NTNU – Trondheim
Norwegian University of
Science and Technology

Next Generation Submerged Pressure Transmitter

Product Development for Kongsberg Maritime

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Master of Science in Mechanical Engineering
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ASSIGNMENT DESCRIPTION

NTNU
Det skapende universitet

MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

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Institutt **Institutt for produktutvikling og materialer**	
Studieprogram **Produktutvikling og produksjon**	Studieretning **Materialer**

3. Masteroppgave

Oppstartsdato **14. jan 2015**	Innleveringsfrist **10. jun 2015**
Oppgavens (foreløpige) tittel **Next Generation Submerged Pressure Transmitter**	
Oppgavetekst/Problembeskrivelse The projects task is to develop and design the next generation KM pressure sensor, based on the GT403. Work should encompass the following dimensions: 1. Design and shape 2. Material 3. Joining 4. Sensing pressure element 5. External connector 6. PCB Additional topics may be Production (Assembly, Easy and stable operations (step by step)), Installation (User friendly and intuitive, Safe and maintenance free), and Operation (Maintenance, Easy replacement).	
Hovedveileder ved institutt **Professor Martin Steinert**	Medveileder(e) ved institutt
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KONGSBERG

ABSTRACT

This master thesis was carried out the spring of 2015 at NTNU, in collaboration with the Norwegian company Kongsberg Maritime AS (KM) Trondheim. It aims to develop the next generation pressure transmitter for water level measurement in ballast tanks.

Today KM delivers the GT403 pressure transmitter that appears to face some challenges, causing a short lifetime. Through research and testing; this project confirms that the main problem is deposition of calcium on the housing, the membrane and in the gap between them, causing wrong signals. The second biggest issue is leakage through the joining points on the transmitter, causing damage to the electronics.

The test setup consisted of a basin filled with 600 L seawater added with calcium hypochlorite (in accordance with the industry requirements), a powered zinc anode and an immersion heater to speed up the process.

In addition to be a validation test to confirm the main cause of failed transmitters, the basin was used as a test environment for the prototypes of the new generation transmitters.

For the new generation pressure transmitter, metal was the only viable choice and titanium was chosen out of simplicity in terms of being able to reuse some existing parts. To make the transition between the sensor element and the housing tight and waterproof, laser beam welding was introduced; hence new weldable pressure sensor elements were bought. A new housing was made from scratch to make the new sensor element fit. The lowermost part, including the membrane, was Parylene coated. When the transmitters were assembled, by laser welding the housing part, they were tested and calibrated. Nine out of ten transmitters passed the test with an accuracy of 0.5 % over the whole temperature and pressure span.

Seven of the new developed transmitter and five of the existing GT403 transmitters were submerged in the aforementioned basin for 26 days and the signals were logged. All transmitters were grounded (as they are today), except one just to see if complete isolation had any effect.

The test was successfully conducted and the new prototypes were waterproof and served as fully operational pressure transmitters.

The result from the test was that the deposition happened to the grounded transmitters as expected. Coated areas seemed to withstand, but in coating-free pinholes (caused by damage) the deposition took place. Furthermore, the isolated transmitter did not experience any deposition at all.

SAMMENDRAG

Denne masteroppgaven ble gjennomført våren 2015 ved NTNU i samarbeid med Kongsberg Maritime AS (KM) her i Trondheim. Målet er å utvikle neste generasjons trykkføler for vannivå måling i ballasttanker.

I dag leverer KM en GT403 trykkføler som har noen utfordringer som fører til kort levetid. Gjennom litteraturstudie og testing bekrefter dette prosjektet at hovedproblemet er avsetninger av kalsium på sensorhuset, membranet og i mellomrommet mellom dem. Det nest største problemet er lekkasje gjennom overganger på sensorhuset som forårsaker skade på elektronikken.

Testoppsettet bestod av et 600 L basseng fylt med sjøvann tilsatt kalsium hypokloritt (i samsvar med industrikrav), en strømsatt sinkanode og en varmekolbe for å fremskynde prosessen.

I tillegg til å være en validerings test for å bekrefte hovedårsaken til feile sensorer, ble bassenget brukt som et testmiljø for noen av prototypene av den nye generasjon sensorer.

For den nye generasjonen trykkfølere ble metall valgt og titan ble valgt av enkelhet for å kunne gjenbruke noen eksisterende deler. For å gjøre overgangen mellom elementet og huset vanntett, ble laserstrålesveising brukt; dermed ble nye sveisbare elementer kjøpt. Et nytt sensorhus ble laget til for at det nye elementet skulle passe. Det ble besluttet at den nederste delen, inkludert membran, skulle Parylene belegges. Da trykkfølerende var ferdidmontert, ved å sveise sammen husdelene, ble de testet og kalibrert. Ni av ti følere besto testen med en nøyaktighet på minst 0,5 % over hele temperatur- og trykkområdet

Sju av de nye utviklede trykkfølerene og fem av de eksisterende GT403 sensorene ble senket ned i det nevnte bassenget i 26 dager og signalene ble loggført. Alle trykkfølere ble jordet (som de er i dag), bortsett fra èn for å se om fullstendig isolasjon hadde noen effekt.

Testen var vellykket og de nye prototypene opplevde ingen lekkasje og fungerte faktisk som fullt operative trykksensorer.

Resultatet fra testen var at kalsiumavsettingen skjedde på de jordede sensorer, som forventet. Parylenbelagte områder stod i mot, men i beleggfrie hull (forårsaket av skade) skjedde avsettingen. Den isolerte sensoren hadde ikke noen synlige avsetning i det hele tatt.

PREFACE

This document constitutes my work on the master project in Mechanical Engineering at the Department of Engineering Design and Materials at the Norwegian University of Science and Technology (NTNU). I carried out the assignment the spring of 2015 in collaboration with Kongsberg Maritime (KM) Trondheim and my supervisor Dr. Martin Steinert and it continues the work done in my pre-master project.

I would like to thank my supervisor at NTNU, Dr. Martin Steinert, for turning the initial premaster idea into a more interesting "fuzzy front end"-project and for good ideas through the whole process.

At Kongsberg Maritime (KM) Trondheim, I would like to thank John Olav Skogås for the initial meeting where he connected me with the relevant people at KM, and for facilitating a decent workspace for me and covering travel costs. I would like to thank my main supervisor at Kongsberg Maritime, Rune Harald Hestmo, for providing all information necessary and for his time and support. Furthermore, I would like to thank Terje Stamnes at the workshop for helping me making parts and for teaching me how to laser weld.

I would like to thank Nora Foshaug for the main of thorough proofreading.

At last I would also like to thank the rest of the people at KM, fellow students, friends and family for numerous interesting conversations and discussions that has been valuable to the project, and for proofreading.

Maria Foshaug

Maria Nissrin Foshaug

Norway, Trondheim, 05.06.2015

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ABBREVIATIONS

A	Ampere
Abs.	Absolute pressure
Atm.	Atmospherically pressure
BSE	Back-scattered electrons
C	Celsius
CAD	Computer Aided Design
DAQ	Data Acquisition
Eq.	Equation
FRO	Full Range Output
HEZ	Heat Effected Zones
IPM	Department of Engineering Design and Materials
K	Kelvin
KM	Kongsberg Maritime
KOG	Kongsberg Group
KV	Kystvakten (The Norwegian Coast Guard)
L	Liter
Laser	Light Amplification by Stimulated Emission of Radiation
LBW	Laser Beam Welding
m	Meter
mA	Milliampere
mm	Millimetre
µ	Micro
µm	Micrometer, also known as micron
NTNU	Norwegian University of Science and Technology
PCB	Printed Circuit Board
ppt, ppm	Parts per thousand/million
PUR	Polyurethane
Rel.	Relative pressure
SEM	Structural Equation Modeling
UPS	Uninterruptible Power Sources
V	Volt

CHAPTER 1

1 INTRODUCTION

This chapter gives an introduction to both the project and the written report. It states the objective, explains the understanding of the problem with its limitations and presents the research methods. Furthermore, it gives the reader some information regarding the structure and formalities of the written report.

1.1 Problem Description

Ships have always aimed to operate safely at sea, hence good stability in water and the ability to correct any changes in the ship's center of mass is crucial. Ballast is used to fulfill this by providing stability and allowing shifting in the ship's center of mass when needed. Back in time, ships were loaded with solid ballast like sand and rocks, but today seawater is commonly used, as it is very accessible and easily added and removed. To distribute the ballast load the seawater splits into small compartments in the ship's hull known as ballast tanks. Each tank is equipped with an inlet, an outlet and measuring devices to report on water content. A commonly used device to report on water content is a pressure transmitter, due to pressures linearity with depth.

This master project was carried out in collaboration with the Norwegian company Kongsberg Maritime AS (KM) Trondheim and my supervisor Dr. Martin Steinert at NTNU. It is a product development project of a new generation pressure transmitter for water level measurement in ballast tanks, and it is a continuation of the pre master project.

The Norwegian company Kongsberg Maritime AS has established a strong position in this industry. They deliver a broad set of systems suitable for dynamic positioning, navigation, marine automation, safety management and cargo handling, just to mention a few. Within their product portfolio is the GT403 Pressure Transmitter, a transmitter intended for submerged installation in ballast and service tanks. It measures pressure, which has a linear relation to the water level. Knowing the shape of the tank, the water level and the water density, the operators are able to calculate the volume and the weights of the water inside each tank at all times and do adjustments by adding or removing water.

The GT403 pressure transmitter that KM delivers today appears to face some challenges due to the harsh environment present in the ballast tanks. **The main problem is presumably due to fouling (deposition).** The transmitters are made in titanium and acts as cathodes receiving particles that form in layers and over time clogs the area in front of the membrane, causing wrong signals over time. **The second presumably issue is leakage through the joining points on the transmitter.** The housing parts are kept together by threads, glue and O-rings that probably are not tight enough, causing damage to the electronics.

KM, as providers of innovative and reliable solutions, would like to reconsider everything from manufacturing and material selection to design and operation. The main focus will be on production and joining, material selection, shape and design. Furthermore, sensing sensor element, external connector and PCBs will be evaluated as well.

1.1.1 Objective

This thesis aim to make a prototype of the new generation pressure transmitter and give advice for further development. To make the already stated objective more clearly to the reader, it is divided into a list of subtasks that this project assignment will answer:

1. Give a brief description of ballasting systems, their main functions, and the need for pressure transmitters in these tanks.
2. Give an overview of the industry with its requirements and today's pressure transmitter.
3. Present the results from, and the research done in, the premaster project including customer need and main issues.
4. Give a summary of earlier test reports regarding failed transmitters due to fouling
5. Make material selection, and consider manufacturing, joining and treatment
6. Evaluate the pressure sensing sensor element and the PCBs
7. Set up a test where some of the putative issues may be (re)tested together with some new solutions as well
8. Look at shape/design, the connection to external cable and installation in the tank.
9. Identify and discuss challenges in relation to the suggested solution, for which needs further research.

1.1.2 Scope and Limitations

This report the only focuses on the submerged application in the ballast tanks on cargo vessels, referred to as *ships*.

Ballast water discharge control is considered as an important environmental issue related to pollution and the spread of species in the oceans, but will not be discussed in this report. To read more, check out The Biomimicry Challenge (Hladis, Frederick, Lee, & Beckman, 2014).

A requirement for any new transmitter that is developed is that the solution is applicable to new ships, as well as existing ships, it should not depend on reconstructing neither the ballast tanks nor the ship.

Furthermore, this project will at all times consider the limitations laying in KMs facility, as well as their available resources, and all decisions will be made in collaboration with KM to ensure the execution capability of the project and the viability of the new product.

1.2 Purpose and Motivation

This master thesis addresses the assumed major causes for failed and returned transmitters based on earlier experiments and reports. Thus is an important part of this project to confirm these assumptions by recreating the test to either reject the results or strengthen their validity. Furthermore, the project intends to find a solution that addresses these issues and test it.

The goal is to end up with a new and better transmitter and give KM an as good as possible foundation for further work and to present information they do not normally seek.

In terms of personal motivation this task gives an unique opportunity to combine theory and practice, in a real and meaningful work environment. For yours truly, there is a "reality check" and an opportunity to build bridges between industry and the academia, expand personal networks and to be part of a larger technology company in Norway.

With an academic background in product development and strong commitment to rapid prototyping and the “fuzzy front end” method, this master thesis with its early stage development and few limitations was an obvious choice.

1.3 Literature Survey and Research Method

This master thesis has foothold in information gathered from KM's customers and field engineers during the pre-master project. The recently completed pre master project will be used to put this work into context and constitute the decision making. The pre master is based on learnings from KM as well as a customer survey and some in-depth interviews and it highlights some important areas and factors relevant in this regard.

Furthermore, reviewing earlier studies relevant to the current field is standard procedure during research, as this serves to put the project work into context of a larger discipline. For this particular project the most relevant and interesting literature to review was the internal reports written by KM from earlier experiments to avoid pitfalls and get an overview of what had been done before and which people to contact.

In addition to the internal research some external research and field work helps expanding the view and gives a reality check. Therefore, some travels were conducted to achieve this in-depth knowledge. Getting some firsthand experience was key to understand the core of the problem, furthermore speaking to extensive experienced personnel out in the field gave a profound understanding. This part raises the validity and creates credibility for the end product, and the decision made on the way.

This means that the learning outcomes from this thesis will be based on both theory from earlier reports and physical, hands-on experiments.

1.4 Research Questions

Research Questions

For the experiment that will be presented in “Chapter 6 Testing” two questions is asked to sharpen the study and to limit the scope of the master thesis:

RQ1: Does addition of calcium hypochlorite cause deposition on submerged transmitters?

This question is asked to confirm assumptions and results from previous tests, as well as experiences from the field.

Hypothesis: The hypothesis is that by adding calcium hypochlorite there will be deposition.

RQ2: How will the addition of a thin layer of Parylene coating affect the problems due to fouling?

The background for this question is KM’s earlier attempts with Parylene that seems to have had a good effect, but without any good experimental foundation or documentation.

Hypothesis: The hypothesis is that by coating the most critical parts of the transmitter (membrane in front) with Parylene there will be a protective and chemically passive surface layer that prevents deposition.

Additional question: Does it make any changes to the fouling problem to ground or not ground the transmitters?

Due to learnings from external sources (see “Chapter 4.4 Visiting External Partners”), isolating the transmitter (not grounding it) seems to have an positive impact

The assumption is that by not grounding the transmitter the usually closed circuit between the transmitter and the sacrificial anode (zinc) is broken. This will stop or reduce the transportation of ions and fouling problem will be solved.

1.5 Structure of the Report

Prior to the actual report, there are lists regarding this paper's structure, figures and tables as well as an abstract of the report and some abbreviations.

Then the first part contains two chapters, whereas the first introduces the master thesis and the second puts it in a context by presenting the industry, the main competitor, how ballast systems work, the need of pressure transmitters in these tanks and a technical review of today's GT403.

The second part of this thesis contains all theory that is relevant to get a profound understanding for both the problem and the solution. It presents equations, information and describes techniques that are of interest.

The third and most important part of this report contains the research done in the project, the development phase and the test setup.

The last part of the report presents the results from the test and explains a solution to the fouling problem. Furthermore, it discusses the results, uncertainties, sources of errors, validity and what further work that is necessary, and concludes the project.

Following the report content, there is a list of references associated with the written report and appendix.

1.6 List of Formulations and Definitions

Customers	All the potential customers in the market, and not only those existing.
Deposition	Layer formation of substances on to a surface.
Fouling	See "*Deposition*"
The Paper	See *"The Report".*
The Report	This written paper. The documentation of the work done in the project.
The Project	The actual work done prior and during the time of writing this paper.
The Thesis	See *"The Project".*
Transmitter	The finished pressure measuring product (sensor element and housing)

See the ship and nautical terminology in "Appendix A: Ship and Nautical Terminology"

CHAPTER 2

2 CONTEXT

This chapter gives the reader the most important information regarding the context to better understand this project. It gives an overview of the industry with its regulative requirements. It continues with a brief description of ballast systems, their main functions, and the need for pressure transmitters in these tanks. It also presents and explains the existing GT403 pressure transmitter and the main competing solution.

2.1 The Industry

Ship construction (shipyards) and *Maritime equipment* (suppliers to the shipyard industry) is the two sub-sectors that constitute the European shipbuilding industry today. KM operates in the second of the aforementioned, as a huge shipyard supplier.

The marine equipment sector has had a significantly growth and is estimated to include somewhere between 5000 and 9000 companies worldwide (ECORYS, 2009) and the total market value was estimated at EURO 57 billion in 2005 (ECORYS, 2009).

The maritime equipment industry in Norway has also had a rapid growth, and the Norwegian ship's equipment manufacturers made sales valued at more than NOK 20 billion in 2012 (Industri, 2014). Interestingly, the industry is dominated by four individual companies: Rolls Royce, Kongsberg Maritime, ABB and Frank Mohn, who are collectively responsible for 40 % of the wealth creation for maritime equipment in 2012 (Industri, 2014).

Figure 1: The cargo ship Rena outside Tauranga, New Zealand (Renaissan Ceronin, 2011)

To read more about the industry see "Appendix B: The Industry".

The Chain

Probably more interesting than looking at the big numbers in the industry, and definitely more relevant in this respect, is the value chain of which KM operates in. The figure "Industry Chain" shows the customers, suppliers, users and other stakeholders in relation to each other.

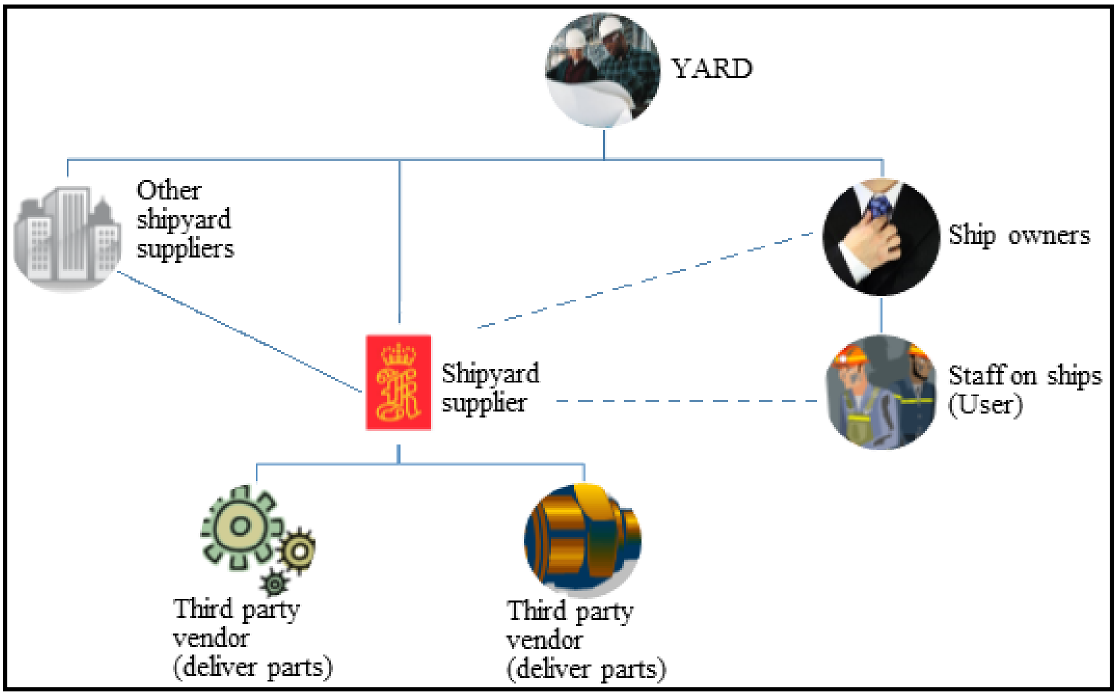


Figure 2: Industry chain (Foshaug, 2014)

It is a simplified representation of the industry chain centered on KM. The Yards buy projects from shipyard suppliers, such as KM, and sell fully built ships to ship owners.

KM mainly sells their products directly to shipyards or to other shipyard suppliers, which covers the "building new ship" part of KM's market. In addition, they sell spare parts and/or services to ship owners or directly to operators (staff) on ships.

2.1.1 Regulatory and Technical Requirements in the Industry

Ex Product Certification

International agreements under the Safety of Life At Sea (SOLAS) Convention requires cargo vessels and passenger ships to be constructed in a certain way to withstand some particular kinds of damage (SOLAS, International Maritime Organization, 1974); this includes all external products that are brought on board as well. To know if the vessel or the products are safe enough there are some requirements designed to classify and certificate.

The purpose of the Ex Product Certificates is to give products the necessary approval to operate or exist in hazardous areas. The overall methods of protection are defined as followed in accordance to Presafes' ATEX standard (Presafe, u.d.).

The classification consists of the letters *Ex* followed by a letter (*d, e, i, m, n, o, p* or *q*) that indicates the protection methods.

To certify a product, the probability of a hazardous atmosphere being present, called the 'zone' has to be considered. Products are designated according to categories to identify at what level of protection they have been assessed, in accordance to Presafes' ATEX standard (Presafe, u.d.). The categories and zones are *Zone 0*, *Zone 1* and *Zone 2*.

In addition to the letter code and the zone, the classification also depends on a temperature class going from T6 (85 °C) to T1 (450 °C).

To get the full overview read "Methods of explosion protection for electrical equipment" by Dietzelectric (Electric).

Appendix C gives a full overview, but for this master thesis the Ex *i* is the most relevant. Under the Ex *i* there exists two subsections, Ex *ia* and Ex *ib*. If two countable faults are considered and the device is still intrinsically safe as per the standard the marking given is Ex *ia* and may be used in any zone including zone 0. Ex *ib* considers just one fault and is good for zones 1 and 2.

IP Code, International Protection Marking

The IP Code, International Protection Marking or sometimes interpreted as Ingress Protection Marking, classifies and rates the degree of protection provided against intrusion (body parts such as hands and fingers), dust, accidental contact, and water by mechanical casings and electrical enclosures (Commission, 2004).

The IP Code is given as the letters *IP* followed by two numbers, for instance IP67. The first number (0-6) indicates the level of protection that the enclosure provides against access to hazardous parts and the ingress of solid foreign objects (Commission, 2004).

The second number (0-9) indicates the level of protection that the enclosure provides against harmful ingress of water (Commission, 2004).

The tables in “Appendix D: IP Code” gives a full overview, but for this project, the most important IP ratings are IP67 and IP68 defined below:

- IP67 - rated as "dust tight" and protected against immersion.
- IP68 - rated as "dust tight" and protected against complete, continuous submersion in water.

KM’s existing GT403 absolute Pressure Transmitter is certificated with the IP68 rating, while the GT402 atmospheric Pressure Transmitter is certificated with IP67.

2.2 Ballast Systems

As early as in 1849 a ballast tank system, to enable cargo vessels to pass over shoals in North American rivers, was patented by Abraham Lincoln. The concept has been invented and reinvented many times since then to serve a variety of purposes.

Today ballast system includes tanks, valves, pumps, pipes and sofware specified for sequential exchange of ballast water. The ballast system is so complex now that it can be divided into subsystems.

2.2.1 Ballast Tank (hardware)

To distribute the ballast weight, seawater splits into several compartments in the ship's hull known as ballast tanks. Both the number and size of these tanks varies a lot from ship to ship, and is determined during production based on the ship's main operations.

Usually the major ballast tanks are located along the sides, star board and port, to provide stability and prevent rolling. There are additional tanks placed in the fore and the aft of the ship to control the trim.

To control the water flow between individual tanks each tank is equipped with pumps and valves to transport water through inlets and outlets.

The piping system, with its respective pumps, constitutes a network and is gathered in the pump room of the ship.

2.2.2 Ballast Monitoring and Control System (hardware & software)

The full monitoring system consists of valve and pump control, level gauging in all ballast tanks, trim and list correction data and a dedicated monitoring and control system. In many cases the system offers a graphic presentation for monitoring and control of the sequential filling or deballasting processes.

Since all tanks are equipped with pressure transmitters to report on water content, there needs to be a control system handling the signals. The remote control system, consisting of a touch-screen control panel to operate the system, allows the operators to operate the ballast system either from the bridge or from a control room. The ballast control logic system translates the operator commands and the feedback from the valves and pumps into electric signals, activating the valve solenoids and ballast pumps (Moen, 2012).

2.2.3 Electrical and Hydraulic Power System (software)

The electric system usually consists of the main power system, the emergency backup generator and the Uninterruptible Power Sources (UPS). The main electric power system is continuously operating.

Electricity is used to power the ballast control stations, pumps, and the hydraulic power system. It is also a transporter of signals from and to all the valves.

In case of power outage the UPS will immediately provide emergency power to the ballast control stations and operator screens. Further, the emergency backup generator will be turned on automatically. The emergency backup generator provides a fraction of the main electric power, but enough power to operate the ballast system for a while.

The main hydraulic power generator and a hydraulic accumulator is what constitute the hydraulic power system. Hydraulic power is used to operate all the ballast system valves. In order to ensure consistent hydraulic pressure, the hydraulic power system is energized and pressurized continuously. In case of loss of electric power, or failure of the main hydraulic power generator, the hydraulic accumulator will automatically provide sufficient hydraulic pressure to operate the ballast valves for some time (Moen, 2012)

2.3 The Need for Pressure Transmitters

SOLAS Convention requires cargo vessels and passenger ships to be constructed so as to withstand certain kinds of damage (SOLAS, International Maritime Organization, 1974).

To use ballast water in an effective way to stabilize the ship relies on knowing amount of water in each tank, and this is where water level measurement is needed.

In addition to the ‘safe’ operation part, there is an ‘efficient’ operation aspect to it as well. If the level measurements are accurate enough, the ship’s position in the water (trim and list) can be adjusted so that the ship lies optimal in the water and uses as little fuel as possible, which is profitable on all journeys.

Safety of Ballast Tanks

Ballast systems are equipped with at least two independent pumps so that ballast water always can be pumped out even in case of a failure at any of the pumps (Sjøfartsdirektoratet, 1991). Ballast systems are made such that no single fault in the system or an operator error could lead to unintended transfer of ballast water from one tank to another or accidental filling or discharging. Emergency power can also operate the whole ballast system (Sjøfartsdirektoratet, 1991). The emergency stop isolate or disconnect the power supply to remote systems and pumps, and the ballast system goes into a safe position where the valves are closed and the pump is stopped (Sjøfartsdirektoratet, 1991).

2.4 Today's GT403 Pressure Transmitter

The submergible GT403 Pressure Transmitter, a transmitter intended for ballast tank installation, is within KM's product portfolio. It measures pressure, which has a relation to the water content (knowing the density).

It has a membrane in front that detects the pressure and mechatronics inside to read the signal and pass it on through a PUR cable to the ship deck (Foshaug, 2014).

The installation is mainly done by the yards if the ship is being built, but if it is changed (maintenance) at a later point it is done by staff on the ship or by KM's service technicians.

Figure 3: GT403
(Foshaug, 2014)

Specifications

Retail Price: EURO 470-660

Opperational Temp. Range: - 45 ° C to + 85° C

Temp. Range: 0 to + 60 ° C

Update rate: 1 sec

Operating range (pressure): 0 to 7 bar abs.

Accuracy (permissible deviation of pressure): <0.25 % of FRO (Full Range Output)

Long term stability: ±0.3 % of FRO/year

Temperature Drift: <0.005 % of FRO / ° C

Pressure Sensing Sensor element

The sensor element KM is using today is a ME501/505 from Metallux, a Swiss company. The sensor element is made of a ceramic substrate, but the operation is based in using a piezo-resistive thick film substrate. The front membrane is ceramic.

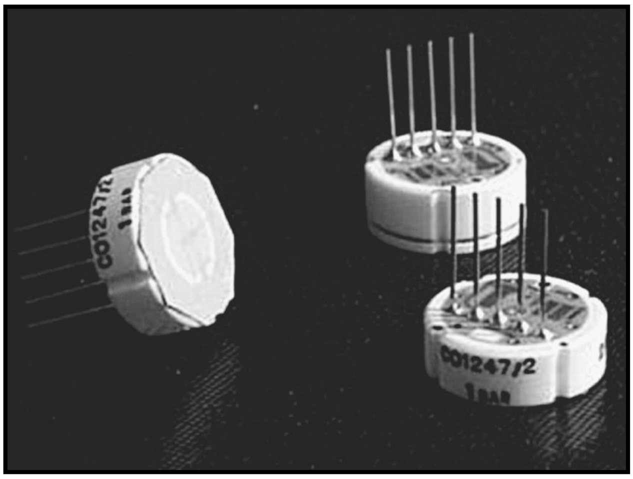


Figure 4: ME501/505 Element (Metallux, 2009)

The ME501/505 is piezo resistive pressure transmitters based on ceramic. The measuring bridge is printed directly on one side of the ceramic membrane by means of thick film technology. The rear part of the membrane can be exposed directly to the medium to be measured. Because of the excellent chemical resistance no additional protection is normally required.

