extent that a functioning prototype of the clamp-on mechanism can be developed.

At this stage, calculations and simulations on acting forces, fatigue capacity and more, would be appropriate to execute. While it is not likely that the clamp-on flow meter would be subject to any extreme forces during normal use, it is necessary to know weak points and relevant safety factors to assure quality and acquire necessary certifications.

The electrofusion welding concept should be a priority in future development, as it has real potential as a new and better clamp-on mechanism. Specific specifications and requirements needed to successfully develop the concept should be determined, possibly in cooperation with a manufacturer with electrofusion welding experience.

Ultrasound gel and coupling agents used to ensure transmission of ultrasonic should be investigated. Either this must be installed at the base of the clamp-on enclosure, or applied to the transducer element itself. While this can be difficult to investigate until more is known about the transducer element, some preparation should be done.

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# 13. APPENDICES

A. Progress plan
B. Instruction manual – end user assembly test
C. Technical drawings

# Appendix A: Progress plan

**Milestones:**

- 1. Review relevant literature and research around water leakage and ultrasonic flow metering.
- 2. Review the measuring principles in use today, and determine the need for a better solution. Study water distribution management and how the market is evolving, and summarize existing solutions.
- 3. Specify suggested specifications for a new clamp-on mechanism.
- 4. CAD-modeling, material choice and simulations.
- 5. Build prototypes to serve as POC and execute simple tests.
- 6. Finalize the report.

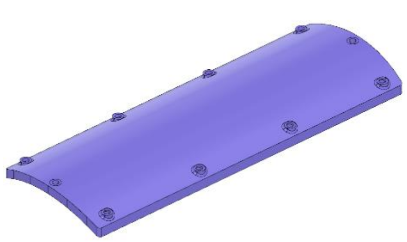
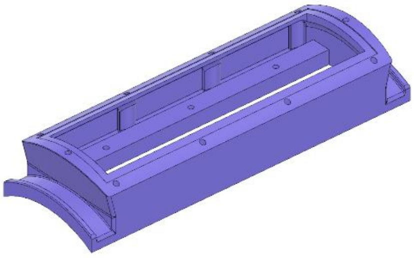
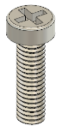
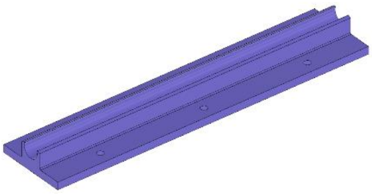
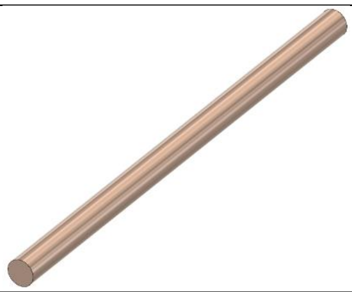
Table A.1: Progress plan with numbered milestones and weekly distribution of activates.

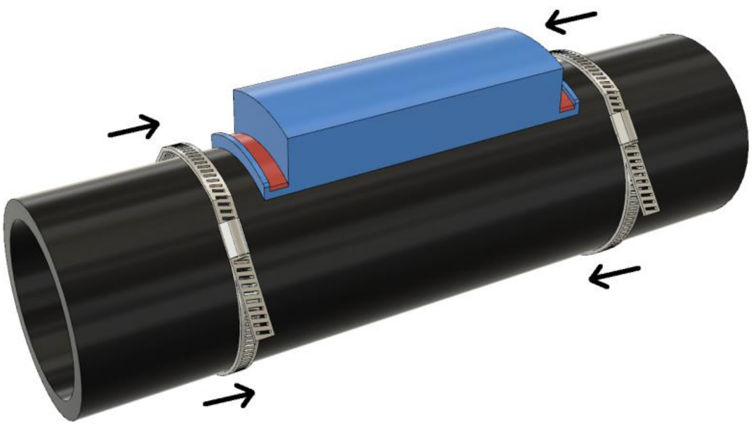
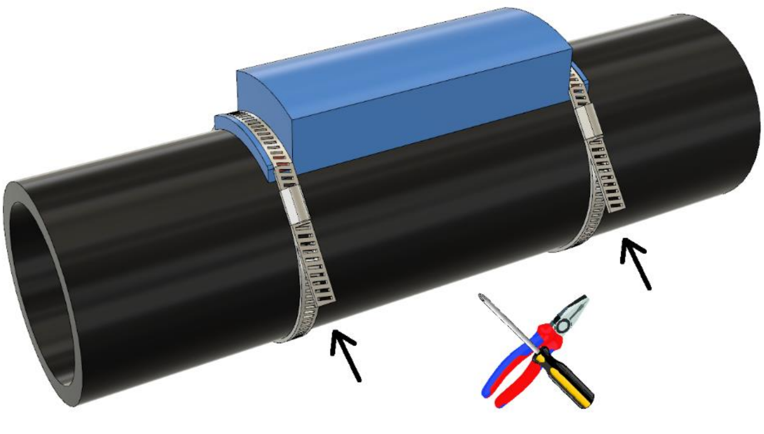
| Activity | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Literature review | | 1 | | | | |
| Theoretical work | | | 2 | | | |
| Product specification | | | 3 | | | |
| CAD-modeling | | | | 4 | | |
| POC building and tests | | | | | 5 | |
| Report work | | | | | 6 | |
| Report deadline | 1. June | | | | | |
| Presentation | 15. June | | | | | |

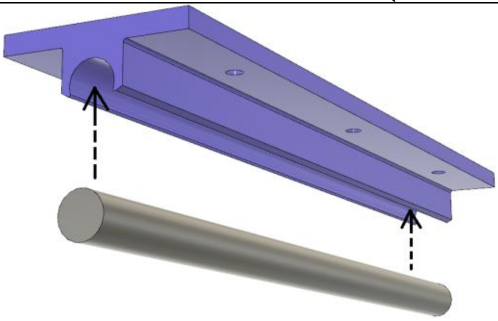
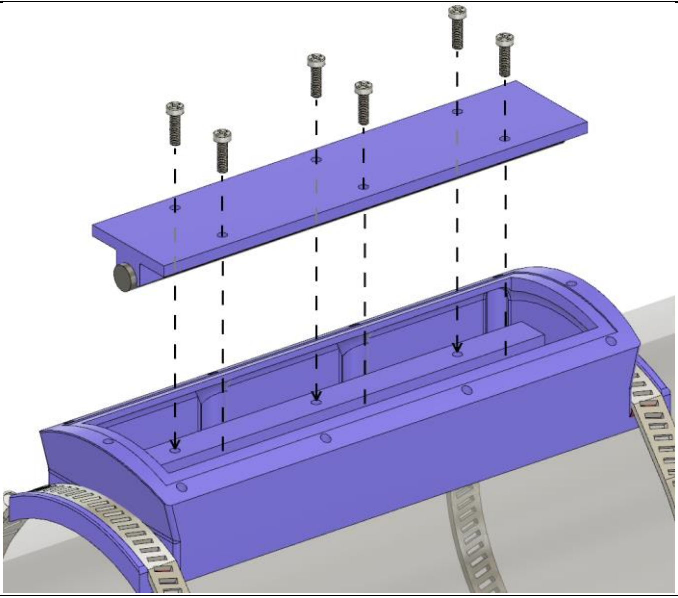
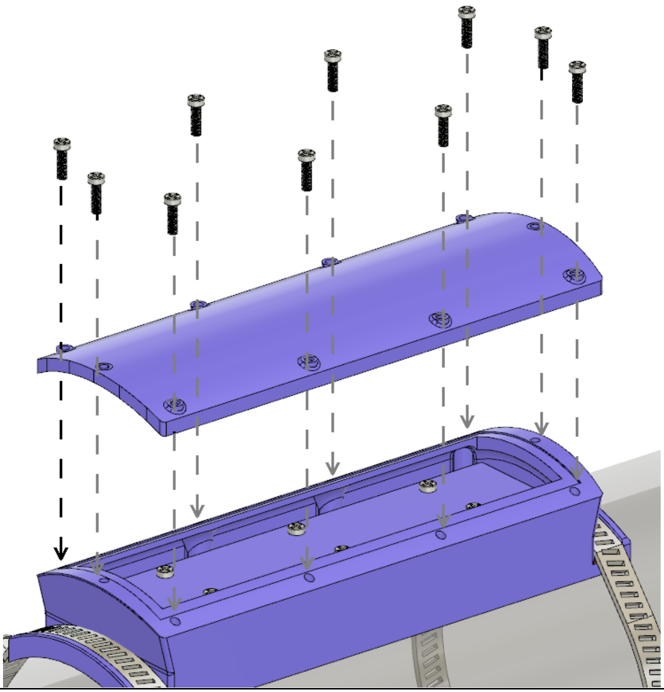
# Appendix B: Instruction manual