The use of ceramic ensures a high linearity across the entire range of measurement and reduces effects of hysteresis to a minimum. The ME501/505 transmitters are thermal compensated by laser adjustable PTC-resistors (Metallux, 2009).

Installation

The GT403 is mounted in the tank, approximately 20-30 cm over the tank's lowest point to avoid the worst area of bottom sediment and dirt.

When installing the transmitter it is important to mount it in such a way that the pressure senor element is facing downwards, to avoid sediment from filling up the inlet. Furthermore, the transmitter and all its wires need to be secured and fixed to avoid movements that could cause fatigue or failure.

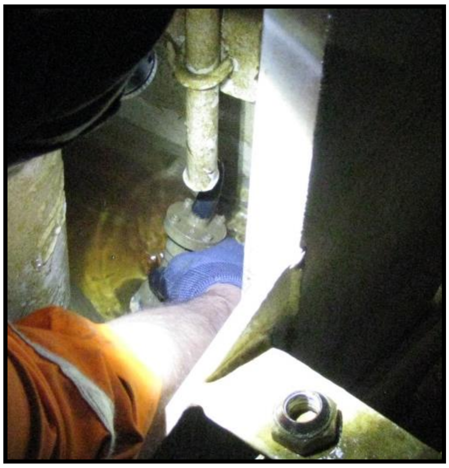


Figure 5: Installed GT403 on KV Bergen

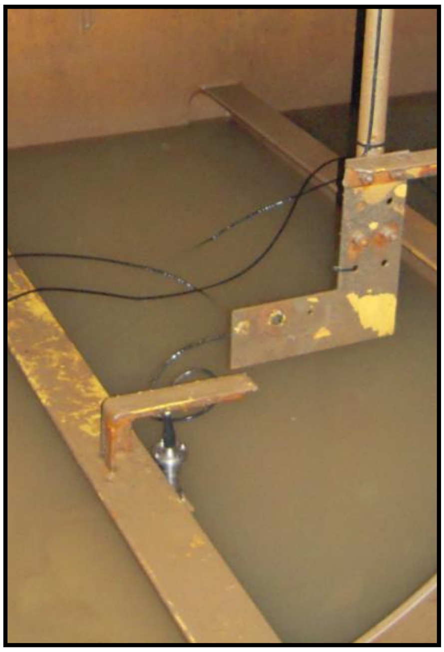


Figure 6: Installed GT403

Total Accuracy

The given permissible deviation of pressure is 0.25%, but since the transmitter is a part of a larger system this is only a part of the experienced deviation for operators. Since the GT403 transmitter measures absolute pressure, one needs to know the atmospheric pressure as well. This is solved by using a GT402 atmospheric pressure transmitter on deck, and subtract the atmospherically pressure from the absolute pressure to get the relative pressure caused by the amount of water.

This atmospheric pressure transmitter comes with the same permissible deviation of pressure at 0.25%. Furthermore, they are both tested in the temperature range 0 to 60 ° C with a temperature drift of 0.005% of FRO / ° C. Giving $60\,°\,\mathrm{C}\, * 0.005 = 0.3\%$ of $\mathrm{FRO}\,/\,°\,\mathrm{C}$ in a worst-case scenario. They are both connected to an I/0 module connection box each that has a accuracy of 0.4 %.

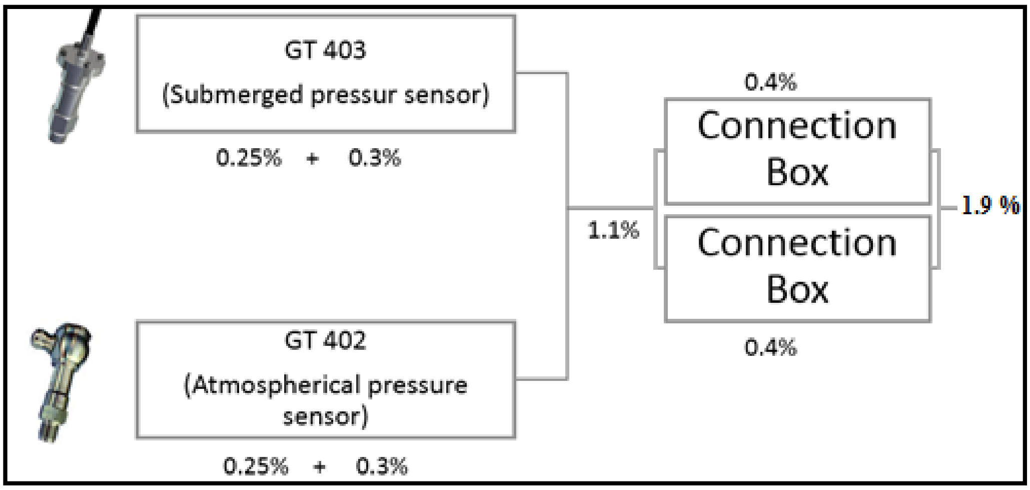


Figure 7: Accuracy of system (Foshaug, 2014)

From the figure “Accuracy of System” it can be seen that the total deviation is 1.9 % in worst case. In addition, the salinity in water will interfere with the level measurement, as well as the variation in gravitational field that increases from g = 9.789 ms^{-2} at the equator to g = 9.832 ms^{-2} at the poles. So an object will weigh about 0.5 % more at the poles than at the equator (Foshaug, 2014).

Furthermore, the way the vessels are operated will influence the readings. As an example; if the list is 8° in a tank with a ground area at 6 m x 6 m, and the transmitter is mounted at one of the sides, the deviation in height is 450 mm.

Thus, there are many factors that affect the accuracy beyond the given 0.25 percent. According to Rune Harald Hestmo in KM an accuracy better than 40-60 cm in a 40 meter tank is not presumable, i.e a system accuracy of 1 to 1.5 %. At worse up to 3 % as explained above.

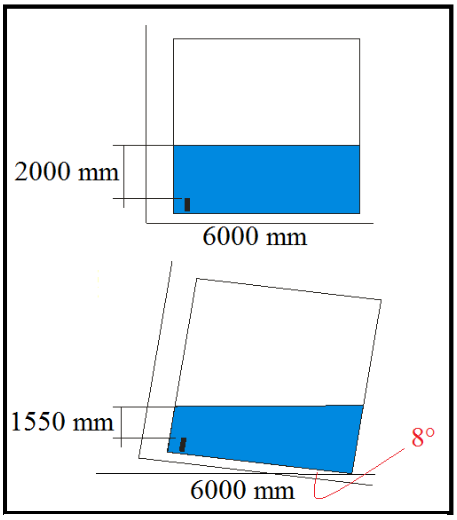


Figure 8: List Affecting Accuracy (Foshaug, 2014)

2.5 Competing Solution

The most competing solution in today's market is the air purge system, a bubbler-tube level system (Foshaug, 2014). It consists of a dip tube that goes almost to the bottom of the tank, bringing a purge gas, usually air. As the gas flows down to the dip tube outlet, the pressure inside the tube rises until it overcomes the hydrostatic pressure existing in the tank, caused by the weight of the water at the outlet. The water level is estimated, accordingly to pressure measured at the moment when bubbles are pushed out (Foshaug, 2014).

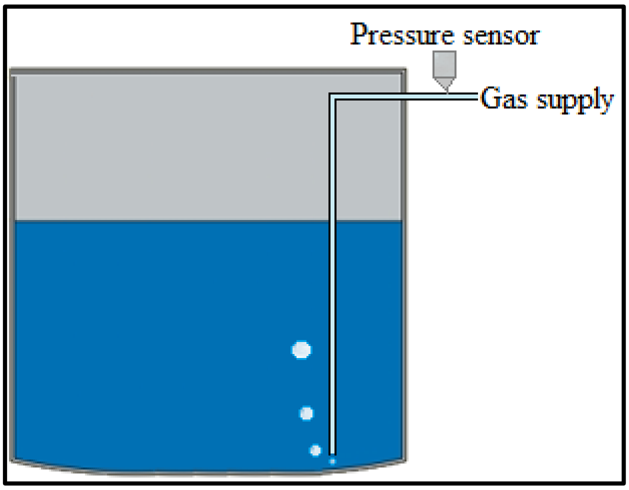


Figure 9: Air Purge Concept (Foshaug, 2014)

CHAPTER 3

3 THEORY

This chapter gives the reader a theoretical foundation for the rest of the report. It presents equations and constants, explains some phenomena and chemical reactions, describes some techniques and reviews some material properties.

3.1 Water Properties

3.1.1 Water Pressure and Density

The water pressure derives from the expression for pressure, p, which is the ratio of force, F, to the area, A, over which that force applies:

$$p = \frac{\mathrm{F}}{\mathrm{A}}$$

Equation 1: Pressure

According to recent interpretations of Newton's second law force, F, is the experienced pull or push needed to cause a mass to accelerate (Cohen, 2002). F=*ma*, where *a* is the acceleration which in this report is exclusively limited to the gravitational acceleration, g *and m* represent the mass of, in this case, the water and are given by m = Vρ, where ρ is the water density. The volume is a product of the area and the water depth, hence V = Ah. Based on the previous equation and Newton's second law the expression can be expand, and the water pressure defined by:

$$p = \frac{\mathrm{mg}}{\mathrm{A}} = \frac{V\rho g}{A} = \frac{Ah\rho g}{A} = \rho g h$$

Equation 2: Pressure (expanded)

From the equation above it is clear that the pressure increases when either the water density, ρ or the water depth, h increase assuming the area and gravitational force to remain unchanged.

The water density, ρ is the ratio between mass, *m*, and volume, *V*, defined by:

$$\rho = \frac{m}{V} = \frac{m}{Ah}$$

Equation 3: Density

3.1.2 Corrosion

Corrosion is a gradual degradation of a material due to a reaction with its environment. Destruction of material implies reduced physical properties of the component, which of course, in almost every application is unwanted. The reduction of physical properties can for instance result in hydrogen embrittlement or crack growth, which will weaken the part or the application.

Oxidation and Reduction

Oxidation means, as in most use of the word, electrochemical oxidation of metals in reaction with an oxidant, here oxygen. When an atom or ion loses electrons, it is said to have been oxidized. Rusting, the most known example of such corrosion is when iron oxides are being produced, according to the following equations.

$$\mathrm{Fe} = \mathrm{Fe}^{+2} + 2\mathrm{e}^{-}$$

Equation 4: Oxidation

The two electrons lost from the iron need go somewhere, and they usually end up on a nonmetallic atom forming a negatively charged nonmetallic ion. Because the charge of these ions has become smaller (more negative charges) the ion or atom which has gained the electrons is said to have been *reduced*.

$$4\mathrm{H}^{+} + \mathrm{O}_2 + 4\mathrm{e}^{-} = 2\mathrm{H}_2\mathrm{O}$$

Equation 5: Reduction

OR

$$2\mathrm{H}^{+} + 2\mathrm{e}^{-} = \mathrm{H}_2$$

Equation 6: Reduction

For this project assignment, corrosion is important in many ways since the main environment for the level measurement is water, in fact salty sea water that is even more corrosive. Salty water acts as voltaic cell, like a transport system, meaning that galvanic corrosion will occur faster. This needs to be taken into consideration when analyzing what the main issues with today’s transmitter are and when developing a new transmitter.

3.2 Fundamental Transmitter Descriptions

Range

The range is given by an upper and a lower boundary that the transmitter gives measurements within. An electrical output is often adjustable to fit most applications, but if the given range is exceeded this can lead to a deformation of the membrane (Skatvedt, 2014). To be safe, the operational measurement range is therefore often narrower than the transmitter's maximum range. This reduces the chance of overloading and provides benefits such as increased accuracy and improved linearity (Skatvedt, 2014).

Disadvantages can be that sensitivity, that is output signal divided by the input signal, may increase and this must be compensated for (Skatvedt, 2014) since to high sensitivity can negatively affect the overall accuracy.

Sensitivity

Sensitivity is defined as the delta change in output of a transmitter for a given delta change in the measurable parameter (input value) (Skatvedt, 2014). The factor can be constant over the whole measuring range of the transmitter, or it may vary, described as a linear or non-linear output.

Linearity

Linearity is an output that is directly proportional to the input over the whole measuring range, so that the slope of the graph of an output relative to input, is described by a straight line making it very desirable to work with (Skatvedt, 2014).

Noise

Noise is interference or disturbance signals that are added to the actual measuring signal. Noise can be picked up from external sources, or caused by instability in the measuring device (Skatvedt, 2014). One way to handle noise is to cover (shield) parts from each other.

Span

Span is the numerical difference between the transmitter's upper and lower signal limits. As an example a thermometer can be made to measure temperatures between 0 ° C and 100 ° C, but the thermometer scale goes from -20 ° C to 110 ° C. In this case, the operational measuring range of 0 ° C to 100 ° C, span = 100 ° C. The thermometer maximum range is however from -20 ° C to 110 ° C with span = 130 ° C (Skatvedt, 2014).

Zero Point

When doing a measurement, it is necessary to have a predefined starting point. For instance is the output of a thermometer graded according to Celsius' scale zero at the freezing point of water, the output of a pressure gauge may be zero at atmospheric pressure and so on (Skatvedt, 2014). Zero is therefore a value previously defined within the measurement range.

Zero Drift

Experience shows that transmitters over time tend to move their zero point from the original, and this is referred to as zero drift. This contributes to an error in measurement output equal to the variation or drift for the zero point.

Response Time

The time interval the transmitter uses to reach its true output value when the input undergoes an incremental change is called the transmitter response time. It tells a lot about the transmitter's dynamic accuracy.

Hysteresis

The transmitter's ability to give the same output when the same increasing and then decreasing pressures are applied consecutively (Bicking, 1998), is described as hysteresis. Pressure hysteresis is usually measured by applying a sequence of test pressures from a lower limit to an upper limit and then repeating the series of pressures in the decreasing pressure direction (Schaad & Wearn, 2000). Hysteresis error is the biggest difference (delta change) between the output curve at any measurement point within de specified range when increasing and decreasing the pressure.

3.2.1 Absolute and Relative Transmitters

Absolute Pressure Transmitter

Measure the pressure relative to vacuum that means atmospheric pressure plus any overpressure, i.e. pressure from water in the tank. Atmospheric pressure must be subtracted before calculating the water level in tanks. The transmitter is suitable for all applications

Relative Pressure Transmitter

Relative transmitters, also called gauge or ventilated transmitter, measures the pressure relative to the atmospheric pressure surrounding the transmitter. There is a small ventilation pipe from inside the pressure sensor element to the outside of the transmitter housing, through the cable. This kind of transmitters are not suitable for environment with changing temperature and humidity due to condensation in ventilation pipe. Further it can be used for measuring negative pressure as well as overpressure.

3.3 Seawater

3.3.1 Sea Water Composition

Seawater is a water solution of salts close to a constant composition of dissolved ions, atoms or atom groups that are electrically charged. It is over 70 sensor elements dissolved in seawater but only six of them together make up over 99% of all the dissolved salts (USA Patentnr. US8076118 B2, 2011). The table below shows the main components and their amount in seawater.

Chloride (Cl):	55.04 wt%	Sodium (Na):	30.61 wt%
Sulphate (SO_4):	7.68 wt%	Magnesium (Mg):	3.69 wt%
Calcium (Ca):	1.16 wt%	Potassium (K):	1.10 wt.%

Table 1: Composition of seawater (USA Patentnr. US8076118 B2, 2011)

As well as major sensor elements, manganese (Mn), lead (Pb), gold (Au), iron (Fe), iodine (I) appears as trace sensor elements. Most ions occur in parts per million (ppm) or parts per billion (ppb) concentrations. They are important to some biochemical reactions - both from positive and negative (toxicity) viewpoints (USA Patentnr. US8076118 B2, 2011)

3.3.2 Salinity

Salinity expresses the concentration of salt in water (Moore, 2010). Usually, the salinity is given as unit parts per thousand (ppt).

35 g dissolved salt / kg sea water = 35 ppt = 3.5% = 35000 ppm (The Engineering Toolbox, u.d.). The salinity is significantly different in seawater, brackish and freshwater

Water Type	Salinity [ppt]
Fresh Water	< 0.1
Brackish Water	5 - 15
Normal Sea Water	30 – 50
Dead Sea	330

Table 2: The salinity in different water (The Engineering Toolbox, u.d.)

3.4 Ballast Water

3.4.1 Sea Life and Sediments

Ballast water is just regular sea water at the place and time when they choose to fill the tanks. Because organisms that live in the sea are pumped into ballast tanks along with the water, the ballast tank can be seen as an aquarium full of medium, small and microscopic life forms.

Some of these life forms quickly take residence in small cracks on installed, submerged pressure transmitters. According to a service engineer at KM they often find that the returned transmitters are clogged because of invasion of small organisms.

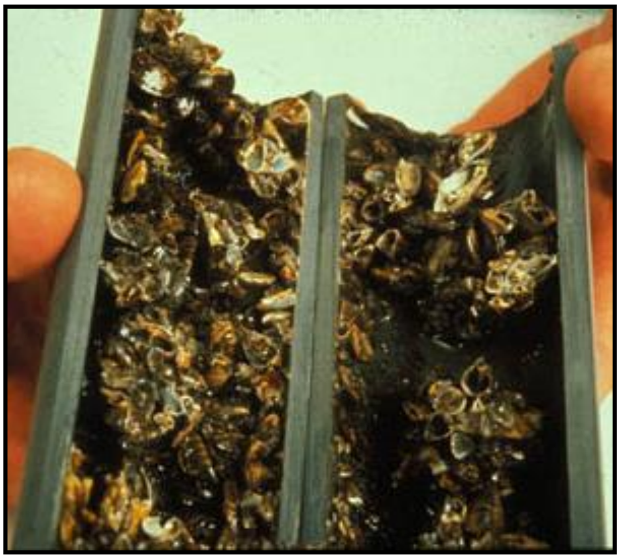


Figure 10: Fouling Problems (Johnson, Carlton, & Carlton, 1996)

An example of invasive species in Europe, that not only cause problems for the marine life, but for the ballast tanks and the vessel as well, is the Zebra Mussel (Dreissena polymorpha), a small freshwater mussel shown in the picture above. It can cause serious fouling problems on the ballast tank and in the vessels infrastructure, for instance by blocking water in pipes (Denton, Manrodt, & Thomson, 2008).

Furthermore, sediments from the seabed may be pumped into ballast tanks as well. This piles up inside the tank and makes the conditions even worse for tank monitoring.

3.4.2 Tank Treatment

From earlier studies from countries all over the world (Organization, 1994), it has been shown that many species of animals, bacteria and plants are able to survive in a viable form inside a ballast tank filled with seawater and sediment, even for journeys of many months duration (Organization, 1994). Discharged of water and sediment in new waters may cause growth of harmful aquatic organisms and pathogens which may in turn expose human, animal and plant life, and the marine environment to a threat (Organization, 1994). Although other media have been made responsible for the transfer of organisms between geographically separated water areas, ballast water discharge still dominates (Organization, 1994).

As results of these unwanted biological invasions a range of ballast water management guideline practices have been introduced.

Required tank treatment prior to water discharge is as follows:

"Addition of 100 grams of powdered sodium hypochlorite or 14 grams of powdered calcium hypochlorite per tonne of ballast water, ensuring thorough mixing and then allowing 24 hours before beginning to deballast" (Lloyd's Register EMEA, 2014).

3.4.3 Calcium Hypochlorite

Calcium Hypochlorite, $CaOCl_2$, an inorganic compound, is a white powder with a smell of chlorine. Calcium hypochlorite is produced by passing chlorine into the lime milk while cooling (Fjellvåg, 2009):

$$2Ca\,(OH)_2 + 2Cl_2 = Ca\,(OCl)_2 + CaCl_2 + 2H_2O$$

Equation 7: Productions of Calcium Hypochlorite

Because it contains more available chlorine than chlorine lime, calcium works more bleach, disinfectant and oxidizing than chlorine lime. It further has the advantage of not decompose by retention in open air. By adding hydrochloric acid, plenty of chlorine develops (Fjellvåg, 2009):

$$Ca\,(OCl)_2 + 4HCl = CaCl_2 + 2H_2O + 2Cl_2$$

Equation 8: Addition of Hydrochloric Acid

Hypochlorite, OCl-, is a powerful oxidizing and with even the effect of the weakest acids it releases chlorine and therefore are very disinfecting (and bleaching, although that is not relevant here) (Nesse, 2009).

Read more about calcium in seawater and see all equations in “Appendix E: Calcium in Seawater”.

3.5 Sacrificial Anode

Sacrificial anode is an alternative name of a galvanic anode, and the name derives from the fact that the anode's loss (or sacrifice) of material, to prevent a less active material surface from material loss. Sacrificial anodes are among several forms of what is known as cathode protection.

Sacrificial Anodes are metal alloy with a more negative electrochemical potential than the metal(s) it is supposed to protect (NAVFAC MO-307, 1992).

When electrolytes come in contact with metal surface, the surface undergoes an electrochemical reaction known as corrosion (see section "3.1.2 Corrosion"). An example is metal in seawater where the iron metal is in contact with electrolytes. For most circumstances, the iron metal would react with the electrolytes and corrosion would initiate (NAVFAC MO-307, 1992).

Figure 11: Two meter long zinc anode on KV Bergen

A way to deal with this unwanted weakening of the material is to introduce a sacrificial anode, for instance in the form of zinc. According to the table of Standard Reduction Potentials, the standard reduction potential of zinc is about -0.76 volts (NAVFAC MO-307, 1992). The standard reduction potential of iron is about -0.44 volts (NAVFAC MO-307, 1992). The difference in chemical reduction potential means that the zinc would oxidize much faster than the iron would, and in this way it protects the iron or any other metal with a less negative reduction potential.

As mentioned, zinc is a commonly used material for sacrificial anode, but also magnesium can be used. Furthermore magnesium or aluminum alloys that have been specifically developed for the task (Petrucci, Harwood, Herring, & Madura, 2007) are also options. In applications where the anodes are buried, a special backfill material surrounds the anode in order to ensure that the anode will produce the desired output (Petrucci, Harwood, Herring, & Madura, 2007).

3.6 Conformal Coating

Conformal coating is when a material is applied to protect the underlying material from the environmental concerns such as moisture and chemicals (Olson, 1998). Conformal coating materials include urethanes, silicones, epoxies, acrylics, poly-paraxylylene (Parylene).

While the development conformal coating technology was fostered primarily by the requirements of military systems over the past several decades (per MIL-I-46058C, Army Regulation, 70-71, NAV. INST. 3400.2, USAF-80-30) (HAALAND & McKINNEY, 1995), sophisticated coating materials and techniques have been widely adopted for industrial, automotive, medical and commercial electronics products as well (Olson, 1998).

MIL-I-46058C

One of the most frequently referenced specifications is the military specification MIL-I-46058C (referred to above). This standard is the core of the conformal coating of printed circuit assemblies.

MIL-I-46058C, Insulating Compound (For Coating Printed Circuit Assemblies) defines the standardized testing required before a coating can be said to have met the requirements, but it is not workmanship standards and it do not define the quality of application.

Historically, the issuing federal agency deactivated MIL-I-46058C in November of 1998. This deactivation meant the standard was 'inactive for new design and is no longer used, except for replacement purposes'. That did not, however, mean MIL-I-46058C would disappear from the landscape and it certainly has not. It is still a common requirement.

Source: (Advanced Coating, 2015)

The variety of materials comes with a variety of applying methods and those might, as well as the material's properties itself, set boundaries for the applicability. The techniques include brushing, dipping, spraying, selective spraying, wave, meniscus, and vacuum deposition methods. *Brushing* is to apply the coating by hand brushing; it is simple and requires little investment and is often used where the tolerances are not very strict and the volume is low, for instance the inside of a ballast tank often get painted. *Dipping* means to fully submerge the area to be coated and is appropriate for smaller objects, in higher volume that need overall coverage. *Spraying* is done either by hand, but often by a machine as a part of a production line. Here the thickness control is better than for dipping, but to reach all desirable areas might be hard for objects with an odd shape. The spraying can also be done as *selective spraying* meaning only a part of the surface is getting hit. *Wave* coating is a wave of coating created by pumping the liquid material through an aperture. The amount of heat controls the viscosity of the fluid. The *Meniscus* coating uses a permeable tube through which coating is pumped to create a fountain. Inverted assemblies are passed through the fountain, and as a moving substrate intersects with a coating liquid, menisci are formed at the leading and trailing edge (Olson, 1998). The technique is limited to flat objects but the precision is good. *Vacuum Deposition* is a method where the object is coated with a very thin, inert and highly conformal layer. The technique is developed to apply Parylene.

Each of the coating techniques are characterized by certain benefits and limitations, which in turn forms the basis for selecting the most suitable method for a specific application.

Coating parameters to be considered in coating process selection include circuit preparation, coating promotion, transfer efficiency, thickness control, bridging, coating removal, thermal expansion, environmental requirements (Olson, 1998).

When coating is applied it is important that this happens without the occurrence of any pinholes, imperfections or gaps in the coverage layer, so no moisture can migrate under the coating. Furthermore, it is important that the area to be coated is sufficiently cleaned, so no ionic impurities becomes trapped under the coating, causing chemical changes.

3.6.1 Parylene

Parylene is the trivial name for members of a unique (p-xylylene) polymer series, used as moisture and dielectric barriers. The Parylene polymers are deposited from the vapor phase and formed at around 0.1 torr (0.000133322 bar), where the average smallest path between the molecules is in the order of 0.1 cm (Changlin Pang, 2005). Entailing that the object, that is to be coated, is uniformly impinged by the gaseous monomer. This property is referred to as Parylene conformal characteristics, and stands out from the regular conventions coating (Advanced Coating, 2015). Due to the uniqueness of the vapor phase deposition, the Parylene polymers can be formed as structural continuous films from as thin as a fraction of as micrometer (SCS Parylene Coatings, 2014).

The three most common types of Parylene are referred to as Parylene N, Parylene C, and Parylene D, in addition there is a newer type called Parylene HT. Parylene N, a completely linear, highly crystalline material, is a primary dielectric that provides high dielectric strength and a dielectric constant that does not vary with changes in frequency. It has a useful combination of electrical and physical properties plus very low permeability to moisture and other corrosive gases, making it a natural choice for coating electronic assemblies as well as the best selection where greater coating protection is required (SCS Parylene Coatings, 2014).

Parylene D, the second commercially available type in the series, gets its structure by substituting two hydrogens in the N-type with chlorine atoms. This version has similar properties to the C-type, but in addition maintains its physical and electrical properties at higher temperatures.

Parylene HT® (Advanced Coating, 2015) is the third and newest commercially available type. Here the alpha hydrogen atom of the N-type is replaced with fluorine. For higher temperatures this version of Parylene is useful.

Parylene C, the fourth and most common variant, is used for all kinds of applications, hence usually the type of material associated with “Parylene”. Its structure is a modified version of the aforementioned N-type where a chlorine atom substitutes hydrogens. It has a very low permeability to moisture and other corrosive gases. This is the kind that is used for experiments in this master thesis. To see material characteristics and typical specifications see “Appendix F: Typical Specifications of Parylene C”.

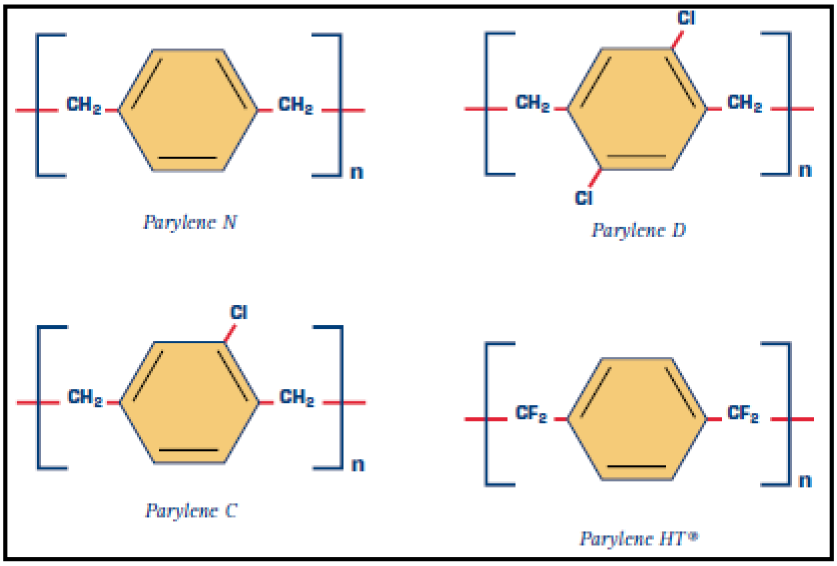


Figure 12: Parylene N, D, C, HT chemical structures. (SCS Parylene Coatings, 2014)

One of the main features of Parylene is that it is able to form in extremely thin layers, even below 1 micron, a hundredth of a sheet of paper.

Objects that are to be Parylene coated are cleaned, masked and in some cases treated with an adhesion promoting agent. They are fixed in the vacuum chamber where gaseous monomers polymerize on all surfaces to create a pinhole-free, transparent and very thin film to protect against the environment. Parylene is highly inert, has high dielectric properties and can be applied in very thin layer with good certainty (Olson, 1998)

Deposition Process

Parylene is applied through a specialized vapor deposition process at ambient temperature. Parylene polymer deposition occurs at a molecular level, where the coating literally grows one molecule at a time on the substrate surface, assuring entirely conformal and uniform layers of Parylene conformal coating are applied (SCS Parylene Coatings, 2014).

The first step is elevating the temperature to approximately 150ºC, under vacuum, to vaporize the solid di-para-xyxlene dimer (di-mer, as in an oligomer consisting of two structurally monomers). Then the next step is the quantitative cleavage (pyrolysis) of the dimer vapor at the two methylene-methylene bonds at about 680 ºC, which yields the stable monomeric diradical, para-xylylene (SCS Parylene Coatings, 2014). Finally, the monomers enter room temperature deposition chamber where it spontaneously polymerizes on the substrate. The substrate's temperature never raises more than a few degrees (SCS Parylene Coatings, 2014).

Since Parylene is non-liquid, it does not pool, bridge or exhibit meniscus properties during application. No catalysts or solvents are involved, and no foreign substances are introduced that could contaminate coated specimens. In contrast to Parylene, the thickness of liquid coatings is related to viscosity, working temperature/humidity, and application process (spray or dip) and can only be controlled to a tolerance of approximately +/- 50% of final thickness (Advanced Coating, 2015). Parylene thickness is a function of the amount of vaporized dimer and chamber dwell time and can be controlled accurately to within +/- 5% of targeted thickness for most typical applications (Advanced Coating, 2015).

Properties

Parylene is an inert and transparent polymer that forms low stress coating in extremely thin layer. One of the features of Parylene coatings is that they can form pinhole-free layers, and is conformal on any type of surface design. It is used as a barrier to oxygen, moisture, chemicals, solvents, carbon dioxide and is highly corrosion resistant.

Parylene has an extreme high dielectric withstand with a 5000 voltage breakdown per 25 microns (Advanced Coating, 2015).

In addition to its outstanding electrical isolation properties it has a thermal mechanically stability between -200ºC and 150ºC and the entire coating process is accomplished at room temperature, alleviating temperature stress on the parts.

It has low mechanical stresses, a very low permeability to gases, is hydrophobic and creates a completely homogeneous surface.

Furthermore, it has no outgassing (NASA approved), the coating itself and the applying process is not contaminating and no solvents, catalysts or other by-products are introduced during coating (Advanced Coating, 2015)

Disadvantage

The first disadvantage is that the machine used for application is very expensive. Furthermore, it might be challenging to mask the parts or areas where coating is unwanted. There are actually very few companies worldwide that seem to master the coating technique and therefore the price is high, even though it has dropped rapidly over the last decade.

3.7 Laser Beam Welding

Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal together by using laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications, such as in the automotive industry. The laser sends a high power laser beam onto the metal, resulting in a small heat-effected zone (HEZ) and high heating and cooling rates. The spot size of where the laser beam hits varies and is referred to as the laser diameter. A continuous or pulsed laser beam may be used depending upon the application. Pulsed beam is often used to keep the heat generation at a minimum, due to thin materiel. Continuous laser systems are used for deeper welds.

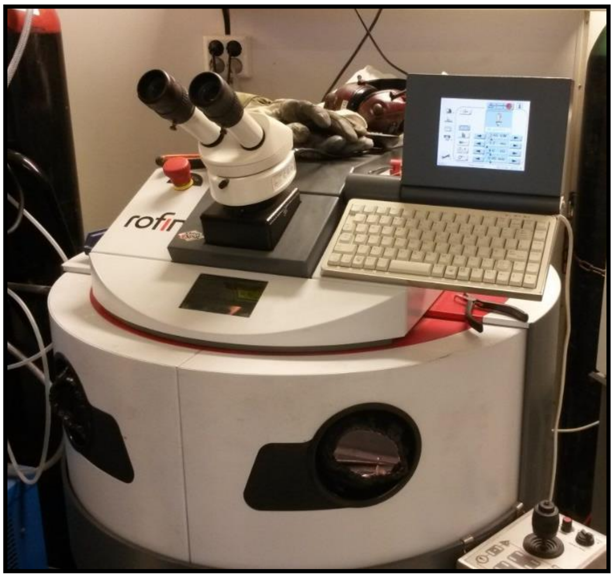


Figure 13: Laser beam machine (KM Trondheim)

3.8 SEM

Structural equation modeling (SEM) is generally the term used to describe a set of statistical methods designed to test conceptual or theoretical models. Common SEM method reveals information including external morphology (texture), chemical composition, crystalline structure and latent growth modeling (Kline, 2011).

Energy-dispersive X-ray spectroscopy (EDS, EDX, or XEDS), also known as energy dispersive X-ray analysis (EDXA) or energy dispersive X-ray microanalysis (EDXMA), is an analytical technique used to analysis sensor elements or to find chemical characterization of a sample (Goldstein, 2003). Each sensor element has a unique atomic structure allowing unique set of peaks on its X-ray emission spectrum and this makes up the basic principle of SEM's characterization capabilities (Goldstein, 2003).

3.9 BSE

Back-scattered electrons (BSE) are beam electrons that are reflected from the sample by elastic scattering. BSE detectors are commonly integrated into either a SEM or EPMA instrument (Goodge, 2005) and therefore often used in analytical SEM. The intensity of the BSE signal has a strong relation to the atomic number (Z) of the specimen. BSE images provide information regarding distribution of different sensor elements in the sample.

Characteristic X-rays, used to identify the composition and measure the abundance of sensor elements in the sample, are emitted when the electron beam removes an inner shell electron from the sample, causing a higher-energy electron to fill the shell and release energy.

CHAPTER 4

4 RESEARCH

This chapter presents the research and the results from the pre-master project, covering customer needs and the main issues associated with today's ballast pressure transmitter, GT403. It discusses some internal reports from earlier experiments, supporting the findings in the pre-master project. Furthermore, it presents experience from the field and the knowledge gains on the travels to external partners.

4.1 The Pre-master Project

Results

The title of the pre master project is “*New Generation Water Level Measurement Equipment for Ballast Tanks*”, and it is a concept study of water level measurement equipment for ballast tanks. The intention was to challenge the traditional pressure transmitter, using the “fuzzy front end” method to find all possible solutions for water level measurement in ballast tanks.

After several rounds in the solution space looking at air purge systems, sonar, radar and floaters just to mention a few, the pre master recommends to proceed with a laser concept, a distance measurement method. Laser transmitters provide very quick and accurate results, and could possibly also be cheap enough.

But, taking into account the known conservative industry and marked, KM decided to further develop the pressure transmitter instead of making a whole new product, and this concludes the background for this thesis.

Research

To select the final solution (laser, as presented over) in the pre master project was just a tiny part of what was done. Being able to come up with many different solutions and giving advice required more in-depth understanding of both the existing GT403 with its main issues, as well as knowledge about the industry. Therefore, the core part of the pre master project was to establish customer needs and uncover the main issues. The research done and the knowledge gained create a foundation for this master thesis.

4.1.1 User Demands

Both existing customers, potential customers, users and other stakeholders were approached by sending email. Some leads were successful, and the customer needs were identified through seven different interviews (phone) and a survey with 14 participants (sheet form). The next part presents a summary of the outcome.

Qualitative Analysis

During the phone interviews some general perceptions started to form. Some of the concluding sentences are highlighted below:

- “If long-time stability and expected lifetime is high it is okay to pay a thousand euros.” - Customer
- “Service is also an important factor when choosing.” - Customer
- “If replacement got easier, I would accept a shorter lifetime.” – Worker on a ship (user).
- “If installation was easier we would accept a higher price.” - Non-customer (Ship owner)
- “Ballast measurement is just a small part of the picture, and price is indeed important” - Yard (buyer)

(Foshaug, 2014)

Due to the small sample of interview objects, it is hard to conclude, but it was indeed instructive to hear the opinions form different stakeholders’ perspective. The excerpts above were not randomly selected, but sentences that reflect much of the essence of the conversation we had and represents kind of an overall perception.

In addition to these sentences, the main issues with today’s GT403 were tried established. Using the qualitative information gathered from the interview and the technique of “encoding schemes”, which is to interpret and concretize statements and translate them into specific needs. Below there are the three main issues ranked by highest incidence rate, based on the conversation with the customers and meeting with the sales department at KM (Foshaug, 2014).

Need Analysis

Problem	Description	Needs
1. Short life time	*The most common problems are related to short lifetime, which in turn causes frequent maintenance.*	
a. Wrong installation	*The most common problem that occurs is errors due to wrong installation*	User needs **knowledge** on how to install.
b. Sediment problems	*The second reason to short lifetime is that sediment clogs the transmitter*	User needs the solution to be **shielded from sediment**
c. Growing of microorganisms	*The next problem, causing short lifetime is growing of microorganisms*	User needs the solution to be constantly **moving** or **shielded from microorganisms**
d. Corrosion due to high salt content	*The last reason to short lifetime is that the salty water causes corrosion*	User needs a **corrosion resistant** solution.
2. Hard to do maintenance	*The next problem is the hassle of do maintenance, and is a result of the short lifetime, leading to annoyance.*	User needs the solution to be more **accessible** and/or have **a longer lifetime**.
3. Hard to install	*The last problem is that the existing solutions are hard to install the first time*	Need a solution that is **easy to install** and **accessible**

Table 3: Need Analysis (Foshaug, 2014)

Quantitative Analysis

In addition to the interview (qualitative) a survey (see "Appendix G: Survey") was sent out, and 14 customers responded (see "Appendix H: Outcome from Survey"). In general, everything the customers were asked to rate was of some importance, but some areas stood out to be more or less important than the rest. With a top score of 5 (meaning highly important), the area with the highest average score of importance was *Easy to install* with 4.6, followed by *Long Life Time* with 4.4 and *Long Time Stability* with 4.1. At the other end of the scale, *Refresh Rate/Response Time* has the lowest score of 3.1 followed by a tie between *Price* and *Easy to clean the tank* with 3.5.

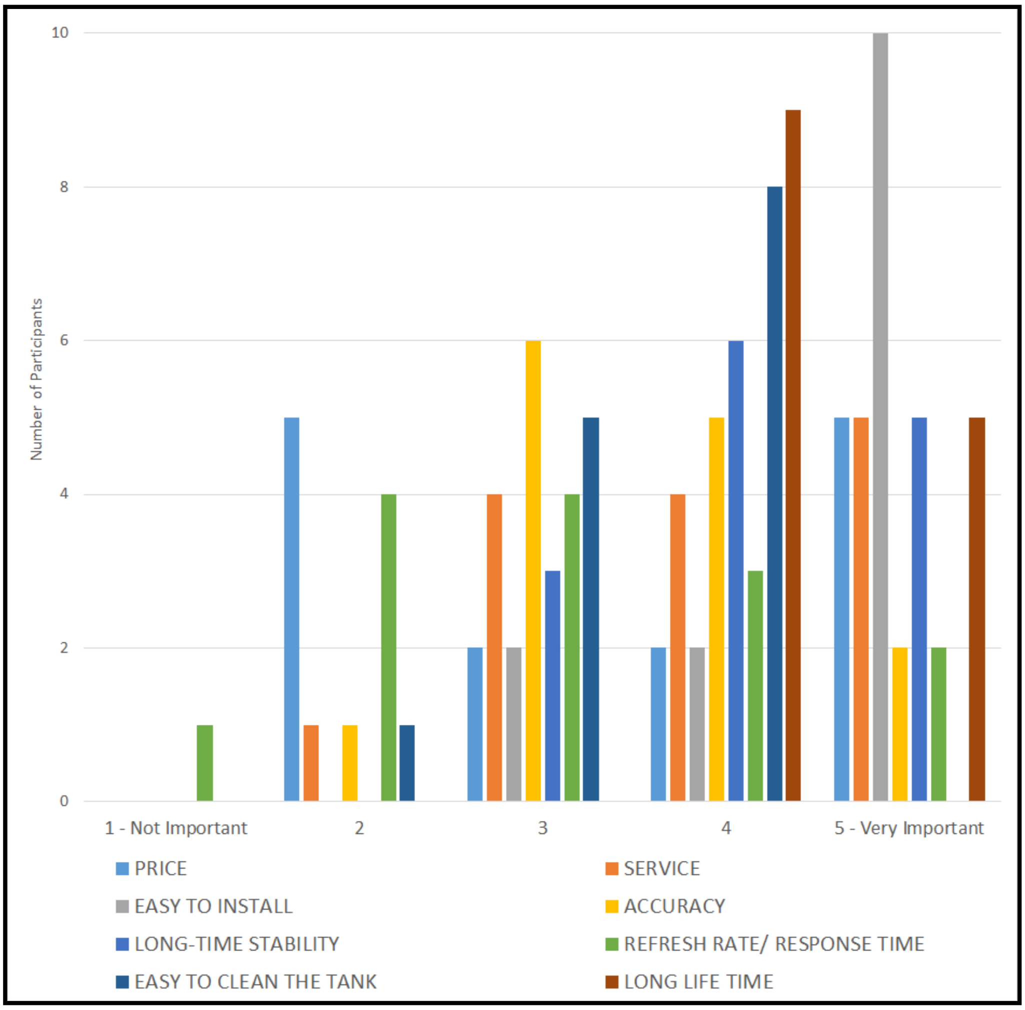


Figure 14: Customer survey (Foshaug, 2014)

Explanation of the figure above: It shows the result of the first two questions of the survey, where the customers were asked to rate the importance of each area when choosing a solution for ballast level measuring. Each column represents one area, and has a unique color in the diagram. The grading goes from one (1 - not important) to five (5 - very important). The height of each column represents the number for participants answering the same.

Distinguishing Between Two Kinds of Customers

In addition, to the average score for each category the pre-master looked at other trends or correlations. For instance, the area *Price* had a remarkable distribution (Foshaug, 2014). For some customers price is highly important in the sense that they do not want to pay much, for others price is not so important and they are willing to pay more as shown the figure below:

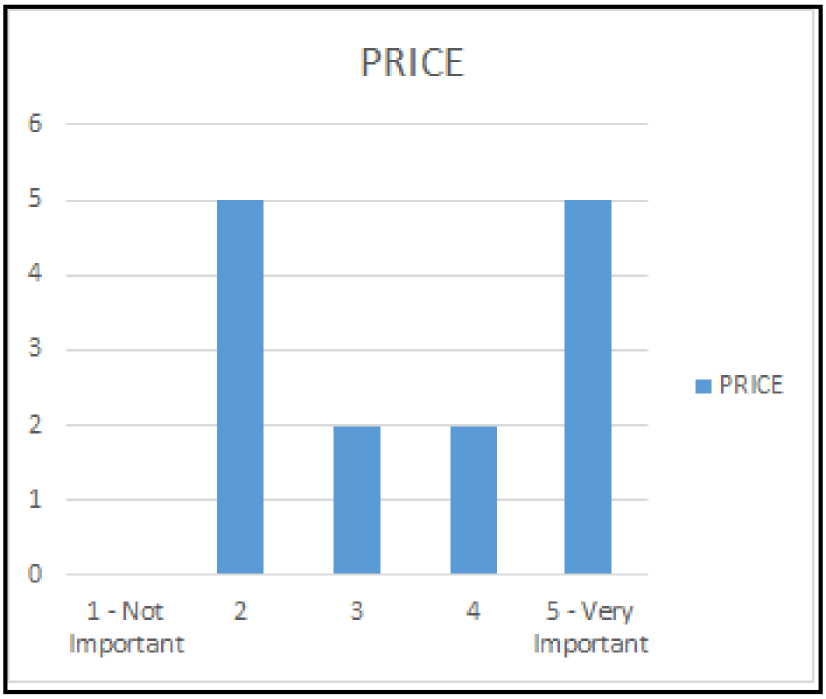


Figure 15: Importance of price (Foshaug, 2014)

Taking this even further by just looking at what the 10 customers, rating *Price* either as not so important (2) or of very important (5), did rate in all the other categories, it is clear that they have different expectations, and those who are willing to pay more expect more on every single area (Foshaug, 2014).

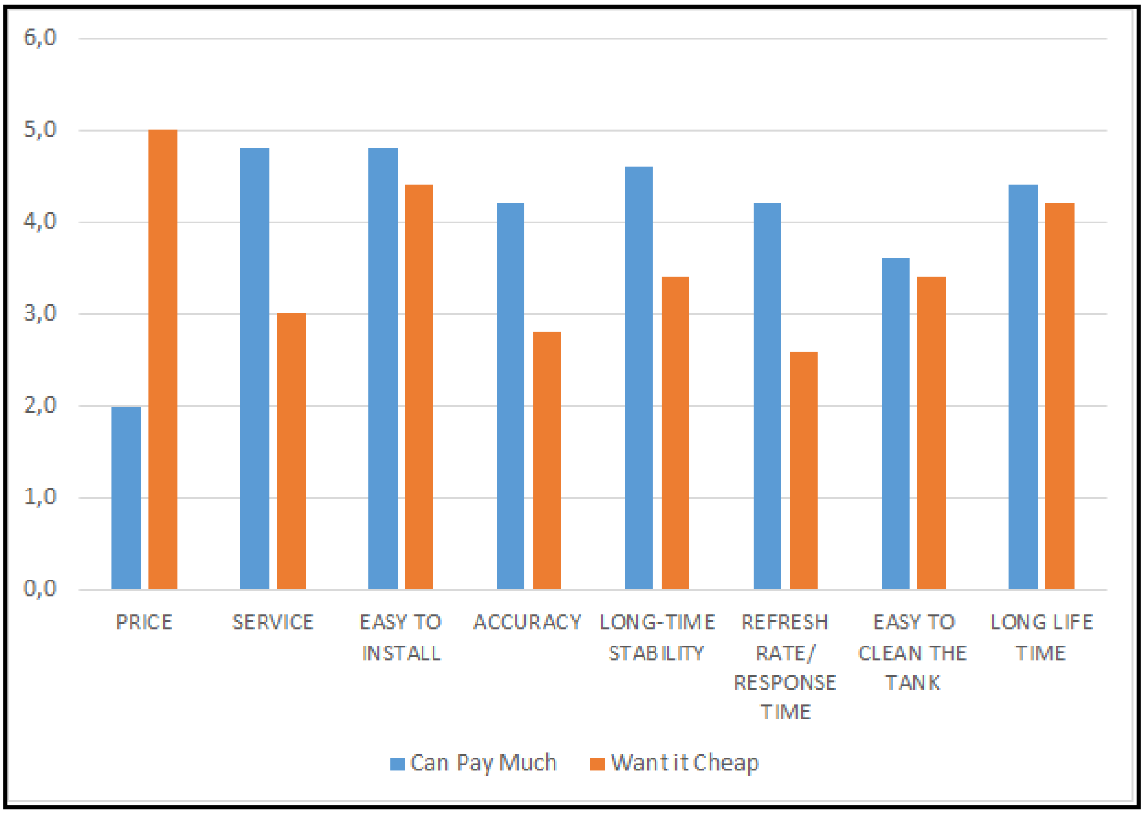


Figure 16: Willingness to pay versus expectations (Foshaug, 2014)

The pre-master project points out this obvious split in the market. Whereas the high-end customers expects a lot, while the low-end customers have totally different expectations.

Value for this Master Thesis

The pre master concludes with an advice to always be aware of these apparently huge differences in expectation and desires in the market.

For some customers price is important – they do not want to pay much. For others price is not so important, and they are willing to pay more to get what they want.

Kongsberg Maritime definitely want to be a provider for the high-end market that is willing to pay and has high expectations to good quality and lifetime. This image is a part of the overall KOG vision that is to be suppliers of reliable, advanced technological solutions that improve the reliability, safety and efficiency of complex operations and under extreme conditions.

Based on that the new generation pressure transmitter will approach the high-end customers and provide a solution that is highly accurate, and advanced integrated to the ships stabilization software with a high update rate and long lifetime.

4.1.2 Product Requirement Specification

Based on both the quantitative and qualitative analysis' the customers' requirements to the new high-end transmitter is presented the table below:

	Should	Must
Low price	✓	
Good service		✓
<u>Installation / Maintenance</u>		
Easy to install		✓
High accessibility	✓	
Takes short time	✓	
<u>Functional requirements</u>		
High accuracy		✓
Long-term stability	✓	
High refresh rate		✓
Long lifetime		✓

Table 4: Product 'Should and Must' List

The *Product 'should and must' list* only gives a rough indication on the importance of each point. Being able to use this as some sort of criteria for the new development, values are needed. Based on user demands and knowledge gained from KM regarding GT403 the product requirement specification is as follows:

	Requirement	*Comment*
Price	< EURO 1500	
Easy installation / maintenance	Easy	Should be easy to install for the yard and to maintain for the user
Service	Good	KM shold at all times be able to give support on the product
Functional requirements		
Range	Min. 40 meters	Depth of water
Accuracy	0.5 %	Permissible deviation of height
Temperature drift	0.005 % of FRO/˚C	
Long-term stability	0.5 % FRO/year	
Refresh rate	Min. 1 sec	
Life time	7 years	
Environment		
Temperature	-20 ° C to 60 ° C	The temperature the transmitter can operate in.
Salinity	0-50 ppt	Must withstand normal amount of salt in sea

Table 5: Product Requirement Specification

4.2 Internal Reports

According to Marta Gjestvang, the product manager at tank monitoring at KM, a large number of Kongsberg pressure transmitters, submerged in ballast tanks, malfunction because of the deposition at the membrane surface. This seems to alter the functionality of the transmitter and give wrong readings.

For a long time it was assumed to be calcium, added as an antibacterial agent (see section "3.4.3 Calcium Hypochlorite"), depositing. To find out if this was the reason an experiment was carried out.

4.2.1 Experiment: Consequence of Adding Calcium Hypochlorite

Back in 2004 Rune Hestmo and Jan Rambech did an experiment and wrote a report titled "An experiment to verify the consequence of adding Calcium hypochlorite into seawater, and its influence on the operation of Kongsberg ballast transmitters". They aimed to verify that adding powdered Calcium hypochlorite ($CaOCL_2$) in salt water results in deposition of calcium at the transmitter housing and sensor element, and its influence on the operation of the GT403 ballast transmitter. Furthermore, they wanted to see the effect of coating with silicone gel on the membrane and whether or not isolating (not connect to earth) the transmitter has any effect on the deposition.

Background

As presented in section "3.4.3 Calcium Hypochlorite" the Calcium hypochlorite is added to the water as a tank treatment.

To recap: In tank treatment prior to discharge "addition of 14 grams powdered calcium hypochlorite, per tonne of ballast water, ensuring thorough mixing, and then allowing 24 hours before beginning to deballast" (Lloyd's Register EMEA, 2014).

The experiment was carried out to verify assumptions for deposition on the transmitters, which in turn ensures short lifetime. Furthermore, it tested the effect of silicone coated membranes and whether or not isolating (not connect to earth) the transmitter has any effect as well.

Experiment

The experiment was a simulation of the operating environment that is to be found in ballast tanks. Genuine seawater with added Calcium hypochlorite and climatic temperature was established in a basin which held approximately 1000 liters. The transmitters were submersed to a level of approximately 20 cm from the bottom. The transmitters were connected to voltage of +24 V. The basin also included a zinc anode which was connected to analogue ground and the transmitters were continuously measured during the test. Every second day they were visually inspected and after 53 days they were controlled in the calibration line.

Five different variations of the Kongsberg ballast transmitter were tested under the same condition. The Kongsberg transmitters were of the type GT303, the generation before GT403, and the different variations were as follows:

1. Standard Kongsberg GT303 ballast transmitter.
2. Standard Kongsberg GT303 ballast transmitter with silicone gel covered membrane.
3. Standard Kongsberg GT303 ballast transmitter with open flush adapter.
4. Standard Kongsberg GT303 ballast transmitter with open flush adapter and gel covered membrane.
5. Standard Kongsberg GT303 ballast transmitter without grounding to earth.

NB!

The GT303 in this test is an earlier version of the GT403, discussed in this thesis. The properties and application areas are similar; therefore one can assume that the observations and experiences from this experiment is transferable to the current GT403.

But; the pressure senor element used in the GT303 had a gold plated ceramic element, while the GT404 only used a ceramic element.

Results

A white layer appeared at the housing and at the inside of the process connection inlet surface after approximately 30 days in seawater. The exception was for transmitter type 5, the Standard Kongsberg GT303 ballast transmitter without grounding to earth, that did not experience this fouling.

After the initial 30 days an amount of 20 g Calcium hypochlorite were added to the seawater. Only four days after the addition some growing spots on the surface of type 1 was observed. Another six day after the test with calcium hypochlorite started, this phenomena could also be observed for the transmitter type 3.

Meanwhile it was added another 20 g of sodium hypochlorite and observed that the color of surface of type 1 had changed from gold to a grey blackish color before that. No particularly visually effects could be observed for the other types. The silicone gel seems to withstand the test, preventing deposition of calcium on the membrane surface.

The signal of the pressure transmitters was measured as a function of seawater level, atmospheric pressure, temperature and the percentage of the signal value are shown in the tables in "Appendix I: Measurements from Experiment with Calcium".

After 52 days, a perceptible change of the signal took place for type 1 and type 3 and the transmitters were dried for inspection. The result from that inspection showed that a major cover of Calcium was attached to the pressure sensor elements surface. The thickness was estimated to be approximately 100-200 microns and it was mechanically stiff, especially for type 1. See the pictures that follows:

Figure 17: Picture of type 1. A 100 micron thick layer of calcium has deposited to the membrane surface of the pressure element

Figure 18: Picture of sensor type 3 with open flush. The element is in the middle and it is covered with a 100 micron thick layer of calcium

For the type without grounding, no calcium deposition at the housing and membrane could be observed. The silicone gel was still intact as shown as well.

Figure 19: Picture of sensor type 5. As a result of not grounding the sensor via the house, no chemical reactions yield deposition of calcium at the membrane surface

Figure 20: Picture of sensor type 4 with open flush. The silicone gel cover is intact and no calcium layer has been deposited to the membrane

Conclusion

The five different transmitters have been tested in the laboratory tank filled with seawater and calcium hypochlorite for approximately two months. Visual inspections show that the Standard Kongsberg ballast transmitter (GT303) and the type without a front adapter had a deposit layer at the surface. The thickness of that layer was measured to be approximately some hundreds of microns.

The type with a thin silicone layer on the pressure sensor element had a non-impacted surface and the film was intact after the test. Also the type without ground connection to the basin was not impacted by any deposition. In addition this type had no deposition at the housing which was observable for the other types.

The silicone gel film clearly shows that it affects the connecting between the membrane surface and the seawater by building up a certain barrier which stops the material flow of calcium carbonate from seawater to the membrane surface.

If the transmitter was not grounded at all, the deposition will probably stop as the non-grounded transmitter type showed.

The precision of the transmitters showed that the types with the silicone gel in front of the membrane had the least drift (0.14%) while the standard GT303 ballast transmitter had the most drift. The deviation for the last type was measured to be as much as -1.5% in the range of 0 – 100 % pressure. The negative sign of the deviation is the same as found for ballast transmitters installed in ballast tanks.

4.2.2 Analysis of the Deposition Layer

A GT403 returned from a 242 NAMURA shipyard ship has been analyzed by running SEM and BSE tests (see more in section “3.8 SEM” and “3.9 BSE”).