## Installation of clamp-on on pipe (*Version 1 & 2*)

Item Check List:

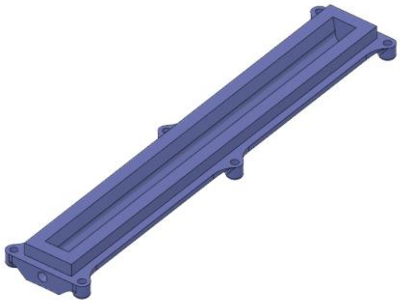
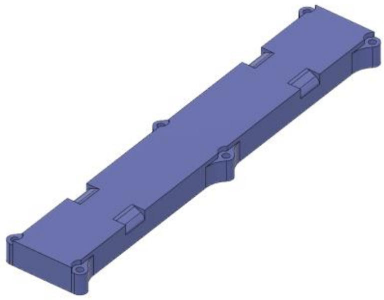
| | | | |
|---|---|---|---|
|  | Top enclosure |  | Hose clamp x2 |
|  | Top enclosure |  | M3x10mm x6<br>M3x16mm x10 |
|  | Transducer holder |  | Tools:<br>Screwdriver<br>Pliers |
|  | Transducer | | |

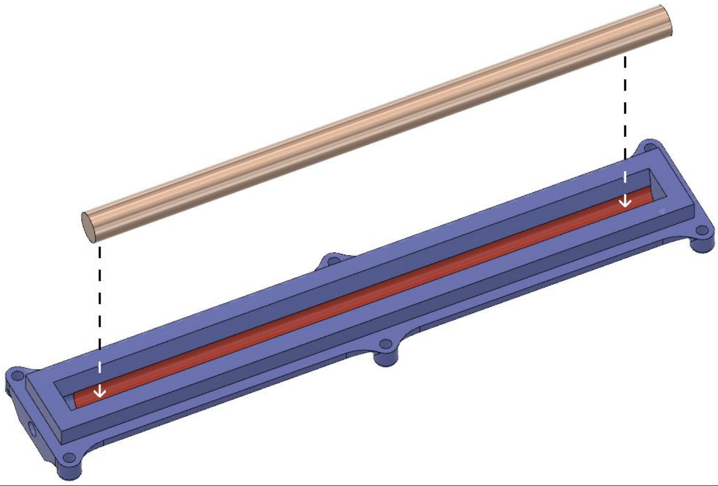
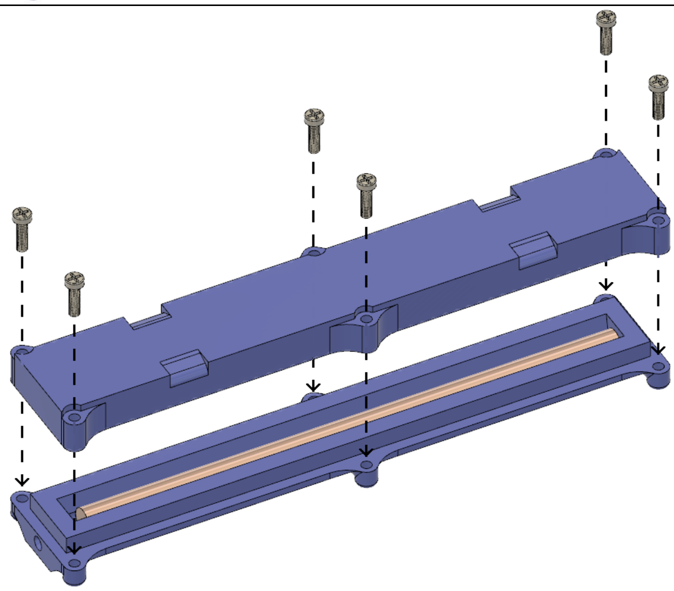
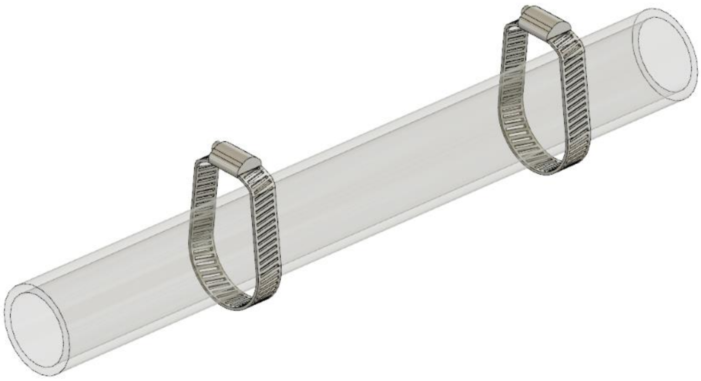
| Instructions: | |
|---|---|
|  | • Ensure pipe surface is clean and without scratches or other damage.<br><br>• Attach hose clamps loosely to the pipe. |
|  | • Place the clamp-on enclosure on the pipe, and adjust hose clamps to the clamp surfaces (red). |
|  | • Tighten hose clamps until clamp-on enclosure is securely fastened. |

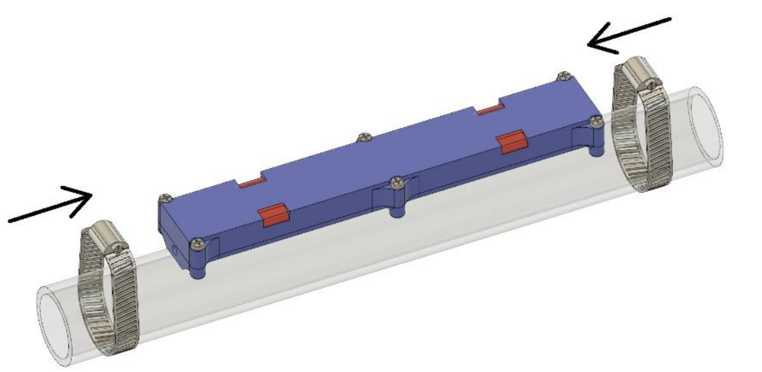
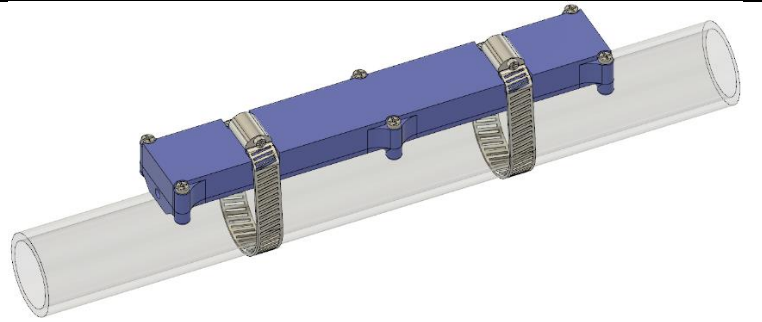
| Installation of transducer and lid (*Version 1 & 2*) | |
|---|---|
|  | • Place transducer in the transducer holder. |
|  | • Install the transducer holder (with the attached transducer) to the clamp-on enclosure.<br>  ○ *M3x10mm x6* |
|  | • Close the clamp-on enclosure by installing the lid.<br>  ○ *M3x16mm x10* |