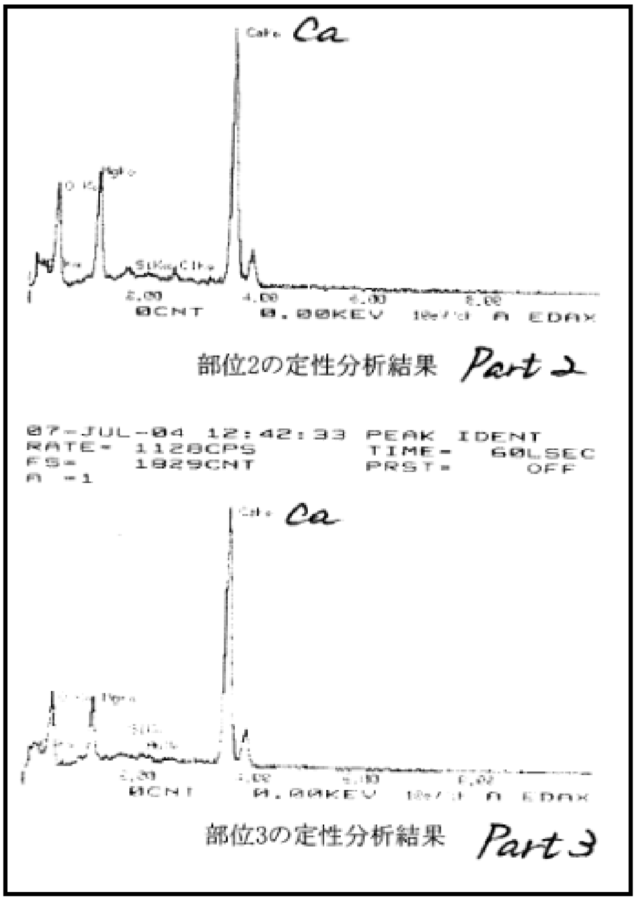


Figure 22: SEM Analysis: Calcium

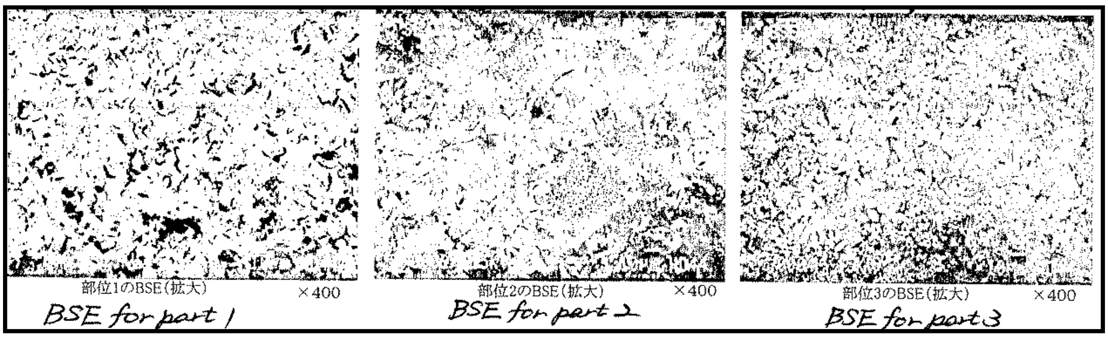


Figure 21: BSE Analysis: Calcium

The result showed, as expected, that calcium was the main component in the deposition layer on the membrane. This was not a surprise, but it was important to confirm anyways.

4.2.3 Experiment with Parylene

Some years after the initial experiment proving the effect of calcium deposition another coating material, Parylene, announced its arrival. The idea was that by coating the whole transmitter in Parylene it would prevent calcium deposits on the transmitters and extend their lifetime. This experiment was also carried out by KM, but with vague documentations; only some pictures and personal memories are available.

Experiment

Some regular GT403 and some fully Parylene coated GT303 were put into the same basin, with approximately 1000L of sea water, and under the same test conditions as given in the summary of the report “Experiment: Consequences of Adding Calcium Hypochlorite”. They were submerged for an uncertain period of time, probably a couple of months according to Rune Harald Hestmo who performed the test. After this period they were visually inspected.

Figure 23: Sensors in tank during earlier Parylene experiment

Results

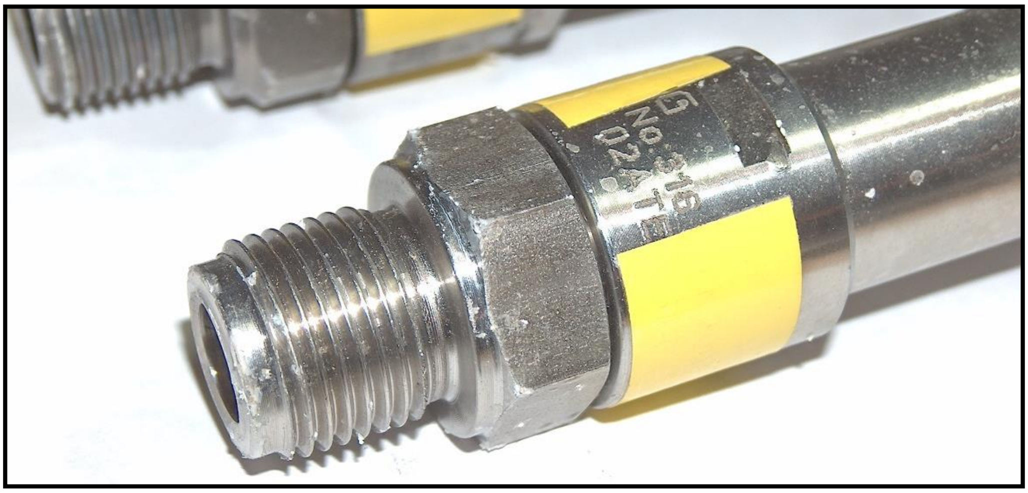


Figure 24: Parylene Coated (20µm) sensor from the GT303 series.

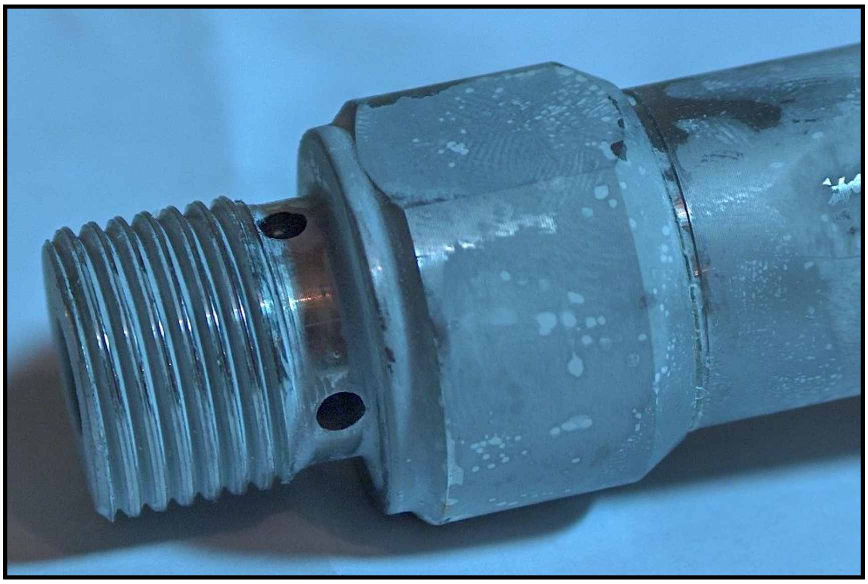


Figure 25: GT403 without Coating

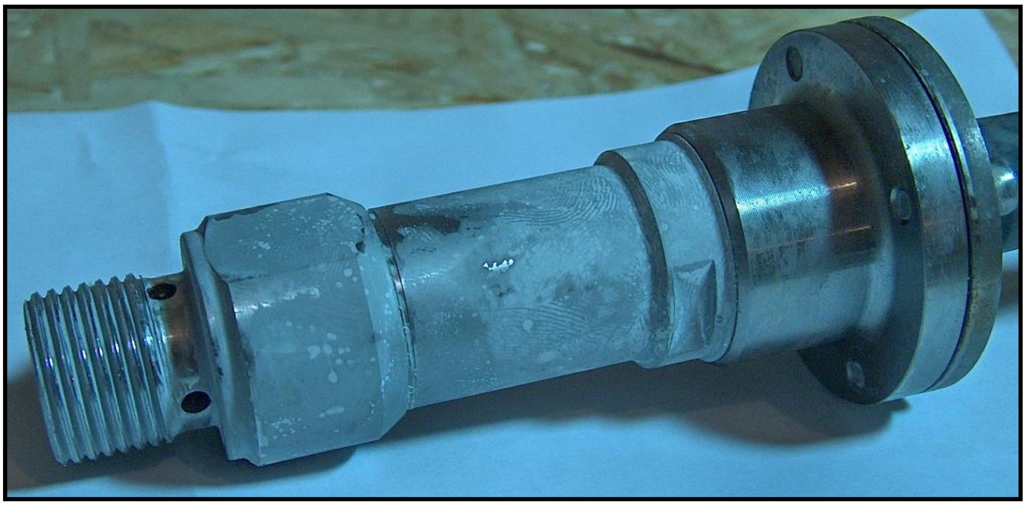


Figure 26: Whole GT403 without coating

Figure 27: Parylene Coated (20µm)

Conclusion

Unfortunately this test have not been documented very well, but based on the pictures and conversation with the person responsible for the test some conclusion could nevertheless be drawn.

It is without doubt advantageously with a thin layer of Parylene, considering the deposition of calcium.

The layer is very thin and almost invisible for the naked eye.

Follow up

This experiment, even though it is a few years old, gives valid reasons to follow up and try to reconstruct the experiment, but with much more testing and documentation.

The thickness of 20 µm gives an indication on what thickness to aim for in new experiment.

In addition three fully Parylene coated ballast transmitter of the type GT303 and GT 403 were installed on the vessel Stolt Concept.

They have been regularly inspected by KM service engineers that can report that the transmitter are working well and are still “shiny” and “new-looking”.

4.3 Learnings from the Field

4.3.1 Service at KV Bergen

Objective

The objective was to participate on a service mission to learn what the challenges are, how to troubleshoot and fix problems due to incorrect readings from the GT403 Pressure Transmitters in ballast tanks at KV Bergen. By bringing the defect transmitters back and analyze them, some patterns might be revealed and from that, a focus areas can emerge.

About KV Bergen

Figure 28: Picture of KV Bergen

The ship is 93 meters long, 16 meters wide and has a ballast capacity at 1642 m^3. It has approximately 30 ballast tanks, of which all contains at least one pressure transmitter, and a few of them two. To read more check out their homepage online: http://maritimt.com/batomtaler/2010/kv-bergen.html

Observations

In advance of the arrival a crew member did an inspection using the software troubleshooting and wrote down the name of the tanks where the transmitters seemed to behave strangely.

Deviations

- One transmitter showed only 15% fulfillment, but they observed almost full tank.
- One transmitter showed a negative pressure, like if it was exposed to a vacuum.
- Three tanks with two transmitters showed a big leap between the values.
- One transmitter seemed to show a very high mA value, indicating transmitter failure.
- A few just seemed unstable over the range i.e. when the tank was filled or empty.

Investigating

Prior to actually entering the tanks, and while they drained the tanks for water, an inspection in the software system was done and ship drawings were viewed to see where each tank was located and what to expect. When the tanks were drained and ventilated it was time to go down to see and change transmitters where necessary. In total seven transmitters in five different tanks were changed.

Learnings

The tanks are in every shape and size, but what is common for the all is that the pressure transmitter is placed in the least available spot in the tank, making service hard.

In the tanks containing two transmitters it was observed that they were placed really close to each other (20 cm) and that the software presents an average of them both. This makes no sense at all. One should either place them in opposite corners and use the average to compensate for tilting and rolling, or place them really close, but then only use one reading and the other one as a control value and as a back-up. Where there was big difference in values both transmitters were tested and the misleading transmitter was changed.

For one of the assumed defect transmitters it was actually found a different problem. The initial problem was they the transmitter show only 15% fulfillment, but when they opened the lid of the tank and looked down it seemed almost completely full. When reviewing the ship drawings one could tell why. The tank consisted of two tanks connected with a pipe in between, so therefor it was correct that only 15% of the total volume was filled. This was one example of misunderstanding the problem, and blaming the transmitter.

Similar misunderstandings have also been seen in tanks with for instance a “ventilation pipe” that causes an extra pressure, due to an increased water column. This can easily mislead the user to believe that the volume should have increased accordingly.

Further, most of the problems was related to defect transmitters, that all had in common a thick deposition layer and dirt, shown in the pictures below.

Figure 29: Defect GT403 on KV Bergen

Figure 30: Another defect Sensor on KV Bergen

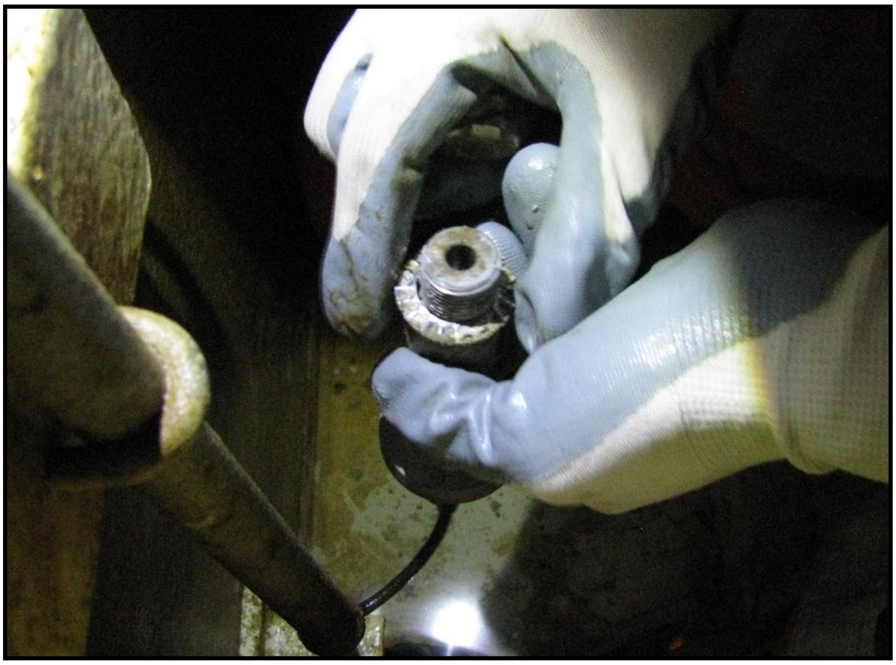


Figure 32: The Membrane has been Prone to Fouling

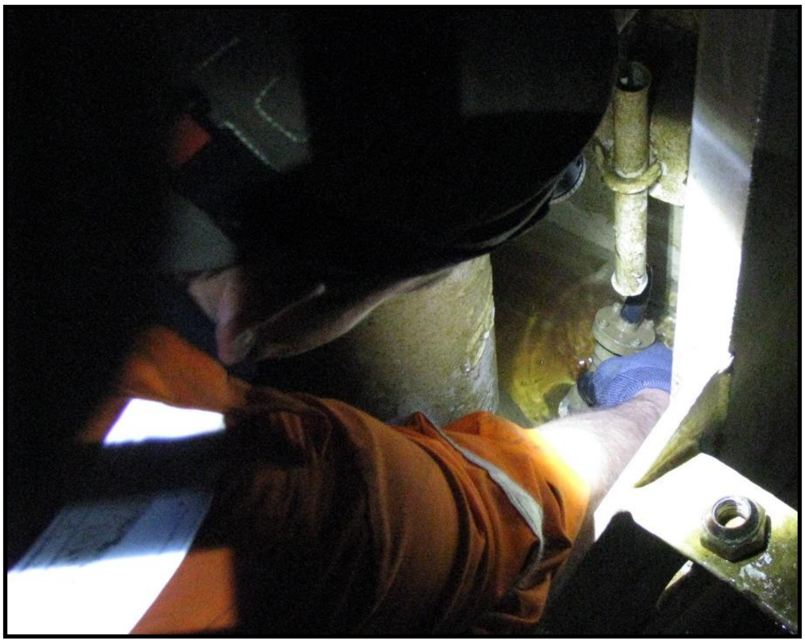


Figure 31: Disconnecting GT403, which is hard to reach

Supplementary Work Analyzing Defect Transmitters

The transmitters that were brought back were analyzed to establish the cause of error. The transmitters were connected to a jig and pressurized, while the output was read in mA by a regular multimeter. After this pressure test, the transmitter length was measured and then parts were taken apart one by one to look for leaks leading to corrosion on electronics. Each part was examined under a microscope. Afterword, the parts were cleaned, put together again and the length established. Comparing the first and second measurement on the length could indicate whether or not the parts were put together correctly in the first place.

Conclusion

The service field survey and the analyze result of the transmitter revealed that not all the problems were related to the senor itself, but could be misunderstandings or similar. Still there were too many defect transmitters on the ship, and during the supplementary work the most frequently repeated observation was established:

- Overgrowth/deposition around the membrane in front of the transmitter sensor element, causing unintended pressure on the membrane and/or leaks into the electronics.
- Leaks trough the threads between the housing parts causing corrosion on the electronics.

4.4 Visiting External Partners

4.4.1 Klay Instruments

Klay Instruments is a Dutch manufacturer of process instruments, founded in 1978, and has a worldwide sales and service network in more than 45 countries. They produce and sell a wide range for level and pressure transmitters. All instruments are designed and produced in the factory in Dwingeloo, The Netherlands.

Kongsberg Maritime AS is a customer of Klay, and bought some valves and pressure transmitters a few years back.

Objective

The main purpose of the visit to Klay, in Dwingeloo, was to learn more about the company, see the facilities, learn about more products and applications, as well as the technology and production.

Pressure Transmitter

The most interesting products in respect to the master thesis were obviously the pressure transmitters. The transmitters were made out of stainless steel AISI 316, with a laser welded membrane in front. The membrane they use, which is only 0.08 mm thick, is often made in AISI 316, but Hastelloy C and Tantalum are also optional materials, in addition to gold plating. The sensor element behind the membrane is based on a piezo sensor element.

Tantalum is a chemical element with symbol Ta and atomic number 73. It is part of the refractory metals group, a class of metals that are extraordinarily resistant to heat and wear.

Hastelloy is the registered trademark name of Haynes International, Inc. The trademark is applied as the prefix name of a range of twenty-two different highly corrosion-resistant metal alloys, loosely grouped by the metallurgical industry under the material term “super alloys” or “high-performance alloys”.

Klay’s Experience

- **Plastic housing:** They have done some experiments using plastic housing on the pressure transmitter, but claim to have experienced trouble with stabilizing the output signal and having some problems due to noise, due to electromagnetic (EM) shielding.
- **AISI 316:** They are proud of using stainless steel AISI 316 in all their products and claim to have no problems, what so ever, due to corrosion arguing that titanium is “overkill”.
- **Avoid corrosion:** In Klay’s experience the double ground of transmitters was the main issue due to corrosion and the formation of oxide layers.

Conclusion

It was really interesting to visit another company with different methods and technique from KM. The ‘not grounding’ phenomena seem to be a recurring action against deposition and/or corrosion both from KM’s experiments and in Klay’s experiments.

Furthermore, the laser welding part seemed interesting and the technique will be tested for this new KM transmitter as well.

4.4.2 KM Horten (Strandpromenaden)

KM Horten is a part of the subsea department within the maritime division in Kongsberg Group (KOG). They are based on the earlier company Simrad, but were acquired by KM.

Contact Person

John Inge Waage
Mobile: 90 54 53 00
Email: john.inge.waage@kongsberg.com

Objective

The objective of this visit is to learn more about plastic molding and plastic in seawater to gain more knowledge prior material selection for the new KM pressure transmitter.

Plastic Molding

Do to the harsh maritime environment they need a way to encapsulate their products and protect them from water intrusion. That is why they have developed expertise in plastic molding. They use different kinds of PUR (Polyurethane) materials to encapsulate metal based constructions.

Learnings

From what was seen and learned from Waage and his coworkers the molding technique is a well-developed method for encapsulate larger products in the size of an American football, but not as suited for small products. Also the transition between the plastic and the moving cable on the transmitter might be tricky to find a good solution to. Furthermore, it still needs to be a metal based under the plastic due to EM noise and EX certification.

Conclusion

Due to the EX-standards in the industry the option of making the whole transmitter in plastic seems to fall out. The idea to encapsulate a metal based transmitter is possible, but hard due to the small size and the moving cable.

Therefore, also considering the limited time of the master thesis plastic does not seem like the obvious choice.

CHAPTER 5

5 TRANSMITTER DEVELOPMENT

This chapter contains information regarding the development of the new transmitter

5.1 Material Selection

According to the fouling problems associated with the electrical circuit that occurs, using a non-conductive material such as plastic was considered early on.

There are several advantages due to making the whole transmitter in plastic or to encapsulate the transmitter in plastic. Most importantly it would isolate it from electron migration, but due to the transmitter’s small size it might be a tricky getting it waterproof in the transitions areas around the sensor element at one end and at the connections to cable in the other. Another challenge associated with a plastic housing is the regulations in accordance with the industry standard on “signal noise” and the EX requirements. Plastic is not commonly used and therefore there are great uncertainties related to the use in this application. The weightiest argument is however that the industry is very conservative, and most important of all; KM does already have a product portfolio and a production line that this product should be adaptable to for its survival.

Based on this, metal was the only viable choice at this point. The natural choice was titanium because this is what the transmitter is made of today and some parts of the old one might be reused. Assembling different metal materials, for instance by welding them together, is difficult mainly due to the various temperature coefficients.

5.2 Coating

To still be able to achieve the “non-conducting, no electron migration” property other solutions were considered. Coatings were a natural technique to look into, since it is so commonly used in other seawater applications such as in the subsea industry. Since the coating mainly should cover the front part of the housing, containing the sensor element with its electronic, high temperature coating methods lapsed. Looking at other options like spraying, dipping, brushing or varnish, they all give a very thick layer which is not desirable when applied to the thin membrane. Read more about the different applying methods in the theory chapter.

In KM’s earlier experiments silicon was used as coating on the membrane, but silicon is applied in a pretty thick layer. In real tests on Namura Shipyard it has been confirmed that its robustness against wearing is quite scarce. Further, it does not cover the transition area, only the actual membrane and does not seem as the optimal solution.

From articles, during the literature study, the conformal protective polymer coating material *Parylene* appeared as a waterproof and dielectric substance used to protect for instance

PCBs. Parylene is the trade name for a variety of chemical vapor deposited poly (p-xylylene) polymers and is commonly used as moisture and dielectric barriers.

So although there are many combinations of coating materials and coating techniques to be considered in selecting the optimum conformal coating process for this application, Parylene coating through vacuum deposition seemed the best choice. Because of its unique properties, Parylene conforms to virtually any shape, including sharp edges and surface roughness.

Since Parylene is applied at the molecular level by a vacuum deposition process at ambient temperature, there are no extreme temperatures involved and the thickness of the layer is controllable down to less than a micron (1 µm). In addition Parylene has really good adhesion properties, which makes it stick well to the surface it is protecting.

5.3 New Pressure Sensing Sensor Element

To avoid water from penetrating and particles from building up in the gap between today's sensor element and housing one action was to look at a new sensor element in a material weldable to the housing, removing and gasket. At such an early point in the development and in accordance with KM's well-working calibration and test procedures, which will be dug into later, the precision of the sensor element was not of any concern. Ten newly developed sensor elements in titanium were bought from the German company, JUMO GmbH.

5.4 Laser Beam Welding

This part gives the reader an insight to the steps towards the final laser welding process that is one of the major innovations of the old GT403 pressure transmitter and that addresses some of the aforementioned core issues with the existing transmitter.

One of the main issues with today's pressure transmitter is the precipitation and growth in the anterior part of the transmitter, in the transition between the housing and the sensor element, where there currently is only an O-ring in a groove separating/joining the parts. As seen on other KM products and at Klay Instrument's products, welding is commonly used to avoid the gap between parts and to make the connections stong.

Regular welding is however not applicable in this application due to the amount of heat it generates and the sensor elements fragile nature. This is where laser beam welding makes its appearance.

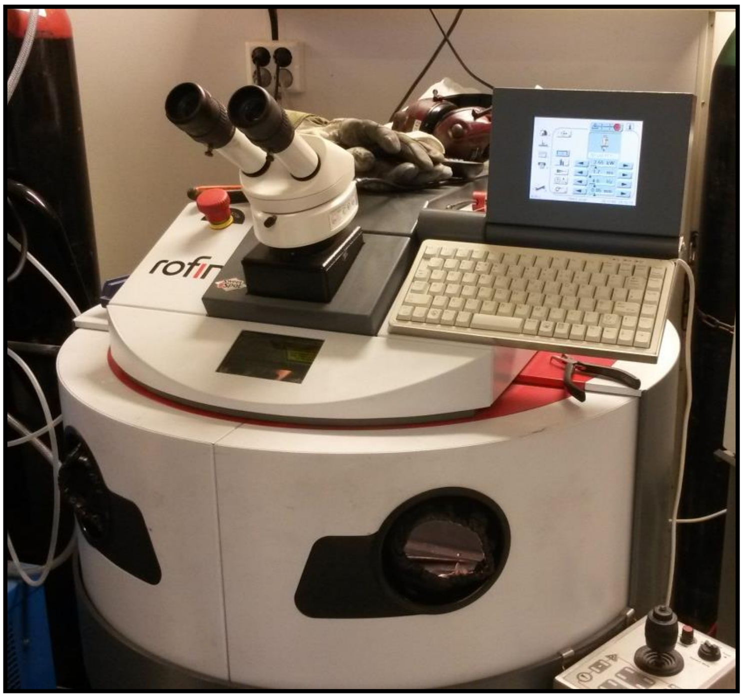


Figure 33: Laser welding machine

LBW is a welding technique used to join multiple pieces of metal by using laser, creating small HEZ. The spot size of where the laser beam hits varies and is referred to as *laser diameter*. For this application pulsed beam was used to keep the heat generation at a minimum, due to the thin materiel.

Parameters

There are a lot of different parameters for adjusting the laser welding machine to obtain the most wanted characteristics and abilities of the weld:

Power [W = J/s], Time [s] (time of each wave), Laser diameter [mm], Energy [J], Energy density [J/cm^2] and Speed [s] (time interval of impact).

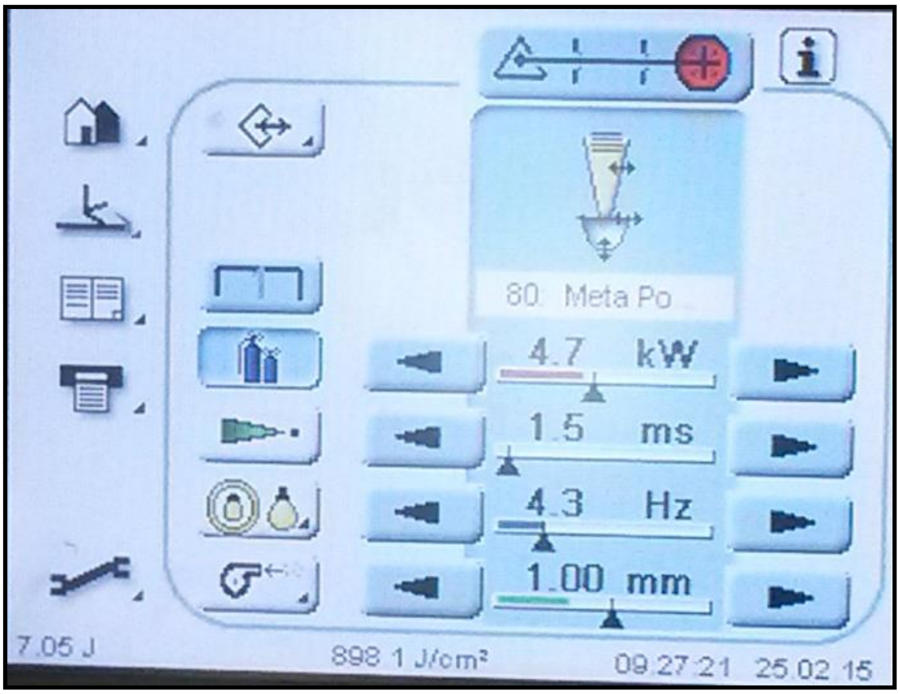


Figure 34: Screenshot from laser machine

First Round

To address one of the aforementioned issues, laser welding was given a try.

Without any significant experience with laser welding, seeking personnel with knowledge and practical experience was essential. Terje Stamnes, a technician at KM's, has got knowledge and experience with the laser welding machine as well as patience and a zeal for innovation. After consulting with him the plan for the laser testing was outlined.

Some "dummy" sensor elements, meaning sensor elements without electronics and membrane, was supplied by the German company JUMO for use in early welding tests. A titanium rod was also ordered to make a new housing and test housing.

The initial round was mainly to see if the laser welding idea had any potential at all, and if so try to find the optimal parameters for the machine. Small pieces were chopped off from the titanium rod and machined so that the sensor element would fit in. The figure below shows the dummy element (upper part) and a pretended housing.

Figure 35: Test housing and dummy element

The objective was to connect the parts hitting them with a laser beam along the line showed by the red arrow in the following figure. The laser welding was done in one area at a time and with different setting to do some evaluation on the adjustable settings on the machine for later welding. For this first test the assembly was in "flush position", meaning that the two parts' surfaces was perfectly in line.

Figure 37: Welding line

The following figure shows a close up photo of one of the laser welding areas, which have had about 7-8 hits with the beam:

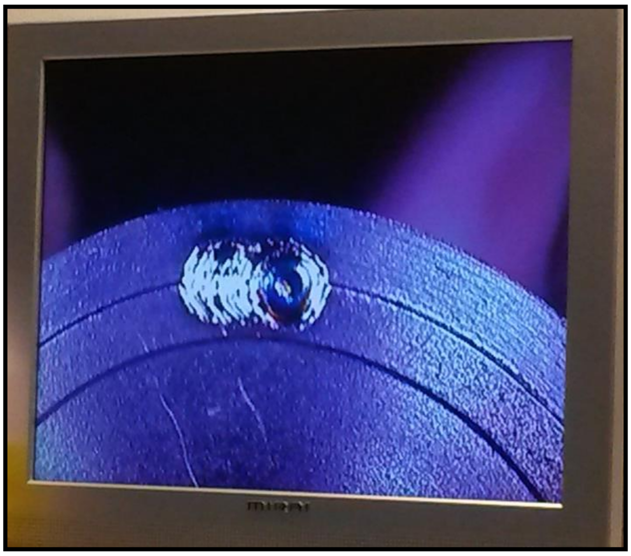


Figure 36: Laser welding

Test Result

Laser diameter	Energy density	Experience
1.10 mm	800 J/cm^2	The power density is to low and the weld seems to be too shallow.
1.10 mm	850 J/cm^2	The power is better, but the diameter was too big, and may hit the membrane of the sensor element.
1.00 mm	900 J/cm^2	This is actually pretty good. **Best so far**.
1.00 mm	1000 J/cm^2	The power density is too high, resulting in deep craters and some metal splashed up.
0.80 mm	1049 J/cm^2	The power density is too high compared to the diameter, resulting in deep craters and some metal splashing.
0.85 mm	929 J/cm^2	**Good**. Seems to be a better diameter (shielding the membrane more), and a fitting power density.

Table 6: Test results from laser welding

Supplementary Work

To learn as much as possible it was necessary to look into the welds, and to see how deep it went, so the joined parts were taken apart.

The most critical part is the sensor element, and it was important to check that the laser did not get all the way through the material in any cases, and fortunately it did not.

Conclusion

In general the welds looked good, and even with the highest power density the weld was only half way through, so the learning was to use as high power density as possible, without creating spilling at the top to get a good adhesion/binding. The diameter should not be too wide to shield the membrane as much as possible from the HEZ, but it should not be too narrow either because that creates unwanted splashing.

Exceeding a power density at 1000 J/cm^2 proved to face some troubles and metal started to splash as can be seen in the following figure:

Figure 38: Metal spilling

A diameter in the range 0.85-0.95 mm might be good. A power density at 850-950 J/cm^2 seems reasonably.

But it should be looked more into the speed of the welding itself, both the time between the impacts and the speed of the object.

Second Round

In the next round it was welded all the way around, not only partly like in the first. This is to see the effect of heating over time, and to make it more realistic. In addition it was tried with one part placed higher than the other, and kind of melt down onto another. The objective was to find the best height ratio between the inner and outer part during welding, with respect to gaining the best welding quality without compromising on protection of the sensor element's membrane.

Figure 39: Three different heights

For this test it was important that the parts were in a good position on the jig inside the laser welding machine, and were able to be turned in a circular path. For this test, based on findings in the previous test, the diameter of the laser was set to 0.85 mm and the power density to 929 J /cm^2. The turning and speed were manually controlled for this test.

The three different experiments were; middle part respectively 0.2 mm above, in line with (flush) and 0.5 mm below.

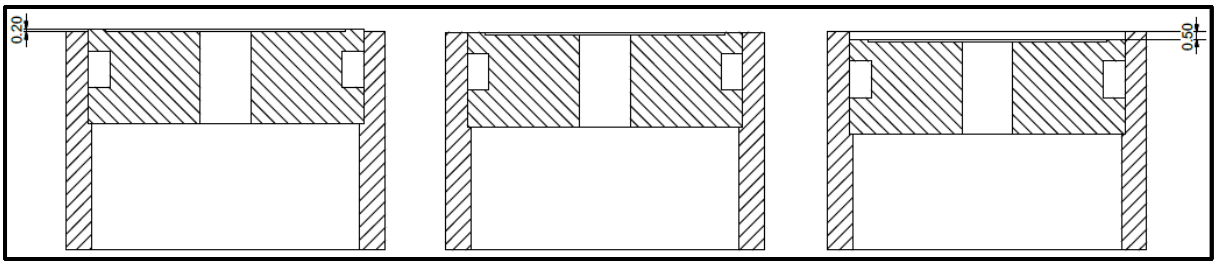


Figure 40: Mechanical drawing of the three types, from the left 0,2 mm, flush and 0,5 mm.

To see more accurate mechanical drawings of the three different heights see "Appendix J: Mechanical Drawing – Test Welding 6.3", "Appendix K: Mechanical Drawing – Test Welding 6.5" and "Appendix L: Mechanical Drawing – Test Welding 7.0".

Results

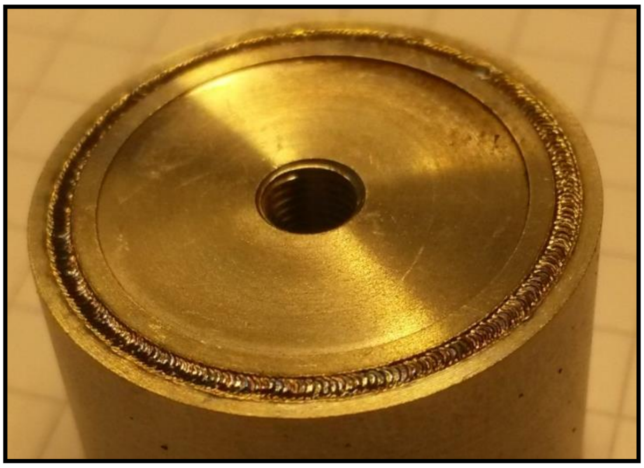


Figure 41: Flush position

In this test the two parts are in line, referred to as flush. This looks good, and the membrane would hopefully not be affected. Here it will be a bump in the center of the welding line.

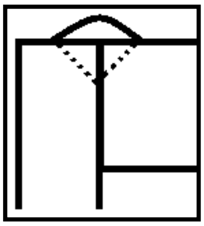


Figure 42: Middle part is above the outer tube

Here the middle part is above the outer tube and the weld material kind of flows outwards. The result look pretty good, and weld seam lies in a good distance to where the membrane will be. But you get this small hill up to the center part.

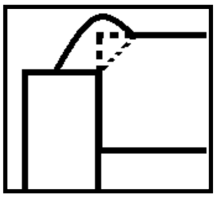
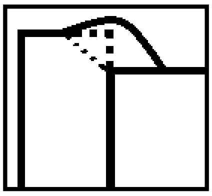


Figure 43: Middle part is below the outer tube

Here the middle part is below the outer part and the weld material kind of flows inwards. This weld seems strong, but it probably covers too much of the sensor element area and may result in damage of the membrane. Here it will be a small hill down to the center part.



Conclusion

After the testing, all parts were visually inspected to see which solution that protected the sensor element from heat and splashing. It was clear that the flush position was the most stabile weld and based on observations, this should not affect the sensor element significantly.

It was also learned that the beam did not have to hit perfectly in the middle of the two parts, but the diameter could cover, for instance, 60 % of the outer part and only 40 % on the sensor element side, which again protects the sensor element from heat, and still seems to give required depth and adhesion.

5.5 Execution/Assembling

Procurements and Preparation

The first thing that was done after the outlines of the new generation pressure transmitter were drawn was to contact JUMO to get them to send ten pressure sensor element; five 1 bar sensor elements and five 5 bar sensor elements. See mechanical drawings in “Appendix M: 1 bar sensor element JUMO” and “Appendix N: 5 bar sensor element JUMO”.

Figure 45: DMZ Ø19 titanium element from JUMO

Four wires were soldered to extend the already existing pins that carries the signals at each sensor element:

Figure 44: Wires soldered to pins on element

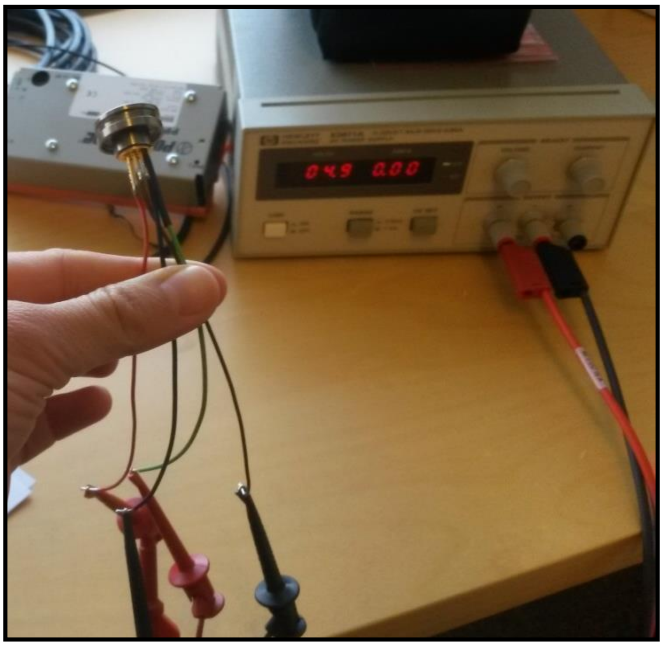


Figure 46: Testing resistors of the sensor element and output signals of the bridge at 5 V supply

When the sensor elements arrived they were all checked by measuring the four resistors (R_1-R_4) and reading the output signal when supplied by 5 volt and compared to the provided product specifications. See the drawing of the element in the figure below.They were all within the requirements. The same test was run after soldering the wires as well to see if this had any effect. They all passed the test again. See the results of the last round in "Appendix O: Measurement Prior and After Laser Welding".

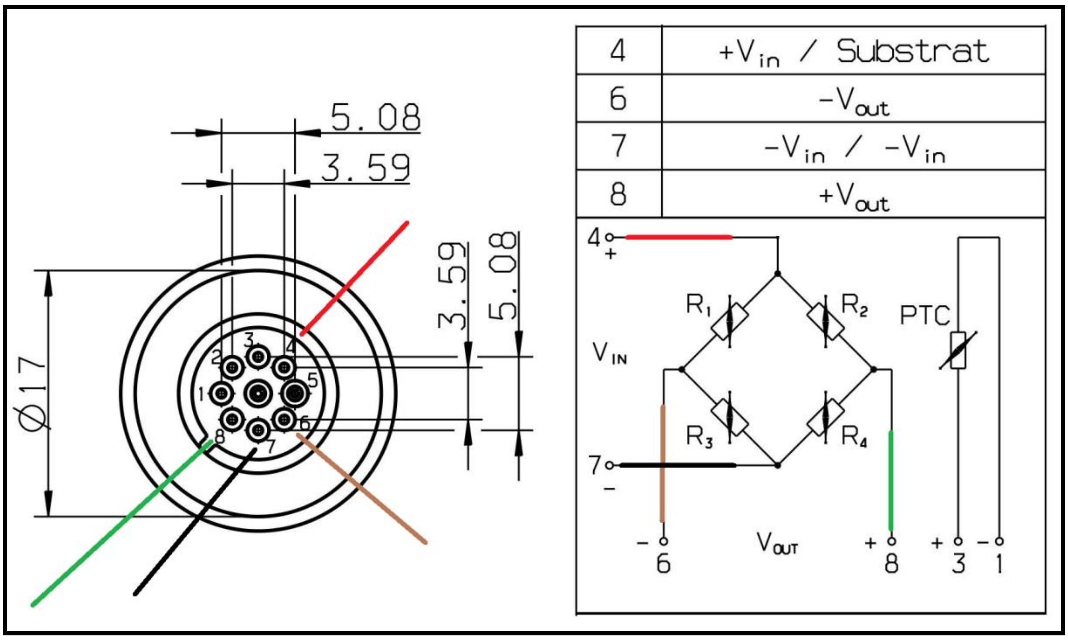


Figure 47: JUMO Element Circuit

CAD Model

Prior to the actual work at the workshop a CAD model was made in Autodesk Inventor to avoid any mismatch between parts. JUMO provided information regarding the shape and size of their sensor element and the rest was designed to match it. After a few modifications and some consultancy with the technician Terje Stamnes at the workshop the dimensions were given and the initial shape specified.

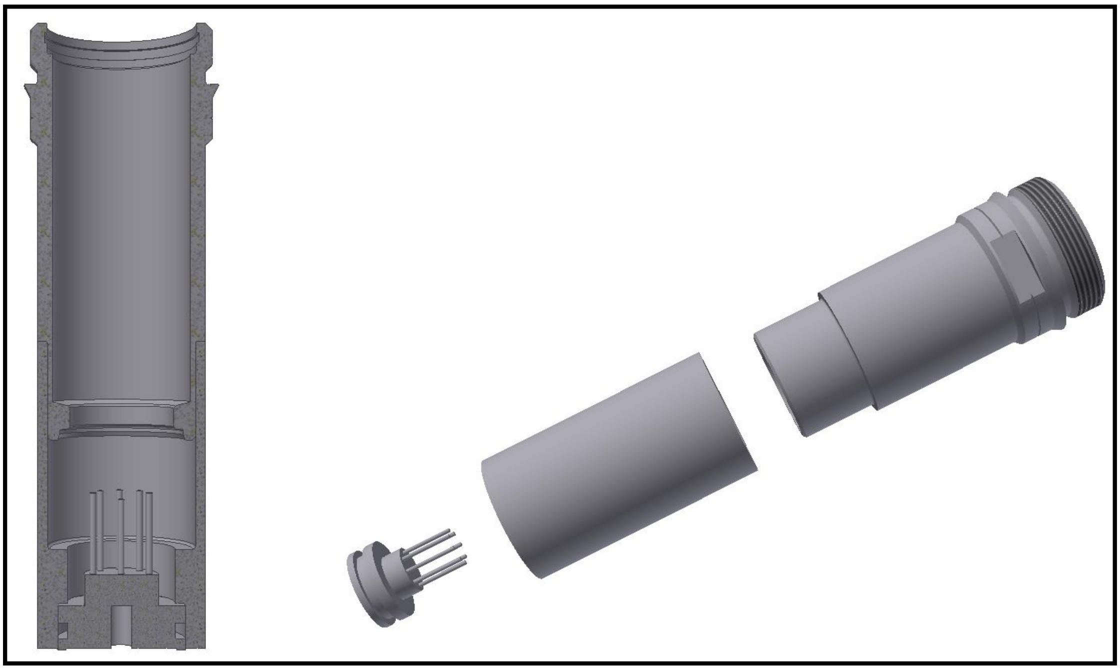


Figure 48: CAD Model

Encapsulate the Sensor Element

To encapsulate the sensor element a new part needed to be made. A custom made housing part (adaper) was machined from a titanium rod, based on the detailed mechanical drawing of the CAD model.

To be able to test the transmitters in the already existing test and calibration line at KM, it was decided to make threads on the outside on the lowermost part of the housing (the adapter).

The following pictures show the new part.

Figure 51: Lowermost housing part with threads

Figure 50: Lowermost housing part and element in flush position

Figure 49: Element laser welded to housing

To join the sensor element to the first housing part, laser weld was used, as shown in the very last picture on the previous page. Due to no experience with the technique some trial and error was needed. Read more about the laser welding technique in the theory chapter. The trial part is also described in the last section.

The laser welding was done at 929 J/cm^2 and with a diameter of 0.85 mm.

After the laser welding, all sensor elements were again tested the same way as in the initial round by measuring the resistors and reading the output when applying 5 volts. See the results in “Appendix O: Measurement Prior and After Welding”. There were some changes in the numbers, but nothing of concern and no clear correlation, so all elements passed the test.

Furthermore, the two random sensor elements were chosen to be exposed with real pressure to see how they would react and behave. When they were to be pressurized in the already existing KM pressure line’s jig, they did not fit into the threads. It turned out that the threads on the transmitter housing were M24, but the threads on the jig were in a different standard and measured to be half an inch. The problem was solved by making an adapter in brass, as seen in the figure below.

Figure 52: Adapter

Then the test could begin; they were connected the jig, pressure was applied and readings were done manually. Keeping in mind that they were not calibrated yet they both delivered great results. To see the results see “Appendix P: Pressure Log: Laser Welded Transmitters (1 bar) before and after Coating”.

Parylene Coating

From the point when Parylene coating was decided to be used, research on providers was done. KM had from about ten years back established contact with the Swedish company ParaTech, and they actually had a few transmitters coated and sent out in the field with great success. Read more about that in section “4.2.3 Experiment with Parylene”. Based on that it was natural to contact them again and the contact person from ten years back still worked there and we figured out an agreement.

They did not have much experience with coating parts for the ballast tank environment application and/or coating of such a thin membrane, but they knew enough to give descent advice. It was decided to try three different coating thicknesses. The thicker the coating is the better it protects, but the thinner it is the less it influences the membrane. Two transmitters with a 10 µm thick Parylene coating, six transmitters with a 15 µm thick Parylene coating, and two transmitters with a 25 µm thick Parylene coating was the final agreement.

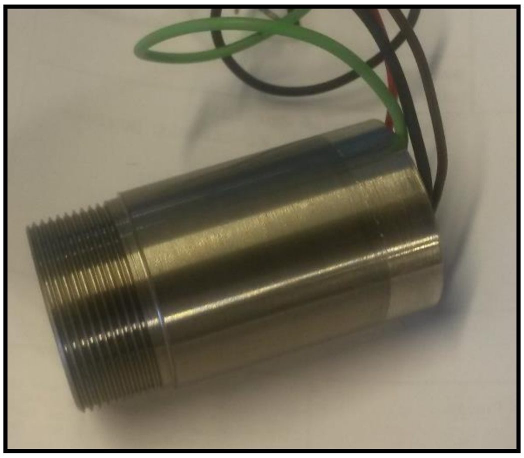


Figure 53: Parylene coated element and lowermost housing part (adapter)

In just a week the transmitter parts had returned and it was time for another round of testing to see the effect of the coating. See the results in “Appendix P: Pressure Log: Laser Welded Transmitters (1 bar) before and after Coating”.

The same procedure was done, by applying pressure and manually read the voltage. Fortunately they matched themselves from the same test prior the coating.

Adjust Housing and Connection

For the further testing the transmitters needed circuit board and the rest of the housing and some sealing at the top.

Since the shape of the part is not so central for this test the existing housing was reused, by just a small modification. The outer threads were removed get it to slide nicely in to the lowermost part of the housing containing the sensor element. See “Appendix Q: Mechanical Drawing of New Housing Part”.

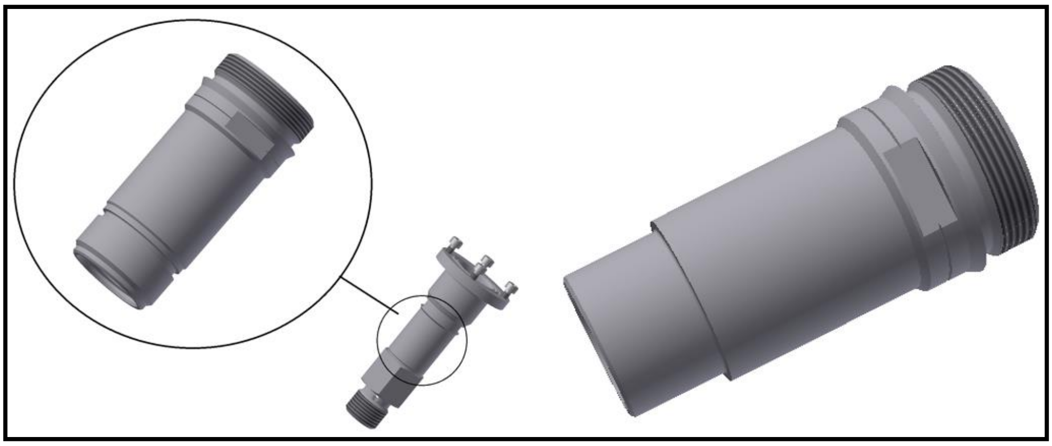


Figure 54: Existing housing and sensor to the left. Modified housing to the right

Figure 55: Adjusted housing (removed threads)

The adjusted housing part and the new made lower housing part (adapter) was laser beam welded as well. This round was less time consuming and some basic experience was present. This laser welding was far less critical due to laser power, spilling and heat generation and it went well.

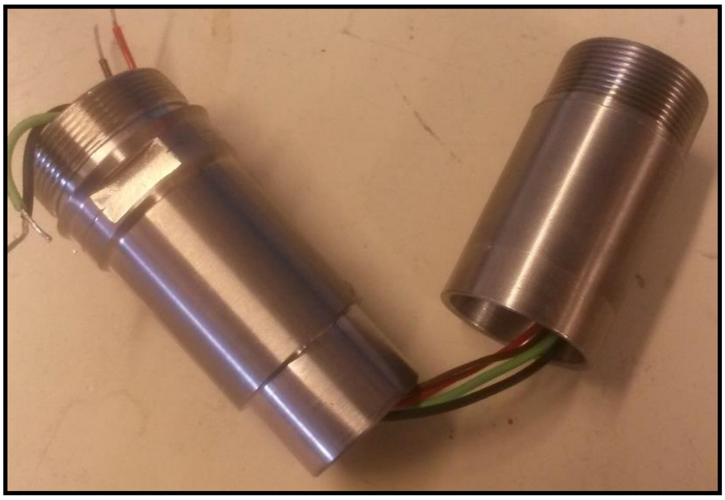


Figure 56: STEP 1 Pull wires through

Figure 57: STEP 2 Push together the two housing parts

Figure 58: Laser welded housing connection

The laser welding was done with 733 J/cm^2, 12.95 J, 3.7 kW, and with a diameter of 1.50 mm and a speed of 3.5 ms and 4 Hz.

See mechanical drawing of the assembly in “Appendix R: Mechanical Drawing of Assembled Prototype”

PCB Installation and Engraving

Since todays GT403 uses an absolute pressure sensor element and this new German titanium sensor element is a relative sensor element another standardized PCB, GTB-23, was used. It was connected to the wires from the sensor element.

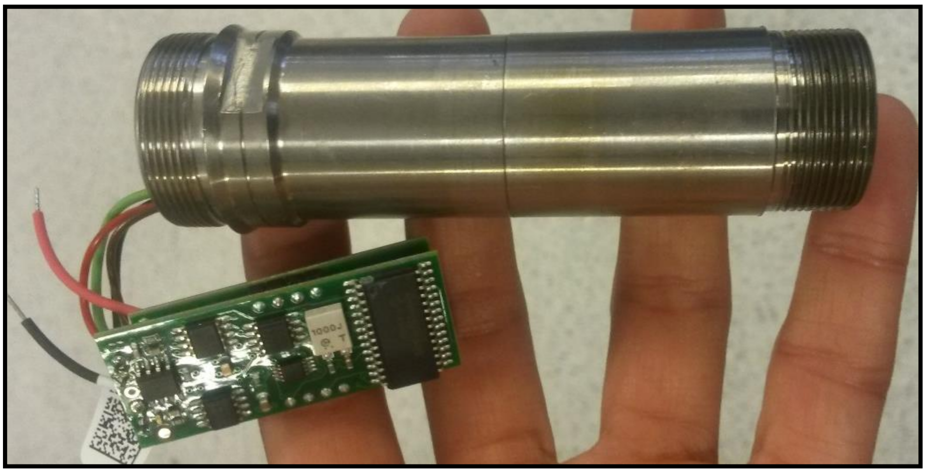


Figure 59: Connecting element wires to PCB

Figure 60: Pressure testing after assembling housing and PCB

After assembling the housing and connecting the sensor element to a PCB a new test was ran.

The small, round PBC at the top could be reused, but it was necessary to drill a hole through it get proper ventilation since it is a relative sensor element, needing ventilation.

Figure 61: Connecting remaining wires to the round PCB

To avoid losing track of the transmitters it was decided to label them using engraving. Each transmitter, when given a PCB, was given a serial number.

The engraving labeled each transmitter with the new serial number, whether it was a one or five bar sensor element, and the thickness of the coating (10, 15, 25 µm).

The final part was to connect the transmitter to the flange, and here the existing solution was used, since it has no effect on the testing. The idea with the flange is to making a watertight transition to the cable.

Figure 62: Sensor with flange

CHAPTER 6

6 TESTING

This chapter contains information regarding the testing that took place during this master project.

6.1 Testing and Calibration Prior Submersion

When the transmitters were completely assembled the real testing and calibration could take place. All 10 pressure transmitters were mounted on the jig and automatically tested over a period of a few hours. They were tested and calibrated according to the standard procedure used for the current pressure transmitters, GT403. The initial accuracy requirement was set to 0.25 %, as for the existing GT403. One of the transmitters actually made it through the narrow requirement, but the rest of the transmitters seemed to fall just outside, so the margin was raised to 0.5 % accuracy, which is still very good.

They were tested at four temperatures, respectively 0, 22, 40 and 60 ºC, and at each temperature they were pressurized at 0, 20, 40, 60, 80 and 100% pressure. The full range of the sensor elements used in the tests are 1 and 5 bar, respectively downscaled to 0.6 and 2.5 bar when used for calibrated pressure transmitters. Signal output was read and compared to linearity, temperature drift and repeatability criteria. If the signal did not fulfill all criteria, the transmitter was rejected. If they were within the criteria an approval certificate was generated. See the figure below, showing the test temperatures and pressures. As shown in the figure, the accuracy of the respectively transmitter is 0.5%. The type of transmitter is given the name

KONGSBERG	PRESSURE TRANSMITTER
Transmitter type: GT403C0G2.5D00 Signa type: 2 wired 4-20mA Signal offset: 4mA at 0 Bar Relative Pressure range: 2,5 Bar	Accuracy: 0,5 % Serial number: 140853 Date of test: 2015-04-29
Test temperatures 0 °C 22 °C 40 °C 60 °C	**Test pressures (% FRO)** 0 % 20 % 40 % 60 % 80 % 100 %
All test passed according to spec.	
Custom order:	Control (sign):

Figure 63: Sensor certificate

GT403C0G2.5D00, where the G2.5 means that this transmitter is of a relative type (G-gauge) and with a range of 2.5 bar. The serial number is also given.

Nine out of ten transmitters made it through the test. See the results in “Appendix S: Result 1 bar Sensor element” and “Appendix T: Result 5 bar Sensor element”.

The way the calibration works is that the machine “gets to know” each unique transmitter and notice how it behave over time. Afterwards it knows how the graph needs to be shifted to be stable over the temperature interval, it adds and subtracts values until the graphs for each temperature is more or less a straight line. The “normalization” of the curves are then saved in the transmitter’s software so that it knows which output to give during operation.

6.2 Transmitter Testing in a Simulated Ballast Tank

6.2.1 Description

The experiment tries to reconstruct the operating environment in ballast tanks on ships by filling a basin of approximately 1000 liter with seawater taken from the Trondheims fjord and submerge the transmitters to about 30 cm from the bottom. The seawater is heated to 30-35 degree Celsius to simulate a climatic temperature in other parts of the world, as well as speeding up the experiment due to the limitation of time. The basin, which is made out of plastic, also contain some metal part simulating the tank itself and also a submerged zinc anode. The transmitters was continuously measured during the test period and visually inspected regularly.