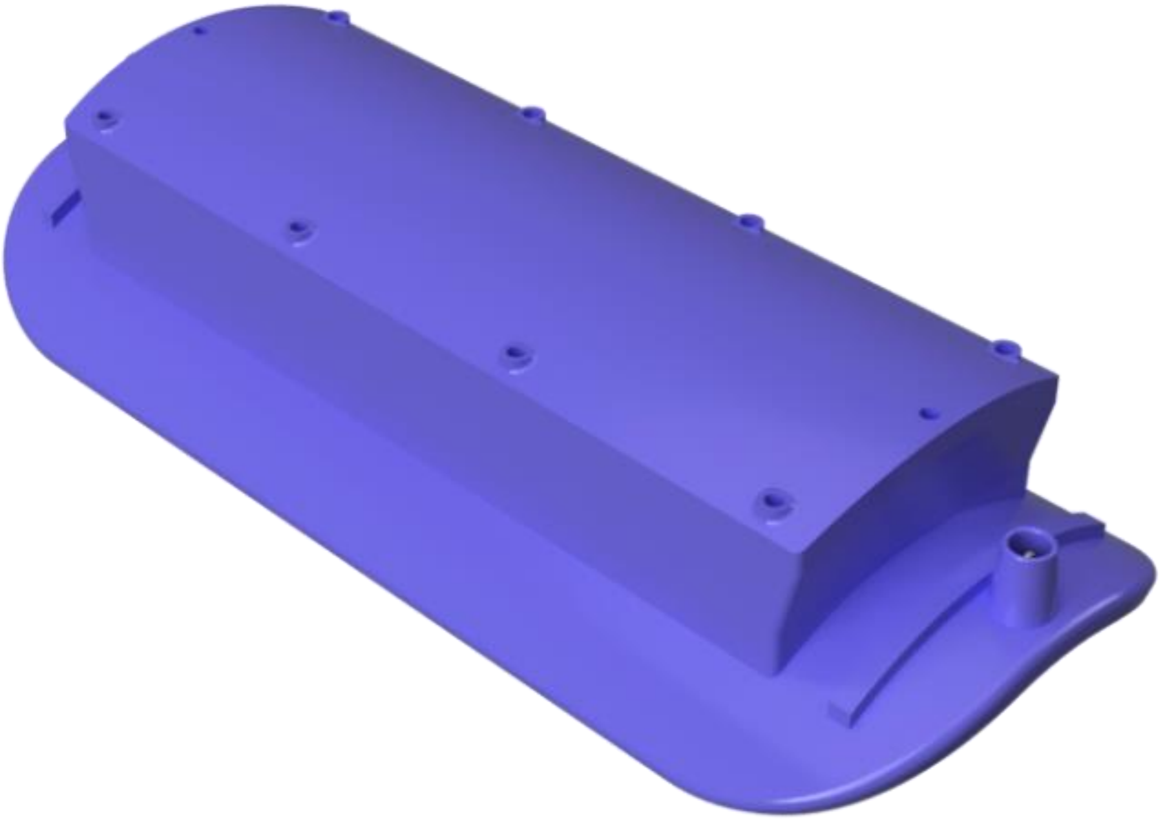
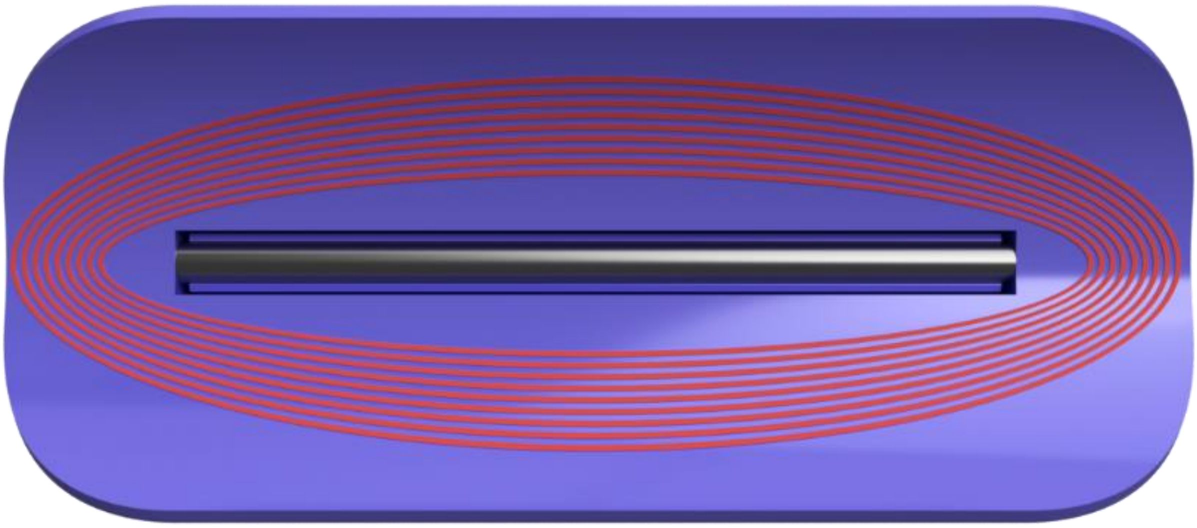
# Installation of clamp-on on pipe (*Version 3*)

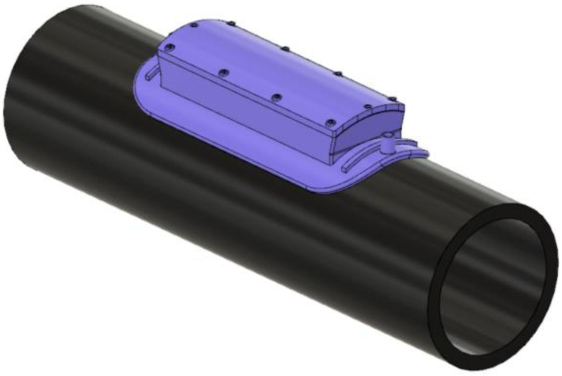
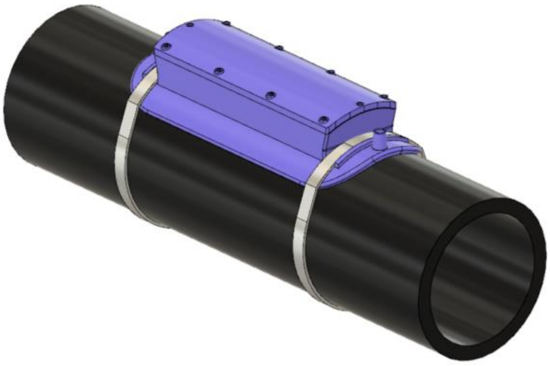
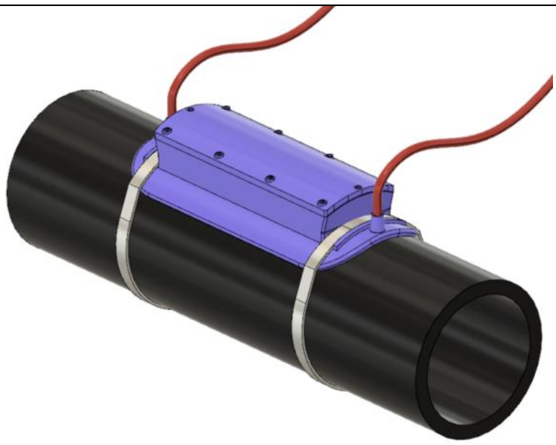
Item Check List:

| | | | |
|---|---|---|---|
|  | Top enclosure |  | Transducer |
|  | Top enclosure |  | M3x14mm  x6 |
|  | Hose clamp x2 |  | Tools:<br>Screwdriver<br>Pliers |

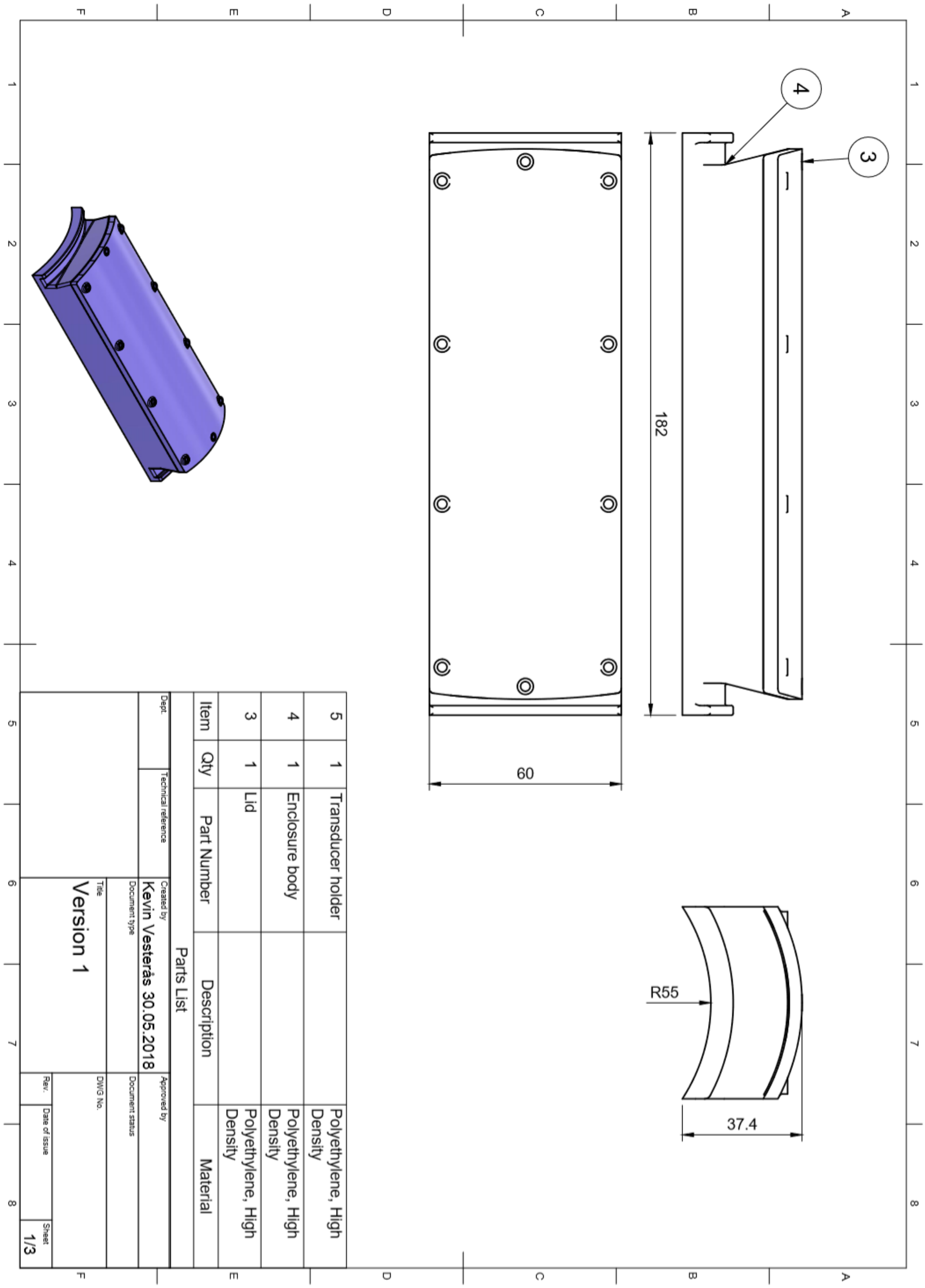
| Instructions: | |
|---|---|
|  | • Install the transducer into the slot (red) in the bottom enclosure.<br>(locks into place, apply force!) |
|  | • Install the top enclosure to the bottom enclosure.<br>○ *M3x14mm x6* |
|  | • Ensure pipe surface is clean and without scratches or other damage.<br><br>• Attach hose clamps loosely to the pipe. |