6.2.2 Purpose

The purpose and objective is divided into three main parts, and one additional test;

1. Verify that the self-made transmitters actually are waterproof, especially in the welds, and that they work properly.
2. Verify that addition of powdered calcium hypochlorite ($CaOCL_2$) in seawater will result in deposition of calcium at the transmitter housing and sensor element.
   …And if so:
3. See if the Parylene coated transmitters experience less or no deposition of calcium on coated areas.

In addition, a test was run in the same experiment tank, with one transmitter to see if there was any effects of isolating it. This was just to give an indication on whether or not KM should look more in to that later.

6.2.3 Background and Hypotheses

Earlier studies carried out at KM showed that some of this calcium deposit on the housing and sensor element, drastically reduces the transmitter’s lifetime. One part of this test will therefore be to reconstruct that experiment and verify it.

Since this deposition is one of the main problems this thesis is trying to address, the test will also include an attempted solution. By using Parylene on the sensor element and its housing it will hopefully reduce or prevent that deposits from sticking to the surface. The difference is, hopefully, that the layer will not allow for growth and since the thickness will be constant, the offset will be too, and not change over time. For this test three different coating thicknesses was tested; 10, 15 and 25 µm, decided in collaboration with the third party coating company, ParaTech. The thicker the coating is, the more robust the transmitter it is due to shocks and water penetration, but at the same time the layer should not affect the thin membrane too much.

Furthermore, some other experiments suggest that the effect of grounding the transmitters should be investigated. The hypothesis is that by isolating both the transmitter and its cable screen, meaning not grounding it, the transmitter will not be a part of a natural electro-chemical process that takes place in a ballast tank, and then hopefully be protected from deposition of calcium.

6.2.4 Equipment List

- Transmitters
    1. New relative transmitter without coating with double grounding
    2. 2 x New relative transmitter with 10 µm coating with double grounding
    3. 2 x New relative transmitter with 15 µm coating with double grounding
    4. 2 x New relative transmitter with 25 µm coating with double grounding
    5. 4 x Standard abs. KM ballast transmitter with double grounding (todays solution)
    6. 1 x Standard abs. Kongsberg ballast transmitter totally isolated
    7. Standard atmospherically Kongsberg ballast transmitter GT402
- 1000 L basin filled with seawater, with a removable lid
- Sink anode with wires (powered)
- Power supply, HP E3611A
- Immersion heater that keeps 600-700 L water at 30-35 º C
- Grounding setup
- National Instruments NI-PXI-6289 Multifunction DAQ modul
- 1 computer, mouse and keyboard
- 14 grams powdered calcium hypochlorite
- Attachments creation for the transmitters with clamps (to fix them under water)

Below is an overview of the 7 new pressure transmitter that participated in the test:

ID	Sensor element Type	Parylene coating thickness (μm)
140864	1 bar	10
140852	1 bar	10
140866	1 bar	15
140865	1 bar	25
140868	5 bar	15
140869	5 bar	25
140853	5 bar	0

Table 7: Seven new prototypes

(NB: The three other prototypes were kept as backup if anything went wrong with these seven and also for further testing and comparison.)

6.2.5 Test Execution

Procurements and Purchases

The same basin as Hestmo and Rambech used in their experiment, was used in this experiment. The size of the basin is approximately 1000 L.

Figure 64: 1000 L basin

To be able to heat the water to a desired temperature at 30-35 º C an immersion heater, made for large aquarium, was bought at a pet store.

Since all ballast tanks usually contains a zinc anode to protect the tank it was bought for this test also to make the environment as realistic as possible.

The warehouse was checked for powdered calcium hypochlorite and the amount left was satisfying.

Filling water

The basin was placed in KM’s basement, and filling it with several hundred liters of seawater was a huge operation. Having two buckets of 10 L, it was realized that this could take forever. Therefore, six larger buckets with screw lid were bought and a car with a trailer was lent. The water collecting place was chosen to be Trolla, a place in the north western part of Trondheim, away from the river mouth to avoid brackish water. Driving to Trolla, parking close to the sea, using 10 L buckets to fill 40 L buckets allowed bringing about 240 L of seawater back in one go. The basin was filled with a total of 600 L.

Figure 65: Using a car with trailer and 40 L pails seawater was transported

Creating an Attachment Creation and Cable Clamp Board with/without Grounding

To be able to fix the transmitters under water an attachment creation was made. Some scrap metal was found in a dumpster nearby and parts were picket to constitute a construction. In addition the warehouse had some spare clamps that were useful for the creation. Welding the parts together and attach the clamps made up the first solution to the problem

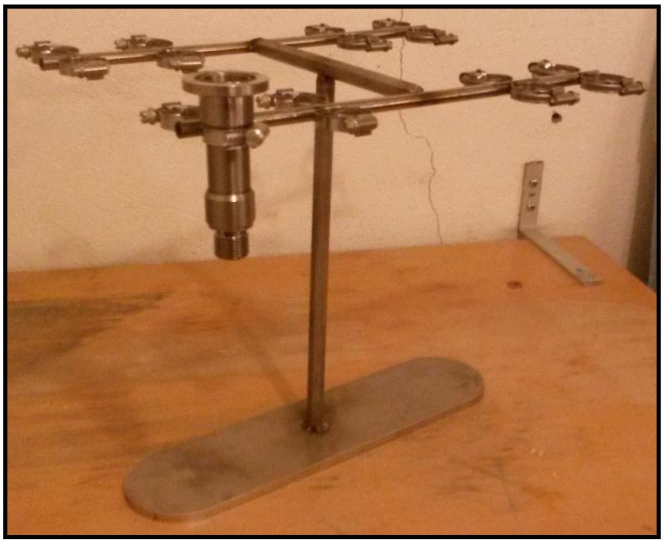


Figure 66: First attachment creation for submerged sensors

At a more thorough review it was clear that the initial creation was a bit too tall and unstable because of the lightweight bottom support. So for the second and final attempt the creation was made shorter and the bottom support was changed to a heavier piece of metal.

Figure 67: Final attachment creation for the sensors

Furthermore, it was necessary to fix the transmitter cables and connect their screens to a common ground. Therefore two rows of cable clamps were connected to chipboard, one for all cables to be fixed and one for connection to common ground.

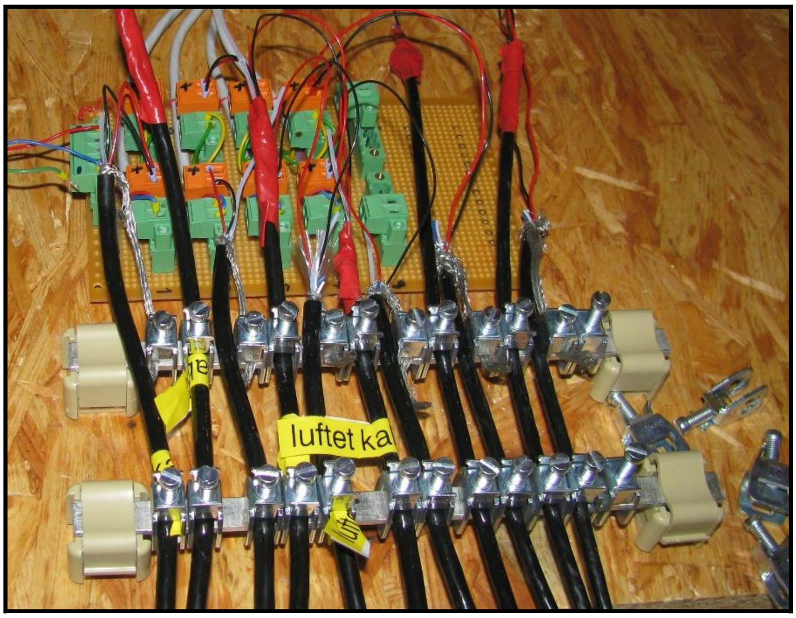


Figure 68: Chipboard for cable connection

The chipboard was also a perfect place to fix the GT402 atmospheric pressure transmitter, shown in the picture below.

Figure 69: Atmospheric sensor GT402 attached to chipboard

Transmitter Installation

First an O-ring was placed in its groove and some grease was smeared onto it, to make the connection tight.

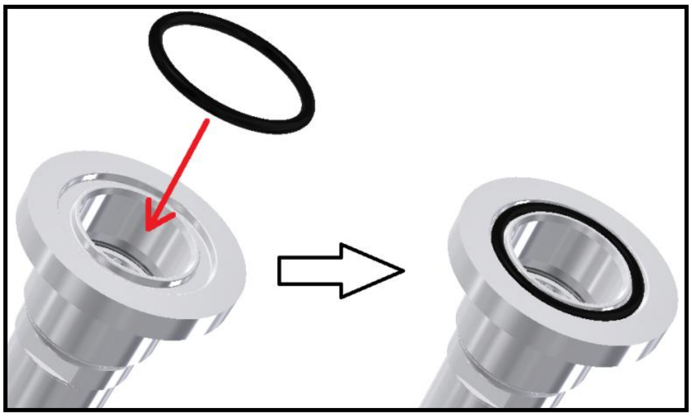


Figure 70: CAD-model: Placing O-ring in groove

The next step was to *click on* the wires form the cable to the transmitter.

Figure 71: CAD-model: Connecting wires from cable to sensor

The last part was to connect the flanges, by four screws:

Figure 72: New generation pressure transmitter ready for submersion

To install the transmitter the cables needed to be fixed by connecting them to the cable clamps on the chipboard, as mentioned above. All output cables (+ and -) were connected to their respective channel on the DAQ system.

The screens were connected to the grounding clamp row. The transmitters themselves were strapped to the attachment creation.

Figure 73: Sensors strapped to the attachment creation

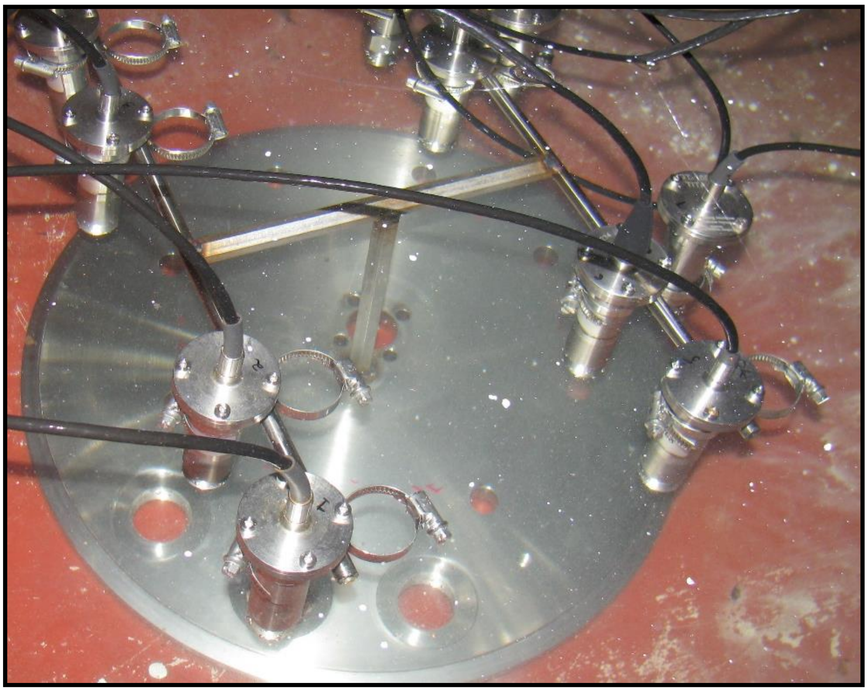


Figure 74: Sensors submerged

Logging

When the test experiment setup was done, the logging program on the computer could run. First there was a test run to see if the logging was happening as expected, and when it seemed to work well the real test could begin.

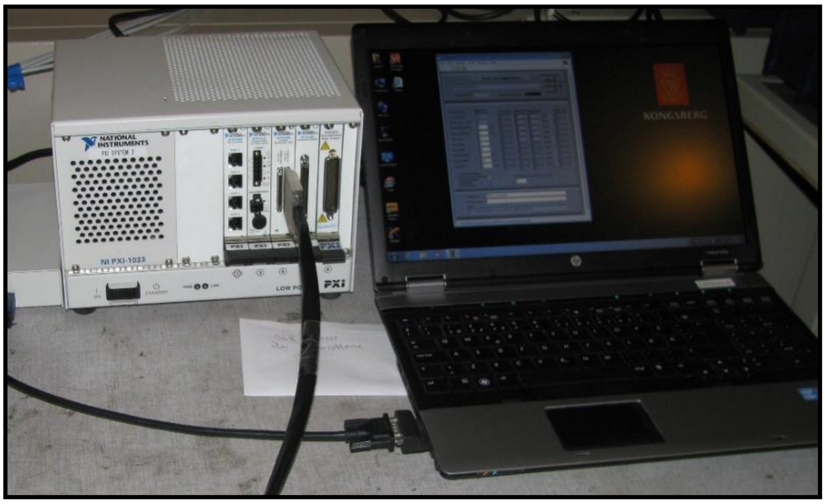


Figure 75: National Instruments DAQ System was used to log the signals

Drawing of Test Setup

The zinc anode was connected to plus (+) and the grounded cable screen row was connected to minus (-). This was done to push the reaction in the desired way and to accelerate the process, due to time limitations of the master thesis. The power was set to give an approximate value of 110 mA, which was the maximal current this power supply could generate. In addition, all transmitter were connected to the DAQ system to read the signal.

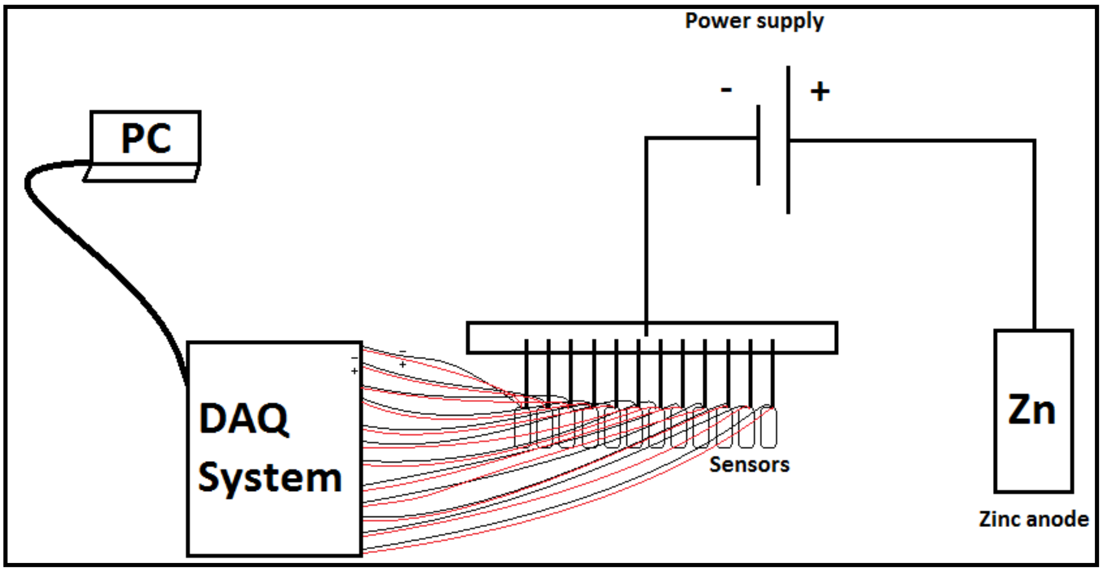


Figure 76: Test setup

CHAPTER 7

7 RESULTS

This chapter presents the outcome from the testing that took place during this master project.

7.1 Test Results

7.1.1 Visual Inspection

The following picture shows seven of the new prototype (six coated and one not coated) and four of the regular GT403. From the overview picture it is easily seen which transmitters that are coated and which are not. Everywhere, but at the coated area, it was a thick, hard, crystal-like layer.

Figure 77: Overview of all sensors

Furthermore, it was clear that the layer was thickest at the welds on the attachment creation, which is natural due to residual stresses.

Figure 78: Thick deposition layer on welds at the sensor attachment creation

Visual Inspection GT403 (after 26 days)

The visual inspection of the GT403 transmitters show a major growth of a calcium deposition layer. The membrane cannot be seen since it is hidden inside the lower thread part, and it is not covered as it is made of ceramic which is more or less inert to deposition. However, over time the growth will affect the membrane as it gradually builds up a layer that fills the process inlet.

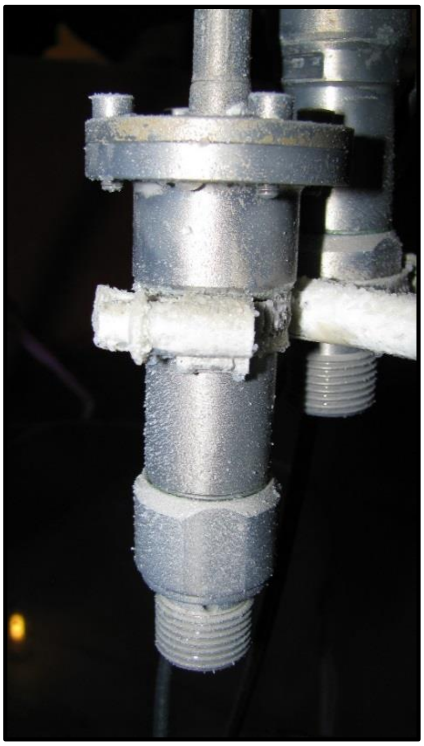


Figure 80: Visual inspection GT403

Figure 79: Visual inspection of GT403 in front (process inlet)

Visual Inspection of the New Prototype without Parylene Coating (after 26 days)

As can be seen in the following pictures the new prototype without coating experienced the same deposition layer as the old GT403. Since the membrane here is in metal it was is heavily covered, as can be seen in the following figures.

Figure 81: Visual inspection of new prototype without coating

Figure 82: Visual inspection of the new prototype without coating in front and the membrane

Visual Inspection of the New Prototype with Parylene Coating (after 26 days)

As can be seen in the pictures below; the Parylene coating clearly had an effect on the deposition. On coated areas there were no deposition layer at all, but some deposition on the size of pinheads, especially on the threads, occurred. The possible reason for this will be discussed in the next chapter.

Figure 83: Visual inspection of new prototype with coating

Figure 84: Visual inspection of new prototype with coating in front and the membrane

Visual Inspection of the isolated GT403 (after 15 days)

The fully isolated GT403 did not experience growth of a deposition layer. It was submerged for 15 days, but shows a good trend and could probably withstand layer formation for longer periods of time.

Figure 85: Isolated GT403 submerged

Figure 86: Visual inspection of the isolated GT403

7.1.2 Logging Data

The DAQ system ran for all 26 days, measuring the pressure values of the seven new prototypes every tenth minutes. This gave 3667 measuring points per transmitter, and it formed a good foundation to evaluate changes, drift or malfunction over time.

The figure below shows the curves of the seven tested and calibrated transmitters and how they have changed over time.

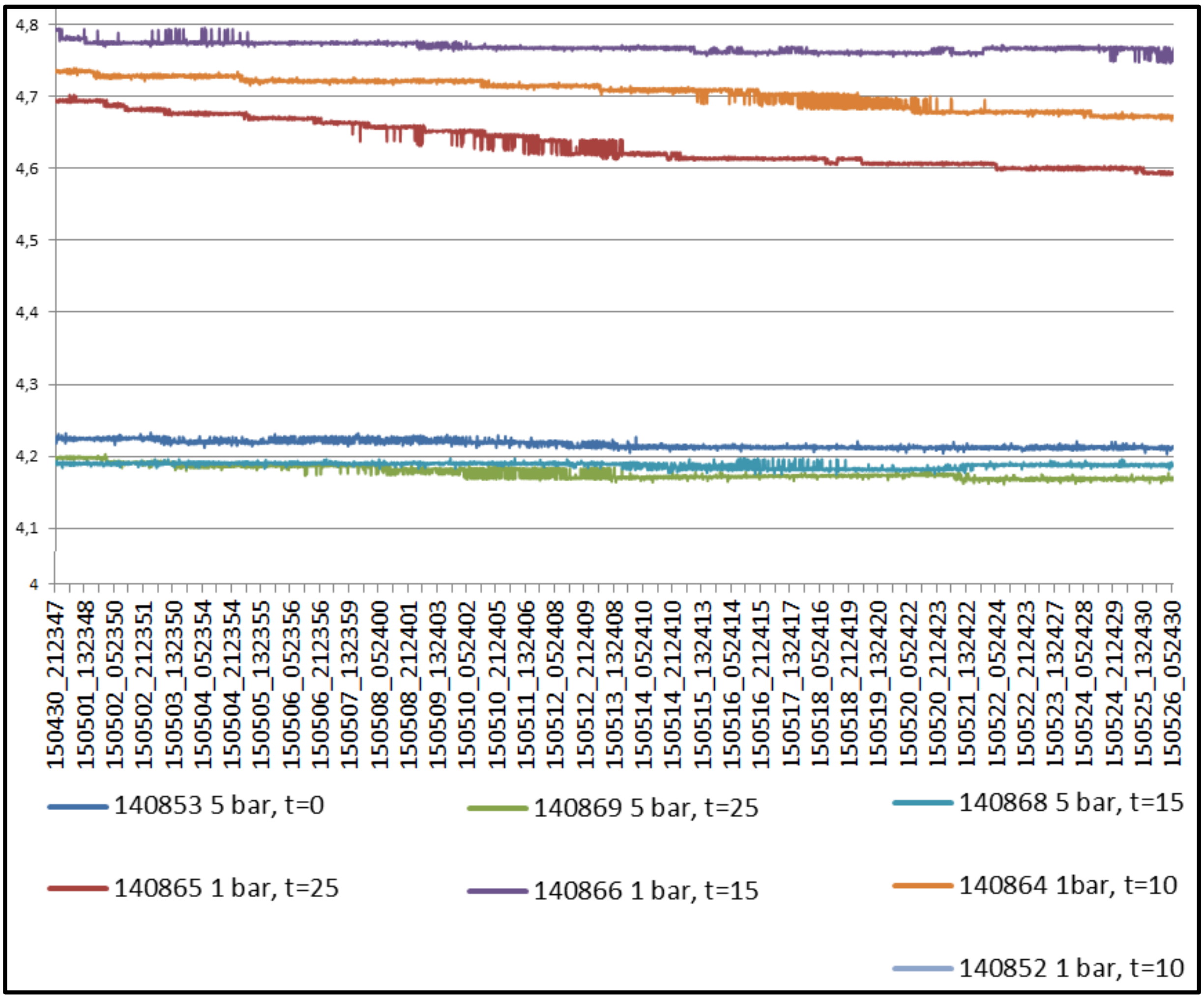


Figure 87: Log of new prototypes from DAQ system

The offset variations at time zero is a combination of tolerance and the individual position in the water column.

The most prominent observation is that the curves of all the 1 bar sensor element transmitters experience declining values over time.

The 5 bar sensor element transmitters seems to be stable.

	140853 5 bar T = 0	140865 1 bar T = 25	140869 5 bar T = 25	140866 1 bar T = 15	140868 5 bar T = 15	140864 1 bar T = 10	140852 1 bar T = 10
Diff.	0,23	**0,85**	0,24	**0,79**	0,21	**0,82**	**0,94**

Table 8: Biggest difference in signal (delta).

As can be seen in the table above, the 1 bar sensor elements shows indeed the biggest differences between the highest and the lowest measurements, hence they are less stable than the 5 bar sensor elements. The differences can be cause by some evaporation of water or disturbance from movements of hands in the water, but this will be discussed in the nest chapter.

7.1.3 Results after the Test in the Simulated Ballast Tank

The figure bellow shows the certificate for transmitter 140866, to see all the other see “Appendix U: Certificate 1 Bar Sensor element” and “Appendix V: Certificate 5 Bar Sensor element”.

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer: Kongsberg Maritime AS
Address: Haakon VII's gt 4, N-7005 Trondheim
Sensor type: GT403C0G0.6D00
Pressure range: 0 to 0,6 Bar Relative
Accuracy 0,05 %FRO in the range 0 to 60°C
Sensor serial no: 140866
Date of calibration: 2015-05-27

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	0,0 %	20,0 %	40,0 %	60,0 %	80,0 %	100,0 %
0°C	-0,58	-0,53	-0,62	-0,70	-0,75	-0,87
22°C	-0,73	-0,92	-1,06	-1,16	-1,17	-1,29
40°C	-1,38	-1,34	-1,43	-1,50	-1,47	-1,41
60°C	-1,73	-1,81	-2,00	-2,13	-2,20	-2,30

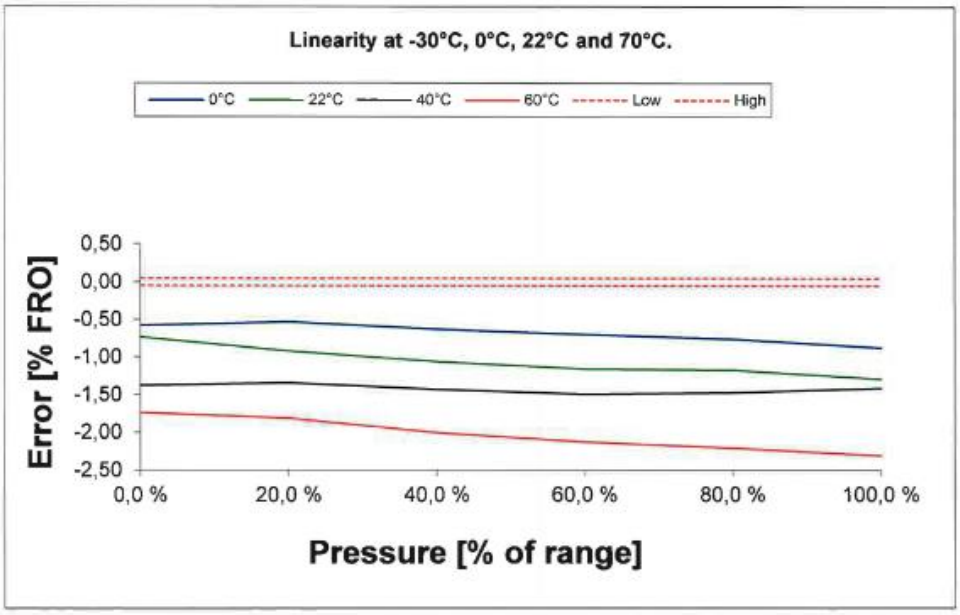


Figure 88: Calibration certificate of the 1 bar (0.6 bar) pressure transmitter

1 Bar (0.6 bar) Sensor Elements

All of the 0.6 bar types had gained a negative signal offset that can be seen from the calibration certificates test, which is a similar test as the approval test, but with the compensation data.

Comparing the offset at 0 % pressure and test temperature of 22°C for the different pressure transmitters in table below, it is a clear tendency that the larger the thickness of the coating is, the larger the offset becomes. The log of the pressure transmitters during the test period, presented in the last section, also shows that the decrement offset took place from the early beginning of the test. At the end of the test, the rate seems to flatten out. This will be discussed in the next chapter.

ID	Sensor element Type	Parylene coating thickness (μm)	Offset in % of FRO (0% pressure and 22 °C)
140864	1 bar	10	-0,09
140852	1 bar	10	N/A
140866	1 bar	15	-0,73
140865	1 bar	25	-1,27

Table 9: Influence of the offset signal of the 0.6 bar range versus coating thickness

5 Bar (2.5) Sensor Elements

The results of the 2.5 bar pressure transmitters did not reveal any significant difference of the signal offset due to the coating thickness as can be seen in in the table below.

The one with largest deviation, 140853, is the one which was not coated and was therefore heavily impacted by a build-up of material in front of the membrane.

ID	Sensor element Type	Parylene coating thickness (μm)	Offset in % of FRO (0% pressure and 22 °C)
140868	5 bar	15	0,10
140869	5 bar	25	-0,03
140853	5 bar	0	0,29

Table 10: Influence of the offset signal of the 2.5 bar range versus coating thickness

CHAPTER 8

8 DISCUSSION

This chapter discusses the results and evaluates external validity and sources of error.

8.1 Discussion of the Results of Testing and Calibration before the Test in the Simulated Ballast Tank

In general, the repeatability of all the ten pressure sensor elements is very good, and the temperature drift and linearity are within the limits of which can be compensated for by the internal compensation logic of the pressure transmitters signal converter.