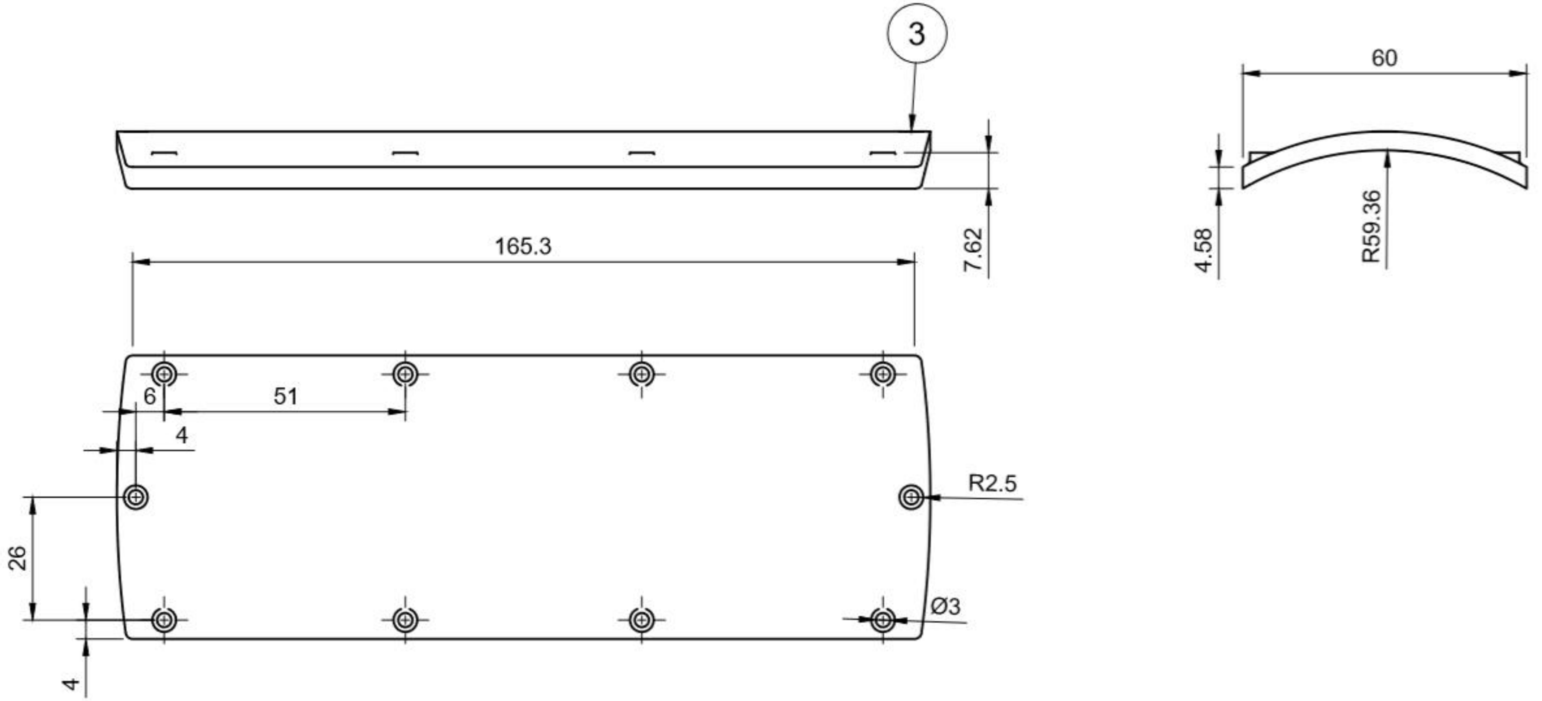
| | |
|---|---|
|  | • Place the clamp-on enclosure on the pipe, and adjust hose clamps to the clamp surfaces (red). |
|  | • Tighten hose clamps until clamp-on enclosure is securely fastened. |

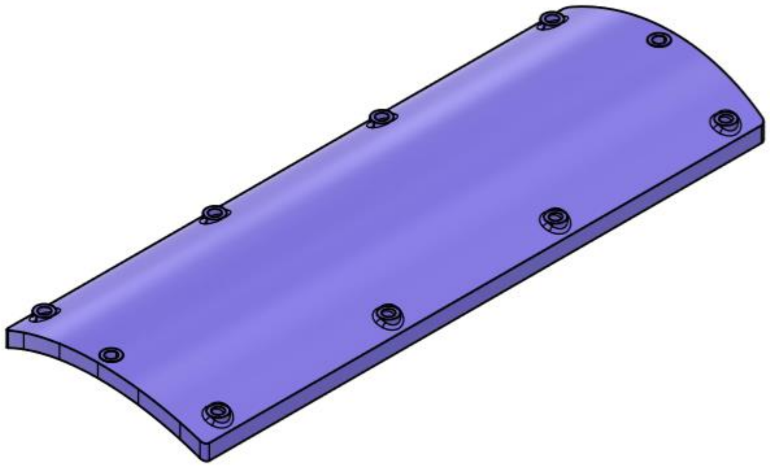
| Electrofusion welding model concept |
| --- |
|  |
|  |

| | |
|---|---|
|  | Place clamp-on enclosure on pipe. |
|  | Fasten enclosure with hose clamps. |
|  | Weld the enclosure to the pipe as instructed. |
|  | Enclosure and pipe is now one part |

# Appendix C: Technical drawings



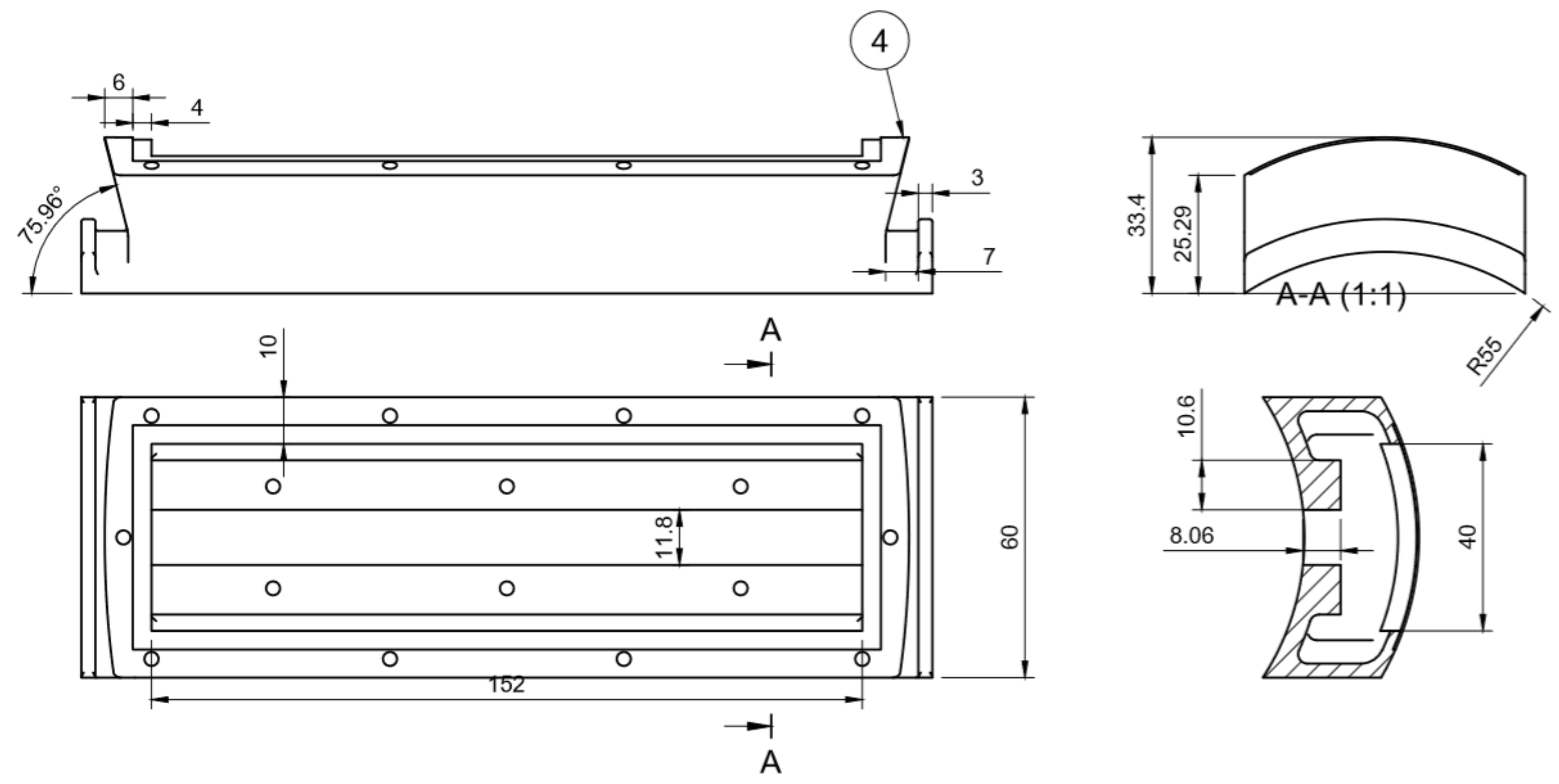


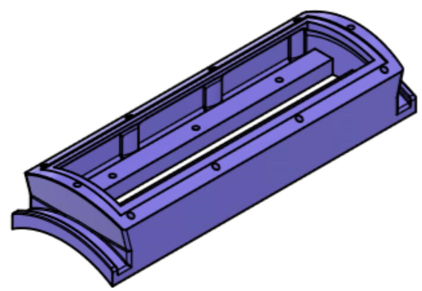



| Item | Qty | Part Number | Description | Material |
|---|---|---|---|---|
| 3 | 1 | Lid | | Polyethylene, High Density |

**Parts List**

| Dept. | Technical reference | Created by | Approved by |
|---|---|---|---|
| | | Kevin Vesterås 30.05.2018 | |
| | | Document type | Document status |
| | | Title: Version 1 Lid | DWG No. |
| | | | Rev. / Date of issue / Sheet 2/3 |



| 4 | 1 | Enclosure body | | Polyethylene, High Density |
|---|---|---|---|---|
| Item | Qty | Part Number | Description | Material |

**Parts List**

| | | | |
|---|---|---|---|
| Dept. | Technical reference | Created by<br>Kevin Vesterås 30.05.2018 | Approved by |
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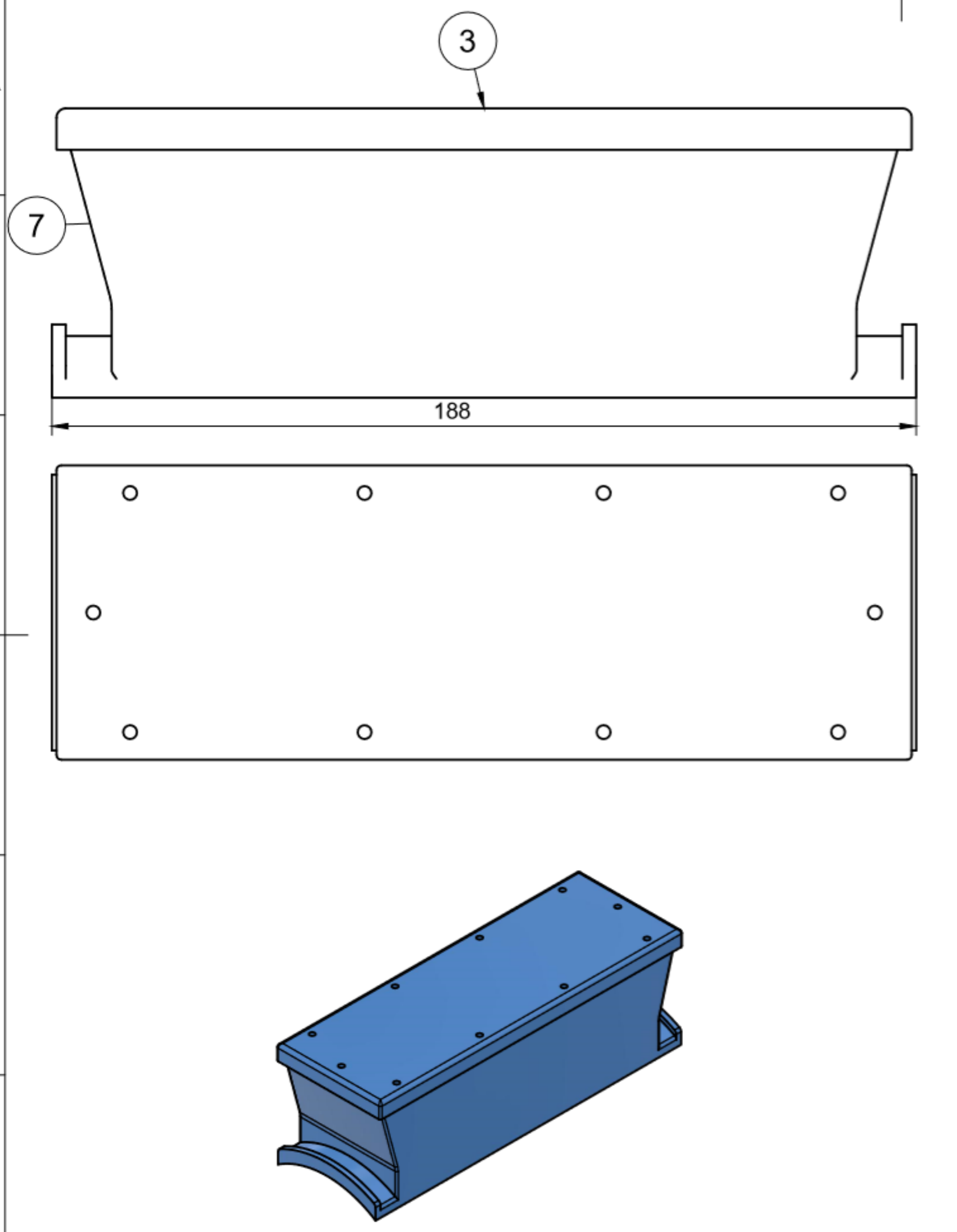
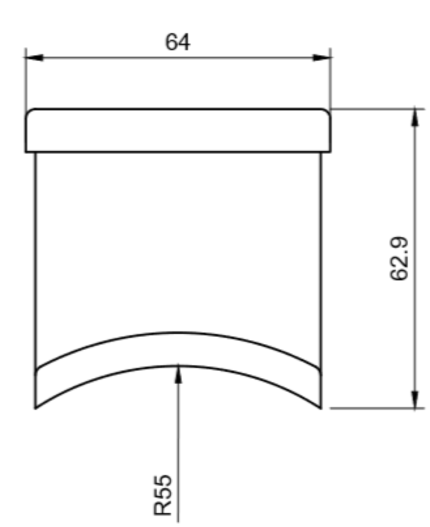
| | | | Rev. / Date of issue / Sheet 3/3 |




| Item | Qty | Part Number | Description | Material |
| --- | --- | --- | --- | --- |
| 7 | 1 | Enclosure body | | Polyethylene, High Density |
| 4 | 1 | Transducer holder | | Polyethylene, High Density |
| 3 | 1 | Lid | | Polyethylene, High Density |