However, one of the transmitter failed on the repeatability test which compares the first and second values at 22 ^{o}C, respectively black and yellow solid lines in the figure below. The criteria is that the pressure transmitters should repeat its signal within 0.5 % of the full range output (FRO). As can be seen below, the 140852 transmitter has fallen slightly outside.

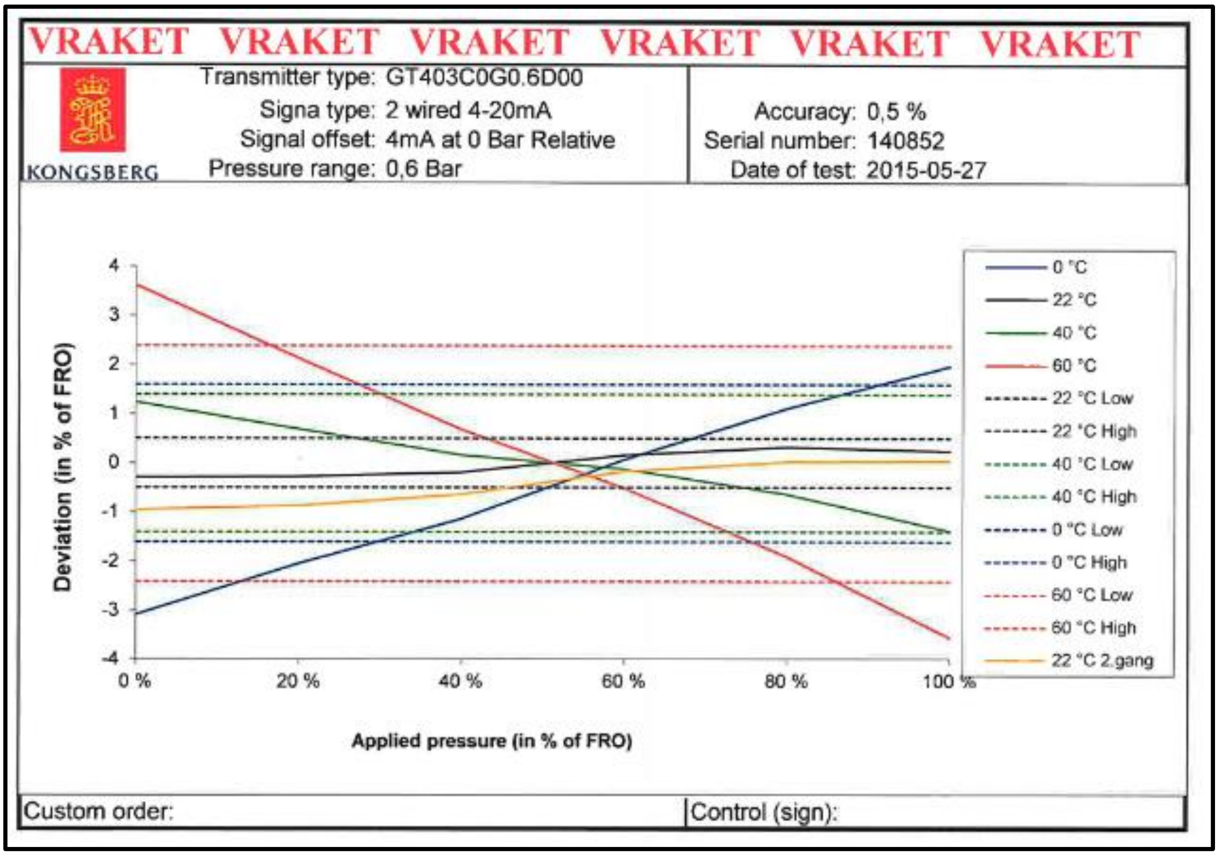


Figure 89: Sensor 140852 failed the initial test and calibration

A reason is hard to establish, but one have to keep in mind that the elements supplied are test element and they might have been inaccurate prior arrival. If not it might have gotten harmed during the transmitter development phase.

8.2 Discussion of the results after Test in the Simulated Ballast Tank

After the experiment, where the seven prototypes was submerged in a simulated ballast tank the sensors were tested.

The results of the 2.5 bar pressure transmitters did not show any significant difference of the signal offset due to the coating thickness.

The one with largest deviation was observed for the 140853 transmitter, the one that was not coated. It was heavily impacted by a build-up of material in front of the membrane.

All the 0.6 bar types showed a negative signal offset as can be seen from the calibration certificates.

The negative offset indicates a negative force on the membrane, acting towards the water column. I.e. there is a mechanism that pulls the membrane outwards. There are three plausible explanations of the mechanism;

1. A small amount of materials can be seen on the membrane surface, and as the rate of the offset decreases by time, the relatively thickness between the membrane and the material in front also changes. The material thickness increases and forms a stable solid with a force going to zero acting on the membrane position.
2. The rate of deposition of materials in front of the membrane might have been slowed down at the end of the test due to reduced available materials of Zn^{2+} and Ca^{2+} to stick on the surface
3. The Parylene coating is changing its structure and behavior giving stresses causing an outwards force acting on the membrane.

Furthermore, on a request to JUMO they answered that the measuring cell in the 1 bar and the 5 bar element is the same, but the sensitivity of the elements is different and this is probably the reason for such big difference in behavior between them.

8.3 Pinholes on Coated Transmitters

As mentioned, and seen in pictures earlier, some pinholes on the threads and the outer part of the membrane was observed. In this pinholes deposition took place, which is not desirable.

The reason for the pinholes is most likely damage caused by screwing the transmitters onto the jig for testing and calibration after coating, prior submersion. The opposite threads (on the jig) must have scratched against the transmitter’s threads tearing of the coating in some places.

8.4 Error Sources

In the calculations of the accuracy of the GT403 the root mean square should have been applied. Due to time limitations this was considered a less important error source. The only value of the figure and the calculations were to give an approximate indication on the uncertainties in the system at present a worst case scenario for the reader.

8.5 Validity of Research

Critically evaluating the narrow sample of transmitters in the test, one must consider external validity, the validity of generalized (causal) inferences in scientific research, usually based on experiments as experimental validity (Mitchell & Jolley, 2001).

The best way to test its validity is to replicate the test; thus doing it over again to see if the same results and trends emerges. Unfortunately, for this project, time did not allow for replication, so this creates some uncertainty.

Furthermore, if time had allowed it, both the qualitative and the quantitative research would have been much broader, and contained a larger set of interview objects and survey participants.

CHAPTER 9

9 CONCLUSION, PROPOSED SOLUTION AND FURTHER WORK

This chapter is the very last one and it concludes the master thesis, proposes a solution and gives advice.

9.1 Conclusion

The objective of this master thesis was to develop a new generation pressure transmitter. To make this new generation better than the current one, the main problems needs to be established and addressed. Existing assumptions, from earlier studies, internal reports and experiment, were challenged by a recreated tests and hands-on field experience.

The assumed main cause for failed transmitters were addressed by looking at changes that could be applied to the production and joining, material selection, shape and design. Furthermore, pressure sensing element, external connector and PCBs were evaluated as well.

9.1.1 Understanding the Problem

Starting with the results from the pre-master project some main issues appeared. Internal reports and the general perception in-house at KM seemed to confirm the present assumptions from the pre-master. To get a broader foundation and a more thorough understanding a service field trip was arranged to the KV Bergen ship. It was absolutely necessary to see the environment, understand the challenges, detach malfunctioning transmitters, establish cause of failure, talk to users and get an external point of view.

Through countless conversations, reviewing reports of internal repeatable experiments, understanding of results, fieldwork and discussions with external customers the problem was deeply understood and the main issues were specified to be

- **The main problem is deposition of calcium on the housing and in the gap between the housing and the membrane.** The transmitters are made in titanium and acts as cathodes receiving particles that form in layers and over time clogs opening in front of the membrane, causing wrong signals over time, such as drift.
- **The second issue is leakage through the joining points on the transmitter.** The housing parts on the GT403 are kept together by threads, glue and O-rings that are not tight enough, causing damage to the electronics.

9.1.2 Development Phase

The material was selected based on existing industrial requirements, KM's desire and advice given by KM Horten that specializes in plastic molding. Metal was the only viable choice and titanium was chosen of simplicity in terms of being able to reuse some existing parts, and it matched the sensing element from JUMO made of titanium.

A 3D CAD model was made in Inventor and updated during the development of the design. The end result of the model and the physical product look very much alike. The model served as a helpful tool during the development. Afterwards it works as a high resolution illustration for the end product.

To be able to make the transition between the sensor element and its housing as tight and waterproof as possible the idea of welding it appeared. LBW was introduced as a new technique of joining transmitter parts. The experience was gained along the way after some testing, failing and learning. New sensor elements with a titanium membrane in front were brought and laser welded to new housing parts made in a lathe from a titanium rod.

When the lowermost part of the housing and the sensor element were united they were sent to Sweden for Parylene coating. When they returned, parts of the transmitter could be assembled and fully tested and calibrated. Nine out of ten transmitters passed the test with an accuracy of at least 0.5 % over the whole temperature and pressure span.

To conclude, the development phase was very successful in terms of working methods, strategic choices and the fact that it gave birth to 10 fully operational, new pressure transmitter prototypes ready for testing.

9.1.3 Testing

The background for the development phase was to recreate a test based on an earlier experiment done by KM Trondheim, to strengthen its validity as well as creating a realistic environment to test the new solutions.

Seven of the new developed transmitters and four of the existing ones were submerged in 600 L seawater with dissolved calcium hypochlorite and connected to a power supply for 26 days. In the basin there also was a powered zinc anode to speed up the process. In addition one of the existing transmitter was put in the same basin, but isolated from the circuit.

To conclude, the test was successfully conducted and the new prototypes withstood water penetration and actually served as fully operational pressure transmitters.

9.1.4 Results

The experiment has shown that the pressure transmitters, submersed into the seawater tank for 26 days, with the lowest range of 0.6 bar ranged transmitters using a 1 bar sensor element are prone to the thickness of the coating. Increased thickness gave an increased negative offset and we can from the three plausible explanations we discussed earlier, that the main mechanism we see is probably due to some kind of transformation of the Parylene coating and interaction between the coating and the steel membrane.

The 2.5 bar ranged transmitters using the 5 bar sensor element did not give any major change of the performance when exposed to the seawater tank. The one found with the largest deviation revealed after the calibration test was without coating showing that a build-up of a material in front of the membrane will influence the performance of the pressure transmitter such as an offset drift.

Coated areas seemed to withstand, but in coating-free pinholes (cause by damage) the deposition took place as well. The isolated transmitter did not experience any growth.

To conclude, the coating had an obvious effect against growth and the isolated transmitter experienced no deposition at all.

9.2 Proposed Solution

Material Selection

For the next prototype I would like to suggest a less cathodic material that still has a good corrosion properties. I think that stainless steel, for instance AISI316 might be a good choice and the price is lower than for titanium.

Pressure Sensing Sensor Element and PCB

I would like to recommend using a weldable sensor element to make the transition between the sensor element and the housing absolutely watertight. I think the sensor element from JUMO works fine, but it should be an absolute pressure sensor element since the ventilated cables offer some challenges, and stand less bending and handling than ordinary electric PUR cables. On a request JUMO confirmed that they have started to produce some absolute range element.

If the sensor elements are switched back to absolute pressure sensor elements the same PCBs can be reused.

Production

The lowermost housing part can be more optimized in terms of manufacturing method and use of material. The rest of the housing should also be made from scratch and re-evaluated. I would suggest to laser weld both the sensor element to the housing and all the housing components to each other. Testing should take place as today, but without thread connection to jig since it is causing damages to the Parylene coated areas allowing for deposition.

Coating

The lower part, including the membrane, should be Parylene coated to expand the lifetime, but an extended test should be carried out to make sure the coating can withstand up to several years operational time, and to find the best coating thickness.

Design and Shape

The transmitter could have a shape similar to the prototypes in this project, but the connection to external cable and flange should be evaluated.

9.2.1 Installation

The transmitter should be connected to the tank wall by a plastic bracket, instead of metal. This must overcome the Ex design criteria which states that the body should be connected to earth, so this need to be dug into.

The following steps how to install the new transmitter. (Pictures below suggest one possible improvement. Instead of using four screws, which is a hassle, a clamp with only one not should make the installation much easier. This area needs more work)

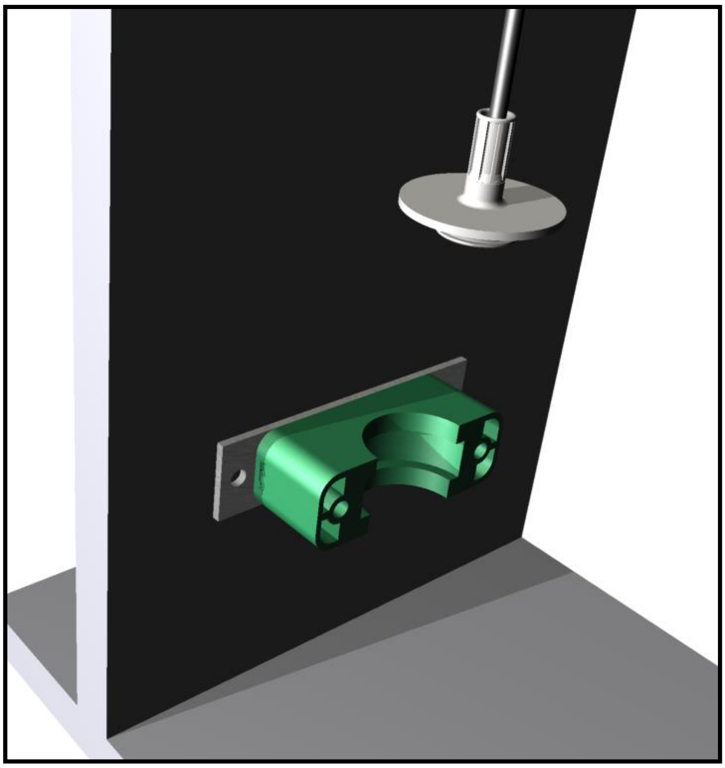


Figure 90: Connect the plastic bracket to the wall, for instance by welding its rear plate to the wall

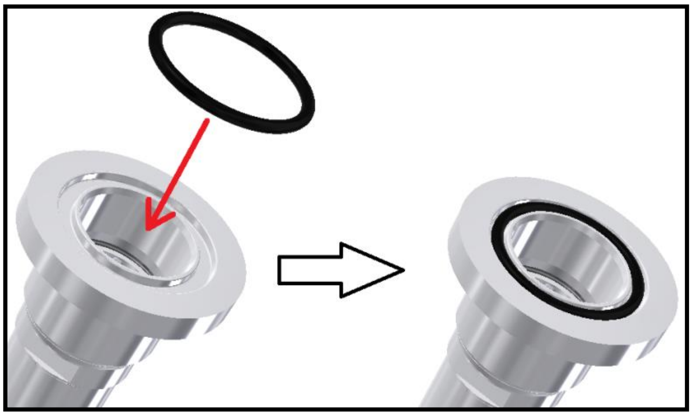


Figure 91: Place the O-ring in its groove

Figure 92: Connect the wires from the flange to the sensor

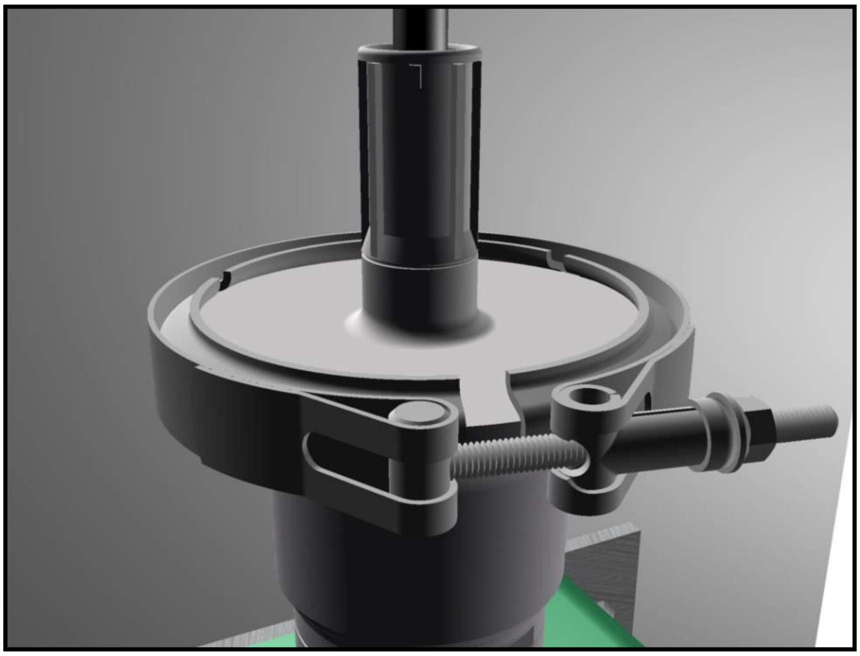


Figure 93: Close the connection by using the clamp

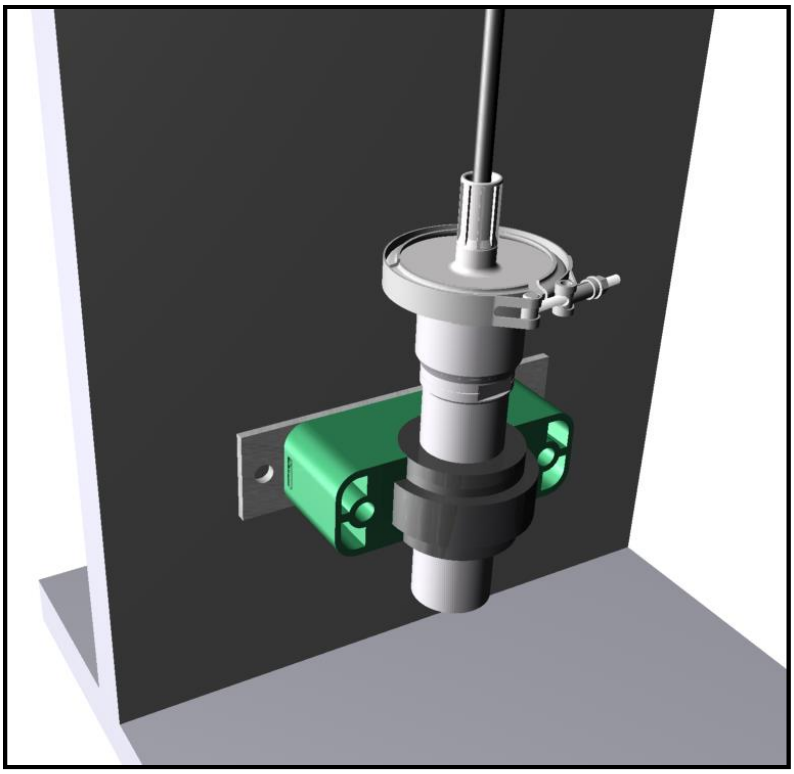


Figure 94: Place the sensor in the isolated rubber part in the plastic bracket

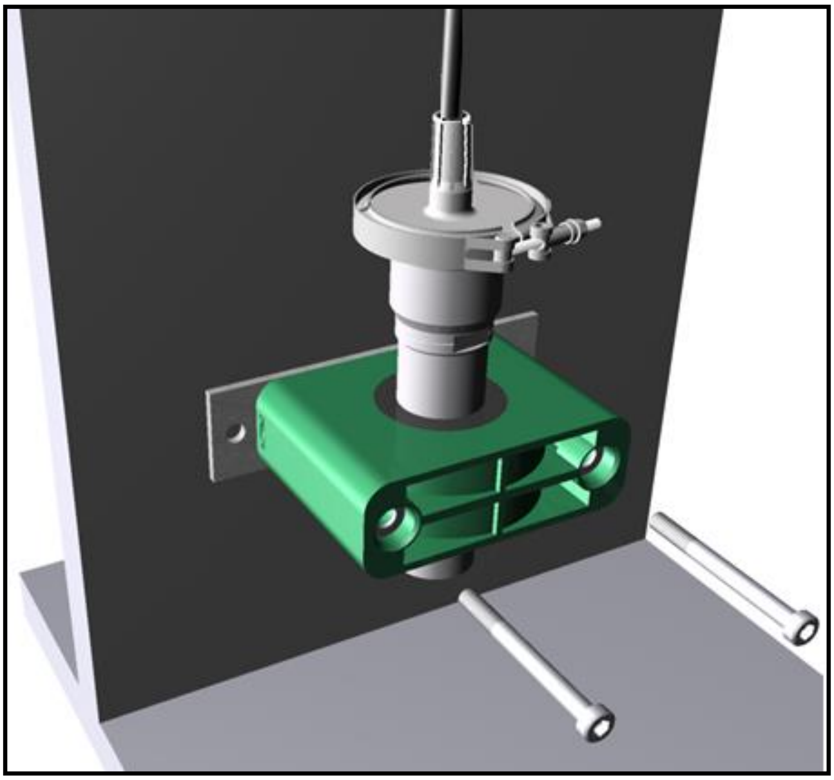


Figure 95: Close the plastic bracket with two screws

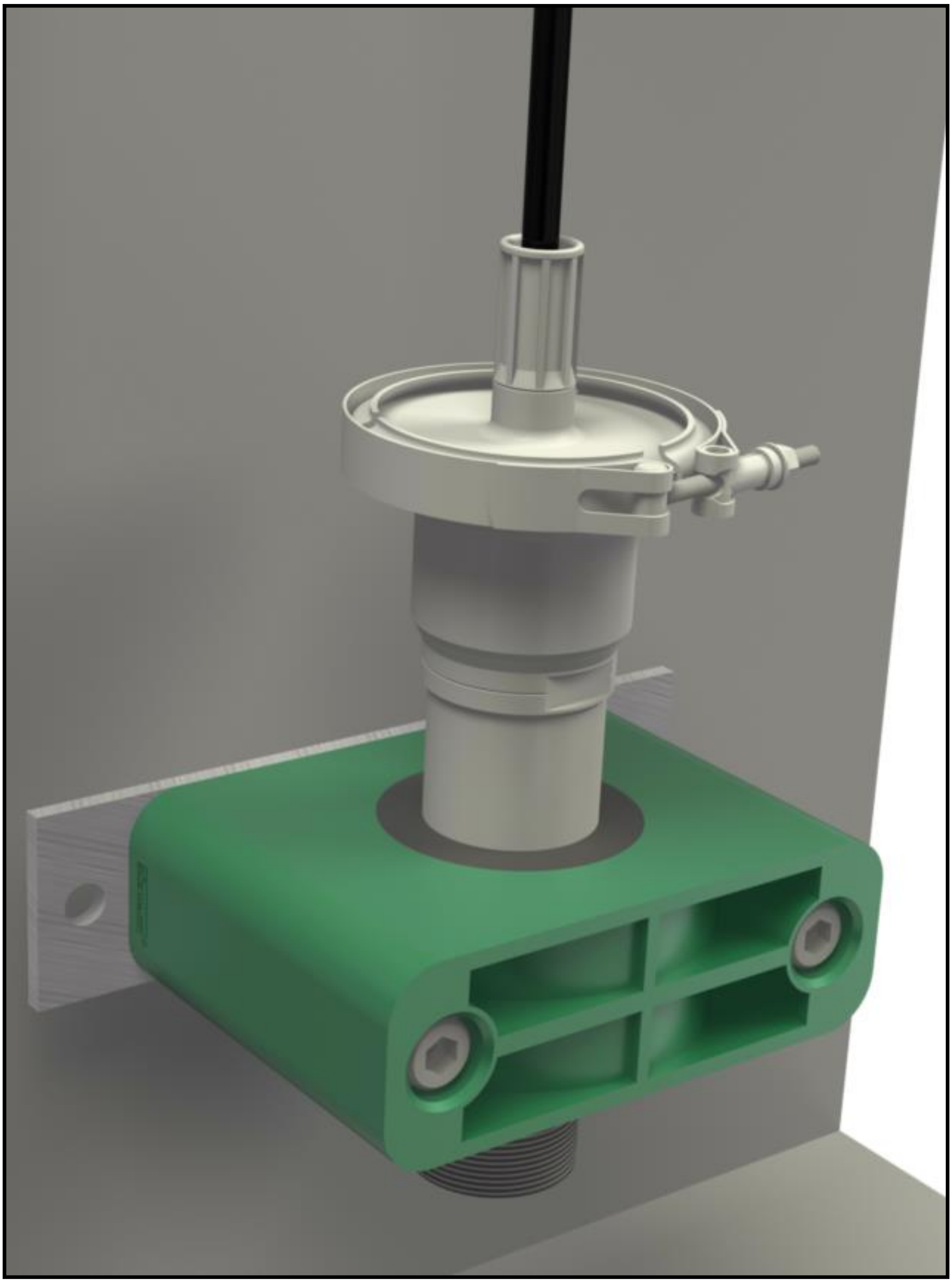


Figure 96: Fully installed sensor

9.3 Advice and Further Work

According to external validity above, one should replicate the study in the pre-master project by giving it a greater scope. The testing with Parylene should be repeated, and include more transmitters. One should also do more dedicated studies on isolating the transmitters totally, since this gave good results here.

Furthermore, the next important steps for KM to look into are:

- Find a new pressure sensing element in titanium that measures absolute pressure. It should not be a 1 bar sensor element, because of its extreme sensitivity. JUMO's 5 bar elements seemed fine, but they also have 2.5 bar elements available, so this could be considered.
- Look more into isolating the transmitter. Find a provider or develop a plastic bracket suitable for the transmitter dimensions.
- Work on a new solution for the external connection to cable.
- See if it is possible to own your own Parylene coating facility or if you can arrange a good deal with a third party.
- Find a new solution for testing the transmitters without using treads on the jig, to avoid Parylene coating getting harmed.
- Look into other coating options such as super-hydrophobic and super-oleophobic coatings which KM has performed an initial laboratory test on (see "NCI Arctic Project" by Oddbjørn Malmo, 2011).

After the last measurements the prototypes were connected to the attachment creation and submerged again. I will recommend to do new measurements after a few more weeks to see if the layer continues to grow and how it effects the transmitters.

I would also like to remind KM of the three prototypes that have not been submerged; and thus are ready for further development or a new round of testing.

KV Bergen has agreed to have two of the new prototypes installed for a period of time for real environment testing, so this is something to consider as well.

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APPENDICES

Appendix A: Nautical Terminology

Ship and Nautical Terminology

Aft

1. The part of the vessel behind the middle area of the vessel.

   Ballast

2. The substance of a ship, which is adjustable.

Ballast error

1. Incorrect ballast, which makes the ship too heavy, too light, or unstable

Bow

1. The front of a vessel.

   Bridge

2. A structure above the weather deck, extending the full width of the vessel, which houses a command center, itself called by association, the bridge (Oxford Dictionaries, u.d.).

Cargo vessels

1. A vessel for transporting goods, in the form of cargo, by sea. In this project assignment referred to as *ship.*

List

1. A vessel's angle of lean or tilt to one side, in the direction called roll. Typically refers to a lean caused by flooding or improperly loaded or shifted cargo.

Trim

1. Relationship of ship's hull to waterline.

Port

1. The left side of the boat. Denoted with a red light at night.

Roll

1. A vessel's motion rotating from side to side, about the fore-aft/longitudinal axis.

Starboard

1. The right side of the boat. Towards the right-hand side of a vessel facing forward. Denoted with a green light at night.

Appendix B: The Industry

General

China is now firmly the world's largest shipbuilder with 45% of the world's total orders, and its quality and technology have improved very much (BRS, 2013).

Rank	Country	%
1	China	45%
2	South Korea	29%
3	Japan	18%
4	European Union	1%
	Rest of the world	7%

Table 11: World shipbuilding market share by countries (2012) (BRS, 2013)

Back in the days, most of the shipbuilding work was carried out at the shipyards themselves, but over time the role of marine equipment suppliers has become more important. Nowadays the share of marine equipment is assessed at 50%-70% of the product value, and can be 70-80% in the more specialized segments (ECORYS, 2009).

The marine equipment subsector is highly heterogeneous and consists of many relatively small companies. Estimated range from 5000 to 9000 suppliers worldwide (ECORYS, 2009). Total market value was estimated at EURO 57 billion in 2005 (ECORYS, 2009).