Parts List

| Dept. | Technical reference | Created by | Approved by |
| --- | --- | --- | --- |
| | | Kevin Vesterås 30.05.2018 | |

| | | |
| --- | --- | --- |
| Document type | Document status | |
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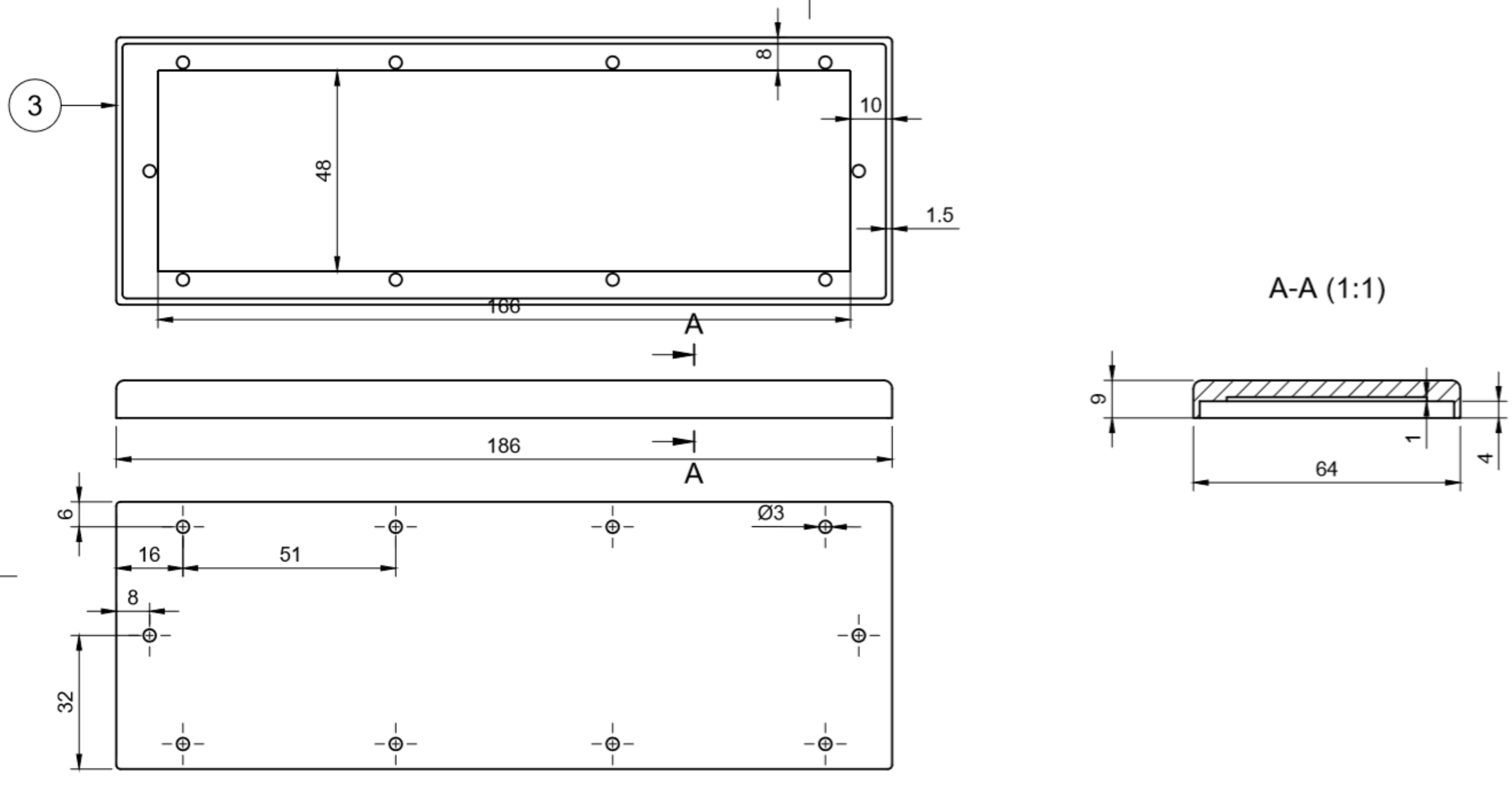
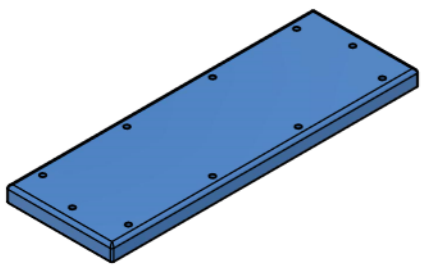
| Rev. | Date of issue | Sheet: 1/3 |



| 3 | 1 | Lid | | Polyethylene, High Density |
|---|---|---|---|---|
| Item | Qty | Part Number | Description | Material |

Parts List

| Dept. | Technical reference | Created by | Approved by |
|---|---|---|---|
| | | Kevin Vesterås 30.05.2018 | |
| | | Document type | Document status |
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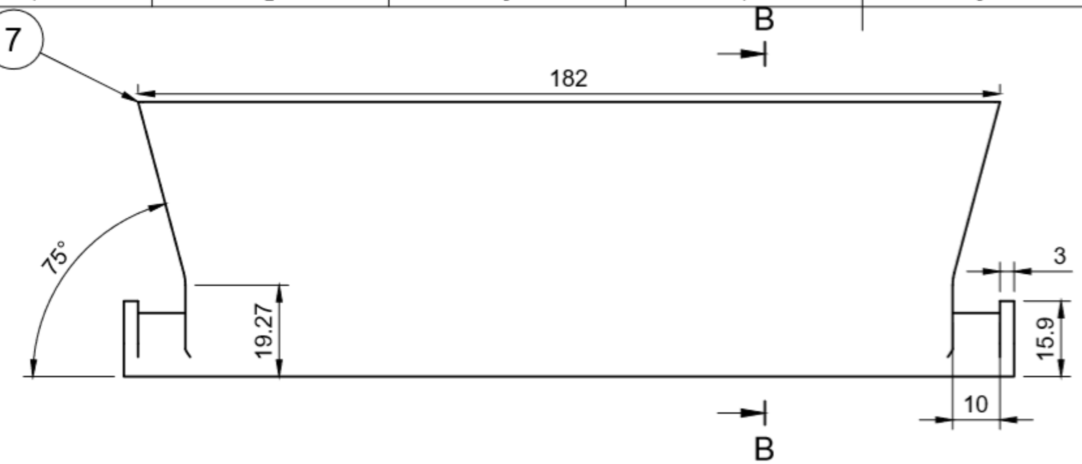
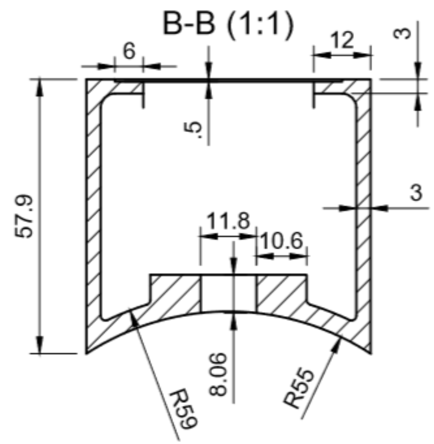
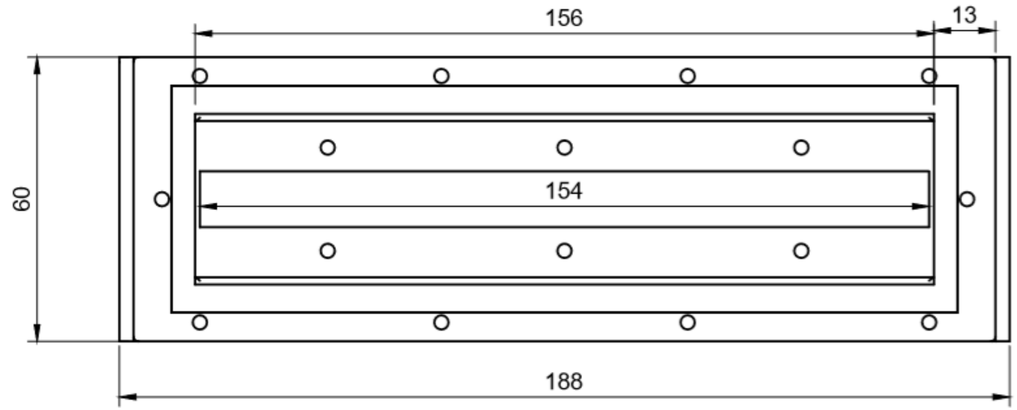
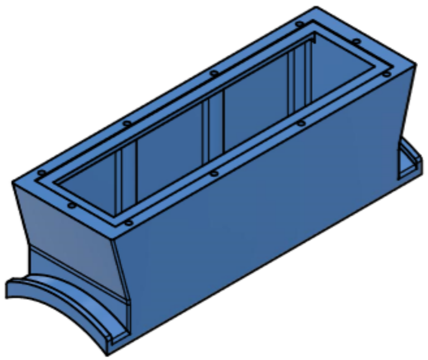
| | | | Rev. / Date of issue / Sheet 2/3 |



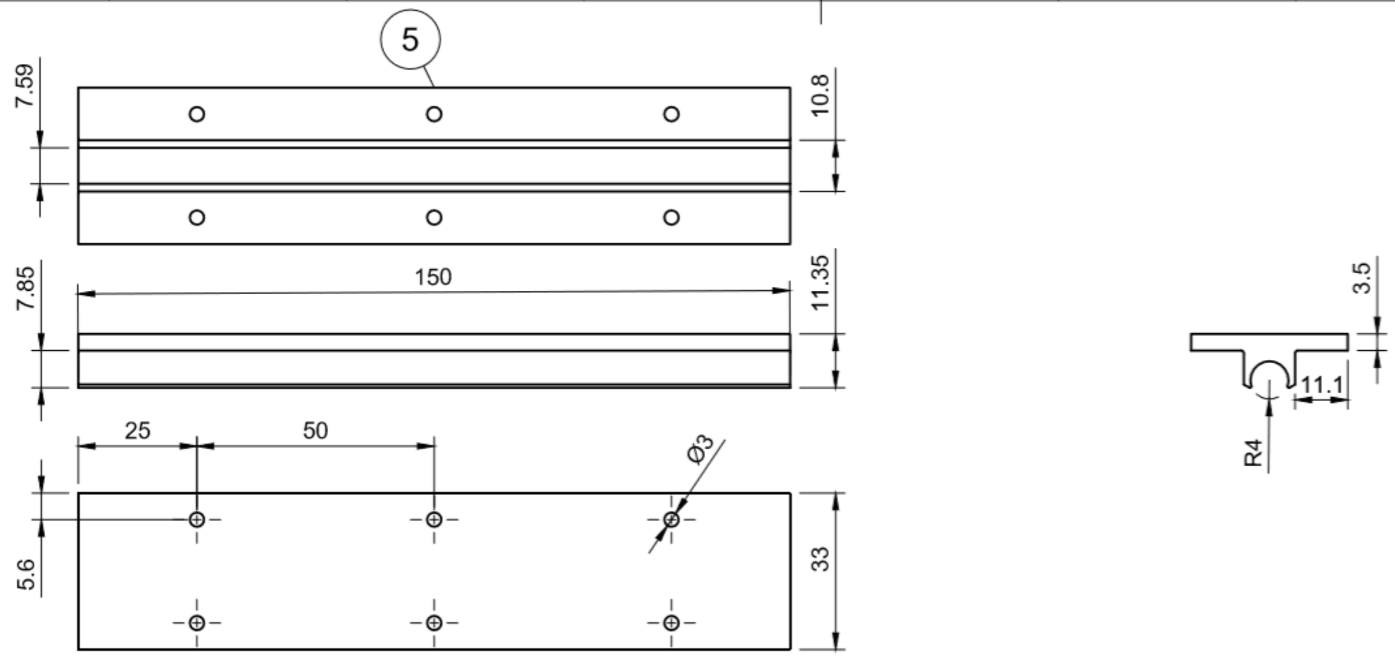



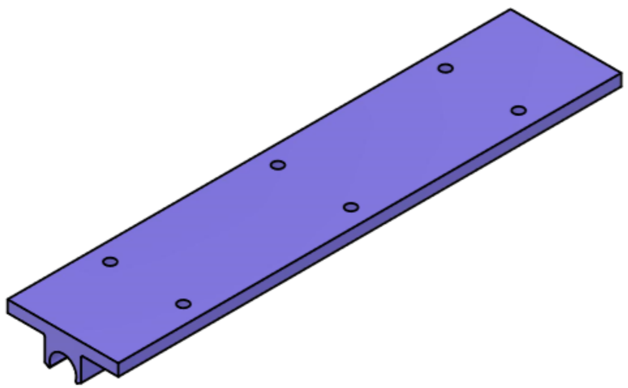



| Item | Qty | Part Number | Description | Material |
|---|---|---|---|---|
| 7 | 1 | Enclosure body | | Polyethylene, High Density |

| Parts List | | | |
|---|---|---|---|
| Dept. | Technical reference | Created by<br>Kevin Vesterås 30.05.2018 | Approved by |
| | | Document type | Document status |
| | | Title<br>Version 2<br>Enclosure body | DWG No. |
| | | | Rev. / Date of issue / Sheet<br>3/3 |

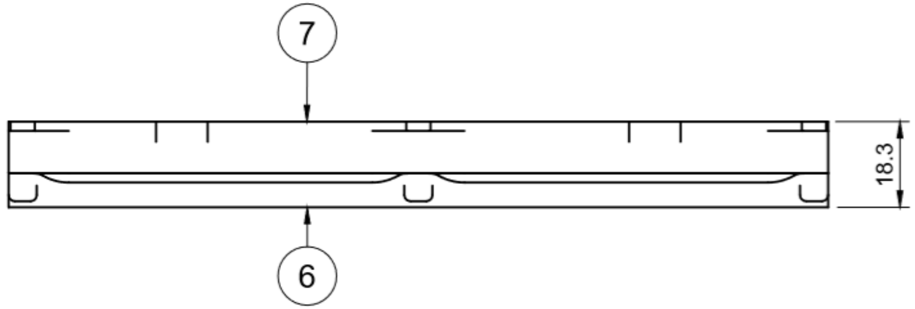


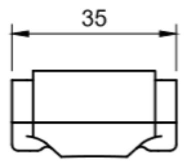



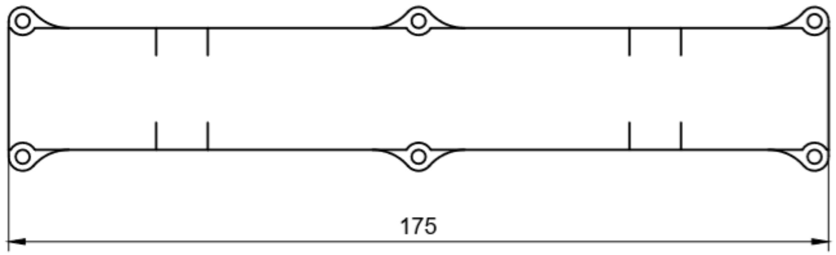
| | | | | |
|---|---|---|---|---|
| 5 | 1 | Transducer holder | | Polyethylene, High Density |
| Item | Qty | Part Number | Description | Material |

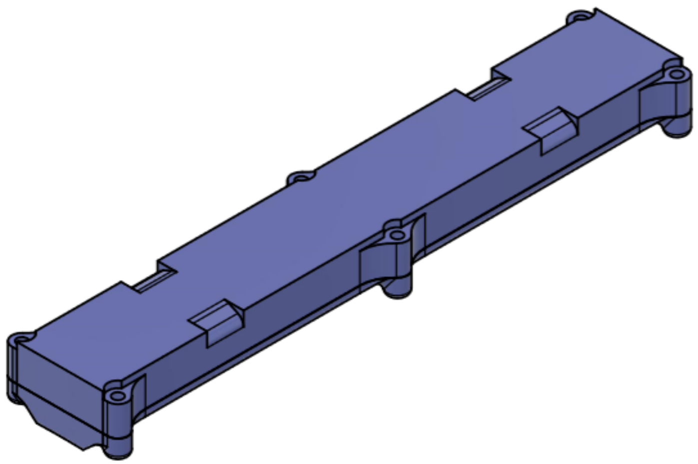
Parts List

| | | | |
|---|---|---|---|
| Dept. | Technical reference | Created by<br>Kevin Vesterås 30.05.2018 | Approved by |
| | | Document type | Document status |
| | | Title<br>Transducer holder | DWG No. |
| | | | Rev. / Date of issue / Sheet 1/1 |



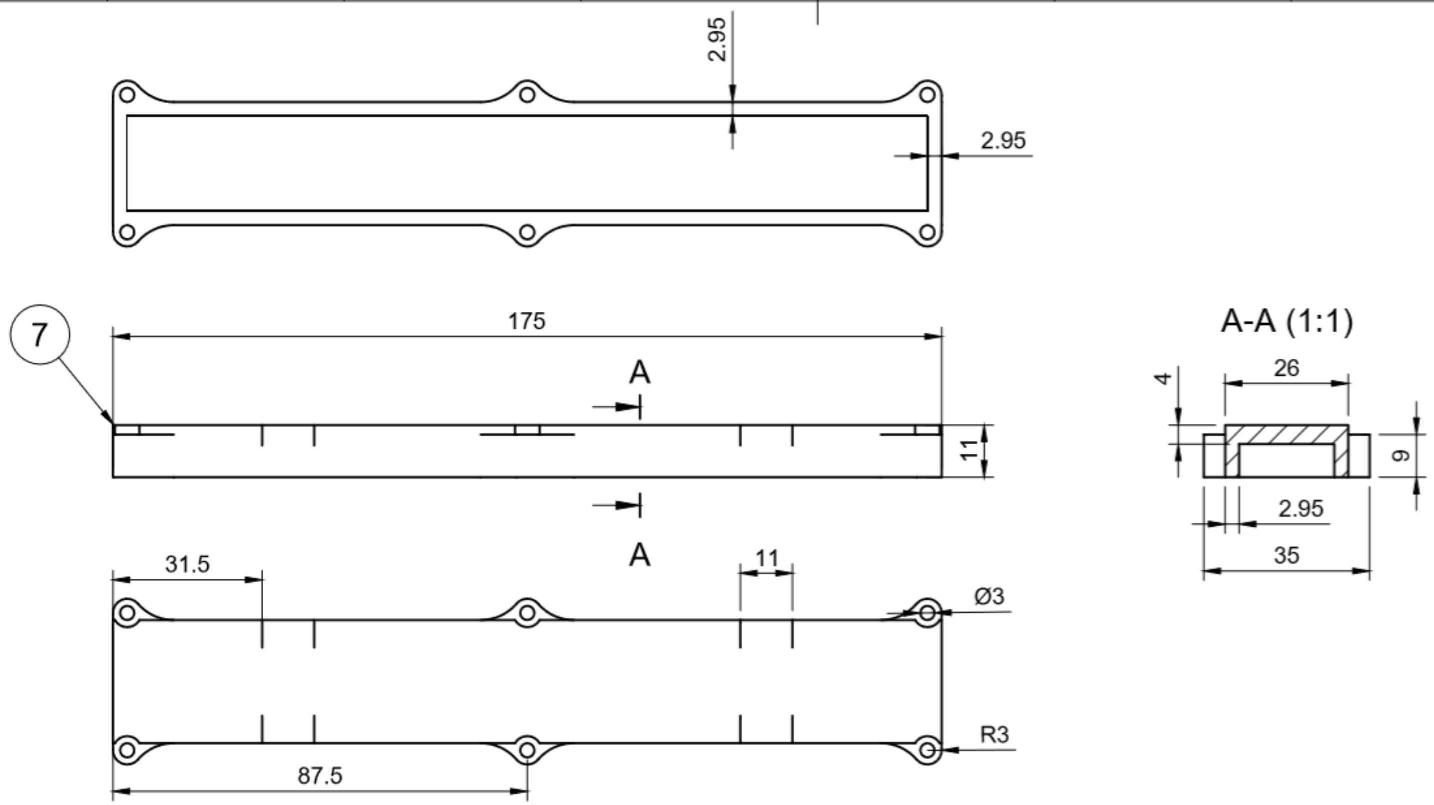



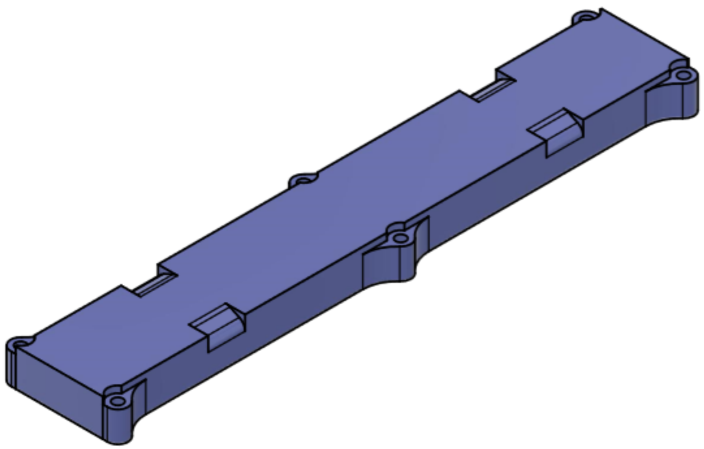



| Item | Qty | Part Number | Description | Material |
|---|---|---|---|---|
| 7 | 1 | Toplid | | Polyethylene, High Density |
| 6 | 1 | Bottomlid | | Polyethylene, High Density |

Parts List

| Dept. | Technical reference | Created by | Approved by |
|---|---|---|---|
| REALTEK | | Kevin Vesterås 30.05.2018 | |
| | | Document type | Document status |
| | | Title: Version 3 | DWG No. |
| | | | Rev. / Date of issue / Sheet 1/3 |

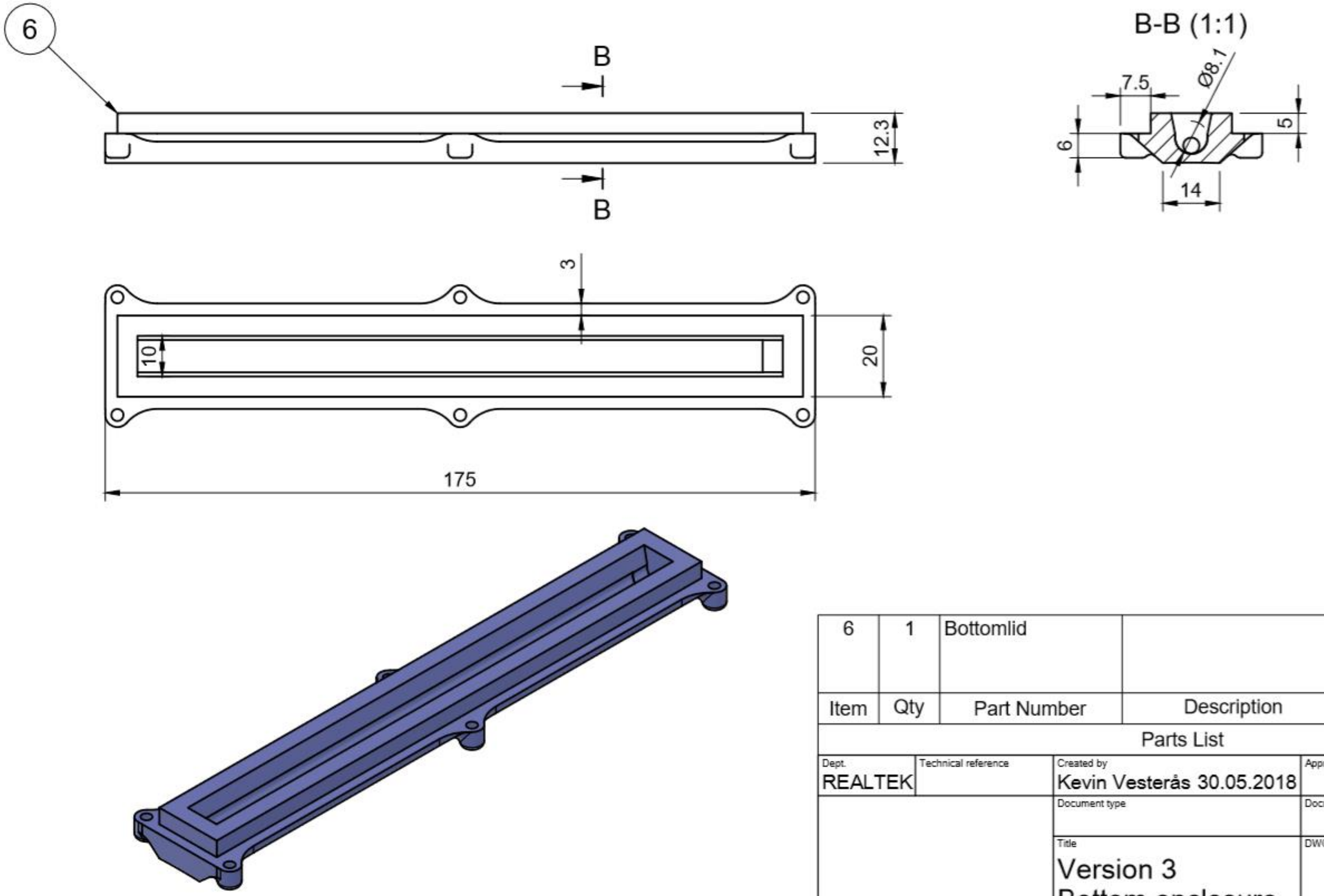


| Item | Qty | Part Number | Description | Material |
|---|---|---|---|---|
| 7 | 1 | Toplid | | Polyethylene, High Density |

Parts List

| | | | |
|---|---|---|---|
| Dept. REALTEK | Technical reference | Created by Kevin Vesterås 30.05.2018 | Approved by |
| | | Document type | Document status |
| | | Title Version 3 Top enclosure | DWG No. |
| | | | Rev. / Date of issue / Sheet 2/3 |




| Item | Qty | Part Number | Description | Material |
|---|---|---|---|---|
| 6 | 1 | Bottomlid | | Polyethylene, High Density |

Parts List

| Dept. | Technical reference | Created by | Approved by |
|---|---|---|---|
| REALTEK | | Kevin Vesterås 30.05.2018 | |
| | | Document type | Document status |
| | | Title: Version 3 Bottom enclosure | DWG No. |
| | | | Rev. / Date of issue / Sheet: 3/3 |

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