Norwegian Marine Equipment Suppliers

The maritime equipment industry has become a significant part of the Norwegian maritime business as well. Relatively speaking, the industry is dominated by a handful of individual companies: Rolls Royce, Kongsberg Maritime, ABB and Frank Mohn, who are collectively responsible for 40 % of the wealth creation for maritime equipment in 2012 (Industri, 2014)

The Norwegian ship's equipment manufacturers made sales valued at more than NOK 20 billion in 2012 (Industri, 2014). Except for a decline in the years 2009-2011, due to financial crisis, it has been a steady growth before and after.

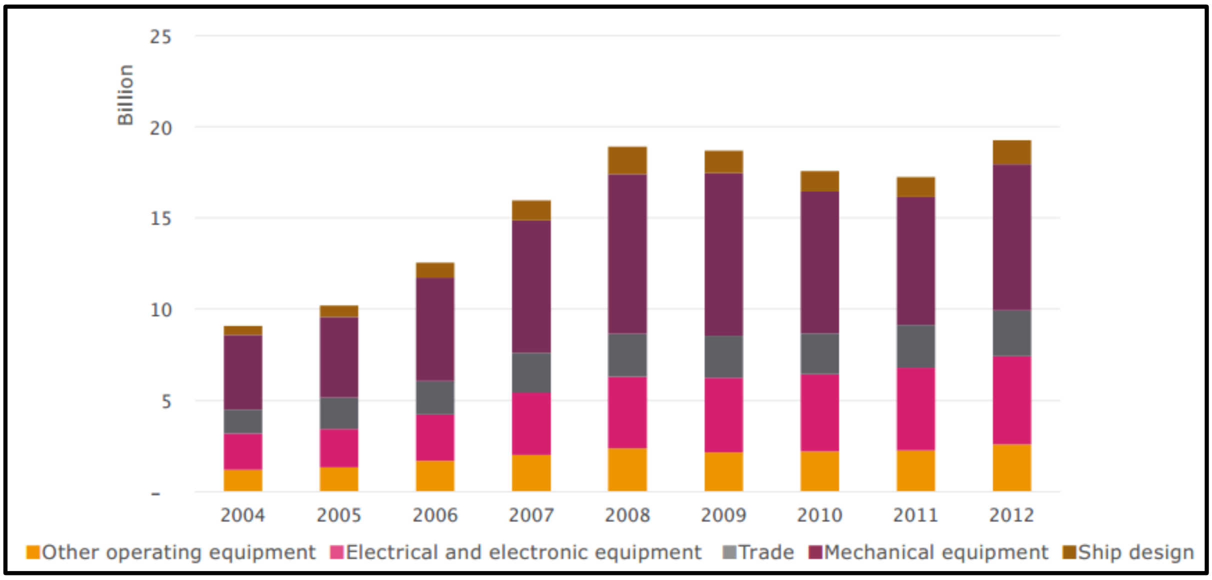


Figure 97: Wealth creation among ship's equipment manufacturers broken down by subgroup, 2004-2012. (Menon Business Economic, u.d.)

Appendix C: Ex Product Certification

International agreements under the Safety Of Life At Sea (SOLAS) Convention require cargo vessels and passenger ships to be constructed so as to withstand certain kinds of damage (SOLAS, International Maritime Organization, 1974), this includes all external products that are brought on board. To know if they are safe enough there is a system to classify and certificate. The purpose of Ex Product Certificates is to give products approval in hazardous area. The overall methods of protection are defined as followed in accordance to Presafes' ATEX standard (Presafe, u.d.):

Code letter	**Protection methods**
Ex d	Flameproof enclosures
Ex e	Increased safety
Ex i	Intrinsic safety
Ex m	Encapsulation
Ex n	Type of protection
Ex o	Oil immersion
Ex p	Pressurized enclosures
Ex q	Powder filling

Table 12: Basic methods of protection

To certify a product the ‘zone’ in which the product will perform have to be considered, that is the probability of a hazardous atmosphere being present and to what extent. Products are designated according to categories to identify at what level of protection they have been assessed, in accordance to Presafes’ ATEX standard (Presafe, u.d.). The categories and zones are:

Category	**Probability of an explosive atmosphere**	**Level of protection**	**Corresponding zone**
1	Continuously present or for long periods of time	Very high level of protection	Zone 0
2	Likely to occur	High level of protection	Zone 1
3	Not likely to occur, and only for short periods of time	Normal operation	Zone 2

Table 13: Ex zones, according to Presafes’ ATEX standard (Presafe, u.d.)

In addition to the codes and the zones, the classification also depends on a temperature class.

Temp. class	**Temperature**
T6	85 °C
T5	100 °C
T4	135 °C
T3	200 °C
T2	300 °C
T1	450 °C

Table 14: Temperature classes, according to Presafes’ ATEX standard (Presafe, u.d.)

To get the full overview read “Methods of explosion protection for electrical equipment” by Dietzelectric (Electric).

Appendix D: IP Code

The IP Code, International Protection Marking, sometimes interpreted as Ingress Protection Marking, classifies and rates the degree of protection provided against intrusion (body parts such as hands and fingers), dust, accidental contact, and water by mechanical casings and electrical enclosures (Commission, 2004).

The IP Code is given as the letters IP followed by two numbers, for instance IP67. The first number indicates the level of protection that the enclosure provides against access to hazardous parts and the ingress of solid foreign objects (Commission, 2004).

Level	**Object size protected against**	**Effective against**
0	—	No protection against contact and ingress of objects
1	>50 mm	Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part
2	>12.5 mm	Fingers or similar objects
3	>2.5 mm	Tools, thick wires, etc.
4	>1 mm	Most wires, screws, etc.
5	Dust protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment; complete protection against contact (dust proof)
6	Dust tight	No ingress of dust; complete protection against contact (dust tight)

Table 15: Solid particle protection

The second number indicates the level of protection that the enclosure provides against harmful ingress of water (Commission, 2004).

Level	Protected against	Testing for	Details
0	Not protected	—	—
1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect.	Test duration: 10 minutes. Water equivalent to 1 mm rainfall per minute
2	Dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position.	Test duration: 10 minutes. Water equivalent to 3 mm rainfall per minute
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.	Test duration: 5 minutes. Water volume: 0.7 liters per minute Pressure: 80–100 kPa
4	Splashing of water	Water splashing against the enclosure from any direction shall have no harmful effect.	Test duration: 5 minutes. Water volume: 10 liters per minute Pressure: 80–100 kPa
5	Water jets	Water projected by a nozzle (6.3 mm) against enclosure from any direction shall have no harmful effects.	Test duration: at least 3 minutes. Water volume: 12.5 liters per minute Pressure: 30 kPa at distance of 3 m
6	Powerful water jets	Water projected in powerful jets (12.5 mm nozzle) against the enclosure from any direction shall have no harmful effects.	Test duration: at least 3 minutes. Water volume: 100 liters per minute

			Pressure: 100 kPa at distance of 3 m
6K	Powerful water jets with increased pressure	Water projected in powerful jets (6.3 mm nozzle) against the enclosure from any direction, under elevated pressure, shall have no harmful effects.	Test duration: at least 3 minutes. Water volume: 75 liters per minute Pressure: 1000 kPa at distance of 3 m
7	Immersion up to 1 m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).	Test duration: 30 minutes. Immersion at depth of at most 1 m measured at bottom of device, and at least 15 cm measured at top of device
8	Immersion beyond 1 m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects.	Test duration: continuous immersion in water. Depth specified by manufacturer, generally up to 3 m.
9k	Powerful high temperature water jets	Protected against close-range high pressure, high temperature spray downs.	—

Table 16: Liquid ingress protection

Appendix E: Calcium in Seawater

Equilibrium

Calcium is in fact super saturated in the form of aragonite, $CaCO_3$, in seawater; but carbonates will not precipitate from natural seawater in convenient experimental times (Chase & Suess, 1970).

Super saturation in this context means that given the right circumstances, it will precipitate as solid calcium carbonate (Hestmo & Rambech, 2004). If the equilibrium is shifted further by adding Ca^{2+} or CO_3^{2-} ions, precipitation is likely to occur (Holmes-Farley, 2002). The equilibrium constant expression for the dissolution of calcium carbonate is shown below.

$$\mathrm{K} = [\mathrm{Ca}^{+}][\mathrm{CO}_3^{-}]$$

Equation 9: Equilibrium of Calcium Carbonate

When K equals the Ksp*, the solubility product constant in seawater at any given temperature, pressure, and salinity, the solution is said to be exactly saturated (Holmes-Farley, 2002):

$$\mathrm{Ksp}^{*} = [\mathrm{Ca}^{+}][\mathrm{CO}_3^{-}]$$

Equation 10: Calcium Carbonate Saturation

When the product of the concentration of calcium and carbonate exceeds the value of Ksp*, the solution is said to be super saturated (Holmes-Farley, 2002):

$$\mathrm{Ksp}^{*} < [\mathrm{Ca}^{+}][\mathrm{CO}_3^{-}]$$

Equation 11: Calcium Carbonate Super Saturated

When the product of the concentration of calcium and carbonate is less than the value of Ksp*, the solution is said to be under saturated (Holmes-Farley, 2002):

$$\mathrm{Ksp}^{*} > [\mathrm{Ca}^{+}][\mathrm{CO}_3^{-}]$$

Equation 12: Calcium Carbonate Under Saturated

When the solution is under saturated calcium carbonate can dissolve if being added to the solution (Hestmo & Rambech, 2004).

The product of calcium and carbonate is about three times the Ksp* of aragonite and five times that of calcite and consequently, calcium carbonate is poised to precipitate from seawater, given the opportunity (Holmes-Farley, 2002).

When Precipitation Takes Place

As indicated, one obvious way to initiate calcium carbonate precipitation is by actually adding calcium carbonate to the seawater. A second way is by a rise in either calcium or carbonate levels, which will shift the equilibrium and cause precipitation (Hestmo & Rambech, 2004).

A third situation where precipitation takes place is if the super saturation is pushed by a rise in pH or a rise in temperature (Hestmo & Rambech, 2004). Since calcium carbonate is already supersaturated, the effect is that when the water is warmed, the super saturation of calcium carbonates rises, making precipitation more likely.

After some solid calcium carbonate has entered the system, either by precipitation or by adding calcium carbonate, precipitation will begin immediately. This solid is principally calcium carbonate, though it likely has other ions in the crystal as well (magnesium and other metals, phosphate and other anions, etc.) (Hestmo & Rambech, 2004).

The super saturation (Ω) for calcium carbonate in seawater is given by (Holmes-Farley, 2002):

$$\Omega > \frac{[\mathrm{Ca}^{++}][\mathrm{CO}_3^{--}]}{\mathrm{Ksp}^*}$$

Equation 13: Super Saturation

A second and perhaps unexpected contribution to the precipitation of calcium carbonate in warmer surroundings has to do with the concentration of carbonate (Hestmo & Rambech, 2004). As water is heated, the equilibrium between bicarbonate and carbonate is shifted toward carbonate (Holmes-Farley, 2002):

$$\mathrm{HCO}_3^- \leftrightarrow \mathrm{H}^+ + \mathrm{CO}_3^{--}$$

Equation 14: Equilibrium between Bicarbonate and Carbonate

Ka* is the dissociation constant and is used to measure how well acid dissociates (Holmes-Farley, 2002):

$$\mathrm{Ka}^* = \frac{[\mathrm{CO}_3^{--}][\mathrm{H}^+]}{[HCO_3^-]}$$

Equation 15: Dissociation Equation

$$[\mathrm{CO}_3^{--}] = \frac{\mathrm{Ka}^*[HCO_3^-]}{[H^+]}$$

Equation 16: Concentration of Carbonate

$$pKa^* = -\log Ka^*$$

Equation 17: pKa Relation

This shift toward carbonate is evidenced by the shift in the seawater pKa* for bicarbonate from 9.00 at 25 °C to 8.68 at 40 °C and 8.16 at 80 °C (calculated from equations provided by Millero; the * simply indicates that it is in seawater at a given temperature, pressure, and salinity) (Holmes-Farley, 2002).

From the equation “Concentration of Carbonate” it is seen that if the Ka* rises, then $[CO_3^{--}]$ will rise, $[H^+]$ will rise, and $[HCO_3^-]$ will decline (Holmes-Farley, 2002).

Assuming that the carbonate concentration is less than the bicarbonate concentration, we can determine the change in H+ with equation “Equation 18: Concentration of Hydron”, which is simply the solution of the equation “Equation 16: Concentration of Carbonate” for H^+ (Holmes-Farley, 2002):

$$[H^+] \sim [Ka^*C + Kw^*]^{1/2}$$

Equation 18: Concentration of Hydron

C is the total concentration of carbonate/bicarbonate/carbonic acid species and pKw* is the constant for the auto dissociation of water (Holmes-Farley, 2002). About the assumption that the carbonate concentration is less than the bicarbonate concentration: it is known this is true for seawater at 25 °C, but it is also generically shown by Pankow (Pankow, 1991) to be valid with this combination of pKa* (about 9), pKw* (about 13) and C (about 2 mM) for other temperatures as well (Holmes-Farley, 2002).

Using the values of Ka* and Kw* at the appropriate temperatures, we find that $[H^+]$ has increased by a factor of about 1.45 between 25 and 40 °C. As a point of curiosity, this has resulted in a decrease in pH of about 0.16 units (Holmes-Farley, 2002).

Still, what we want to know is the change in the carbonate concentration. Going back to equation 8 we have:

$$[CO_3^{--}]_{25} = Ka^*25 \frac{[HCO_3^-]_{25}}{[H^+]_{25}} \text{ at 25 °C}$$

Equation 19: Concentration of Carbonate at 25°C

$$[CO_3^{--}]_{40} = Ka^*40 \frac{[HCO_3^-]_{40}}{[H^+]_{40}} \text{ at 40 °C}$$

Equation 20: Concentration of Carbonate at 40°C

We assume, as above, that $[HCO_3^-]_{25} = [HCO_3^-]_{40}$ (that is, that the bicarbonate concentration is so high that taking a bit away to form carbonate does not impact the bicarbonate concentration significantly). Substituting the known change in Ka* (Ka*40 = 2.1Ka*25) and H^+ ($[H^+]_{40} = 1.45[H^+]_{25}$), we get (Holmes-Farley, 2002):

$$[CO_3^{--}]_{40} = 2.1Ka^*25 \frac{[HCO_3^-]_{40}}{1.45[H^+]_{25}}$$

Equation 21: Concentration of Carbonate (expanded)

Combining equations 11 and 13, and the fact that $[HCO_3^-]_{40} \sim [HCO_3^-]_{25}$, we get (Holmes-Farley, 2002):

$$[CO_3^-]_{40} = 1.45[CO_3^-]_{25}$$

Equation 22: Concentration of Carbonate (shortened)

Consequently, ongoing from 25 °C to 40 °C, the relative concentration of carbonate has increased by a factor of 1.45. We can now go back and confirm our assumption that carbonate is still far below the bicarbonate concentration, and it clearly is, so that assumption was valid (Hestmo & Rambech, 2004).

Going back to what we really care about, the super saturation of calcium carbonate, we find that if the carbonate has increased by a factor of 1.45, then the super saturation of both calcite and aragonite have increased by the same factor (Hestmo & Rambech, 2004).

Running the same calculations for 80 °C (pKa = 8.16) we get the carbonate concentration to increase by a factor of 2.4x compared to 25 °C. The $[H^+]$ also increases by the same factor (Hestmo & Rambech, 2004).

Appendix F: Typical Specifications of Parylene C

PARYLENE C VALUE	ASTM METHOD	
GENERAL		
Density (g/cm)	1.289	D1505
Refractive index	1.639	
ELECTRICAL		
Dielectric strength (voltage breakdown) volts/mil	5,600 volts	D149
Dielectric constant		D150
60 Hz	3.15	
1 kHz	3.10	
1 MHz	2.95	
Dissipation factor		D150
60 Hz	0.020	
1 kHz	0.019	
1 MHz	0.013	
Dielectric strength @ 25µm, short time MV/m	220	D149
Dielectric strength @ 25µm, step-by-step MV/m	185	D149
Volume resistivity @ 23ºC, 50% RH, ohms	8.8×10^{16}	D257
Surface resistivity @ 23ºC, 50% RH, ohms	1×10^{14}	D257
MECHANICAL		
Tensile modulus, GPa	3.2	D882
Tensile strength, MPa	70	D882
Tensile strength, psi	10,000	D882
Yield strength, MPa	5.5	D882
Elongation to break, %	200	D882
Yield elongation, %	2.9	D882

Coefficient of friction-static	0.29	D1894
Coefficient of friction-dynamic	0.29	D1894
Rockwell hardness	R80	D785
THERMAL		
Melting point, ºC	290ºC	
Linear coefficient of expansion (10^{-5}/ºC)	3.5	D696
Thermal conductivity @ 25ºC (watts/meter-Kelvin)	0.082	C177
Specific heat @ 20ºC cal/g/ºC	0.17	
BARRIER		
Water absorption, % (24 hr)	0.06 (.029")	D570
Water vapor transmission @ 37ºC (ng)	0.0004	D570
Gas permeability cc-mil/100 in 2 - 24 hrs		
N_2	0.6	
O_2	5	
CO_2	14	
H_2	110	
Moisture vapor transmission gm-mil/100 in - 24 hrs	1	

Table 17: Typical Specifications of Parylene C

Source: (Advanced Coating, 2015)

Appendix G: Survey

In the two next following questions, I want you to put in just ONE number to each column, based on this scale:

1	2	3	4	5
Not important				Very important

1. When you are to choose a solution to measure water level in ballast tanks (pressure sensor, air purge, etc.) how important are the follow factors:

Give your score

	Not important				Very important
PRICE	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
SERVICE	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EASY TO INSTALL	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Do you have any comments?

2. How important are the following properties during operation?

Give your score

	Not important				Very important
ACCURACY	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
LONG-TIME STABILITY	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
REFRESH RATE/ RESPONSE TIME	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EASY TO CLEAN THE TANK	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
LONG LIFE TIME	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Do you have any comments?

3. What solution(s) do you use, or have you used, to measure water level in ballast tanks?

4. What do you think is an accepted deviation of water level in a tank with a depth of 20 meter?

☐ 0-10 cm ☐ 10-30 cm ☐ 30-60 cm ☐ 60-100 cm ☐ 1 meter or more

Do you have any comments?

5. What do you think is an appropriate price for a water level measurement equipment in ONE ballast tank? (1 Euro = 8,5 NOK = 1,3 USD)

☐ 100 Euro or less ☐ 100-300 Euro ☐ 300-500 Euro ☐ 500-800 Euro ☐ More than 800 Euro

Do you have any comment?

6. What do you think is the main issue(s) with today's available solutions in the market?

7. Please share any additional comments and/or suggestions.

Figure 98: Survey

Appendix H: Outcome from Survey

	Existing Customers			Potential Customers										
Customer #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
PRICE	3	3	2	2	2	5	5	5	4	4	5	2	5	2
SERVICE	4	5	4	5	5	3	2	3	3	4	3	5	4	5
EASY TO INSTALL	5	3	5	5	4	5	5	3	5	5	5	5	4	5
ACCURACY	4	4	5	4	5	3	2	3	3	4	3	3	3	4
LONG-TIME STABILITY	5	5	5	5	4	4	3	3	4	4	3	4	4	5
REFRESH RATE	2	4	4	3	5	3	3	2	1	2	2	4	3	5
EASY TO CLEAN THE TANK	4	4	4	3	4	3	4	2	3	3	4	3	4	4
LONG LIFE TIME	4	5	4	5	4	5	4	4	5	4	4	5	4	4

Table 18: Outcome from survey

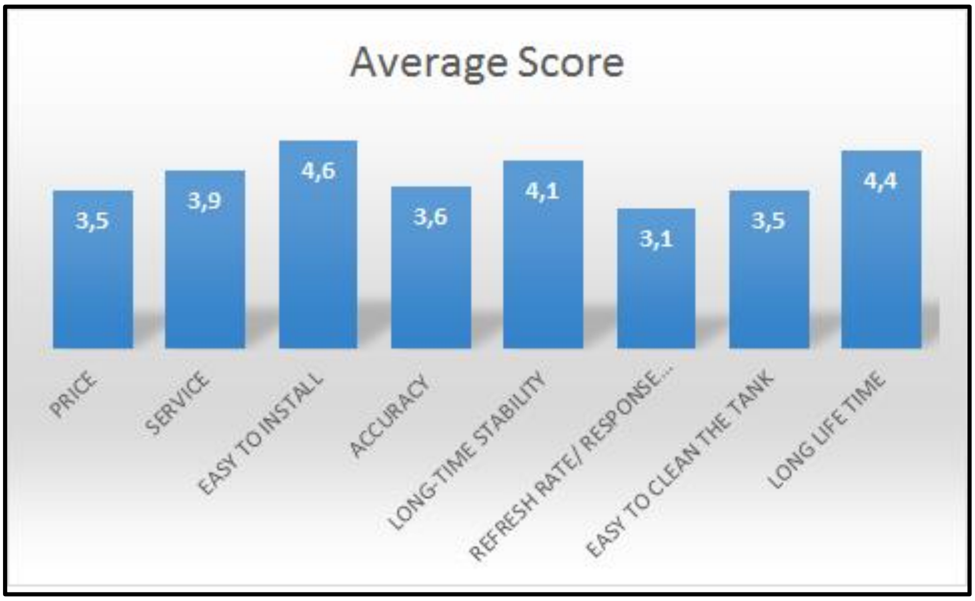


Figure 99: Average score from survey

Appendix I: Measurements from Experiment with Calcium

The table shows the measurement of type 1 and type 3 of the GT303 Kongsberg ballast transmitter where deviation from actual value is calculated.

Kongsberg	GT303					
Type			Type 1	Type 3		
Date	Atm.(Bar)	Level(Bar)	Dev.(%)	Dev.(%)	Temp(ºC)	Comments
13.08.2004	1,01	0,06				
14.08.2004						
15.08.2004						
16.08.2004	1,00	0,06				
17.08.2004	1,00	0,06				
07.09.2004	1,03	0,00	0,20	-0,20	17	ATM
09.09.2004	1,03	0,06	-0,40	-0,22	18	Added 20g $CaOH_2$
13.09.2004	0,99	0,06	-0,48	-0,25	17	
14.09.2004	0,98	0,06	-0,47	-0,31	19	Dep. at housing, type 1&3
15.09.2004	1,00	0,06	-0,42	0,27	37	Added 20 g $CaOH_2$
16.09.2004	1,01	0,06	-0,38	0,28	45	Dep. at sensor element, type 1
22.09.2004	0,99	0,06	0,48	0,25	29	Dep. at sensor element, type 3
24.09.2004	0,99	0,06	0,60	0,16	29	Added 40 g $CaOH_2$
29.09.2004	1,02	0,06	0,60	0,12	29	
04.10.2004	1,00	0,06	-1,37	-0,37	31	
06.10.2004	0,99		-1,50	-0,65	24	End of test.

Table 19: Measurements from transmitter 1 and 3 in experiment with calcium

The table shows the measurement of type 2, type 4 and type 5 of the GT303 Kongsberg ballast transmitter where deviation from actual value is calculated.

Kongsberg	GT303						
Type			Type 2	Type 4	Type 5		
Date	Atm.(Bar)	Level(Bar)	Dev.(%)	Dev.(%)	Dev.(%)	Temp(ºC)	Comments
13.08.2004	1,01	0,06					
14.08.2004							
15.08.2004							
16.08.2004	1,00	0,06					
17.08.2004	1,00	0,06					
07.09.2004	1,03	0,00	0,10	-0,40	-0,10	17	ATM
09.09.2004	1,03	0,06	-0,46	-0,23	-0,93	18	Added 20g $CaOH_2$
13.09.2004	0,99	0,06	-0,01	-0,27	-0,61	17	
14.09.2004	0,98	0,06	-0,35	-0,17	-1,01	19	Dep. at type 2&4
15.09.2004	1,00	0,06	-0,21	0,10	-0,61	37	Added 20 g $CaOH_2$
16.09.2004	1,01	0,06	-0,23	-0,02	-0,76	45	
22.09.2004	0,99	0,06	0,17	-0,13	-1,56	29	
24.09.2004	0,99	0,06	0,05	-0,08	-1,53	29	Added 40 g $CaOH_2$
29.09.2004	1,02	0,06	-0,24	-0,36	-1,58	29	
04.10.2004	1,00	0,06	-0,25	-0,24	-1,13	31	
06.10.2004	0,99		-0,14	0,21	0,66	24	End of test.

Table 20: Measurements from transmitter 2, 4 and 5 in experiment with calcium

Appendix J: Mechanical Drawing – Test Welding 6.3

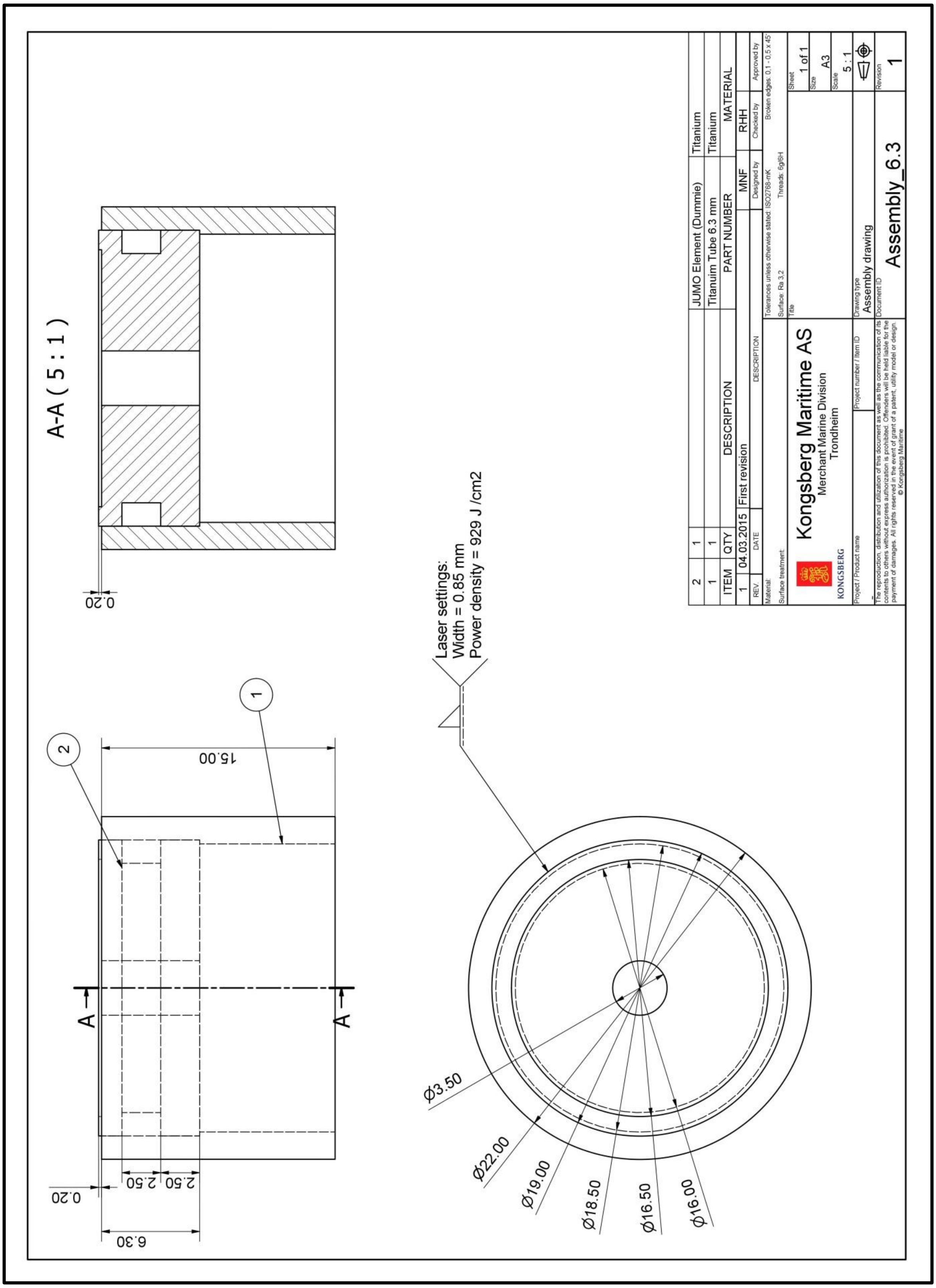


Figure 100: Test welding part, 6.3 mm

Appendix K: Mechanical Drawing – Test Welding 6.5

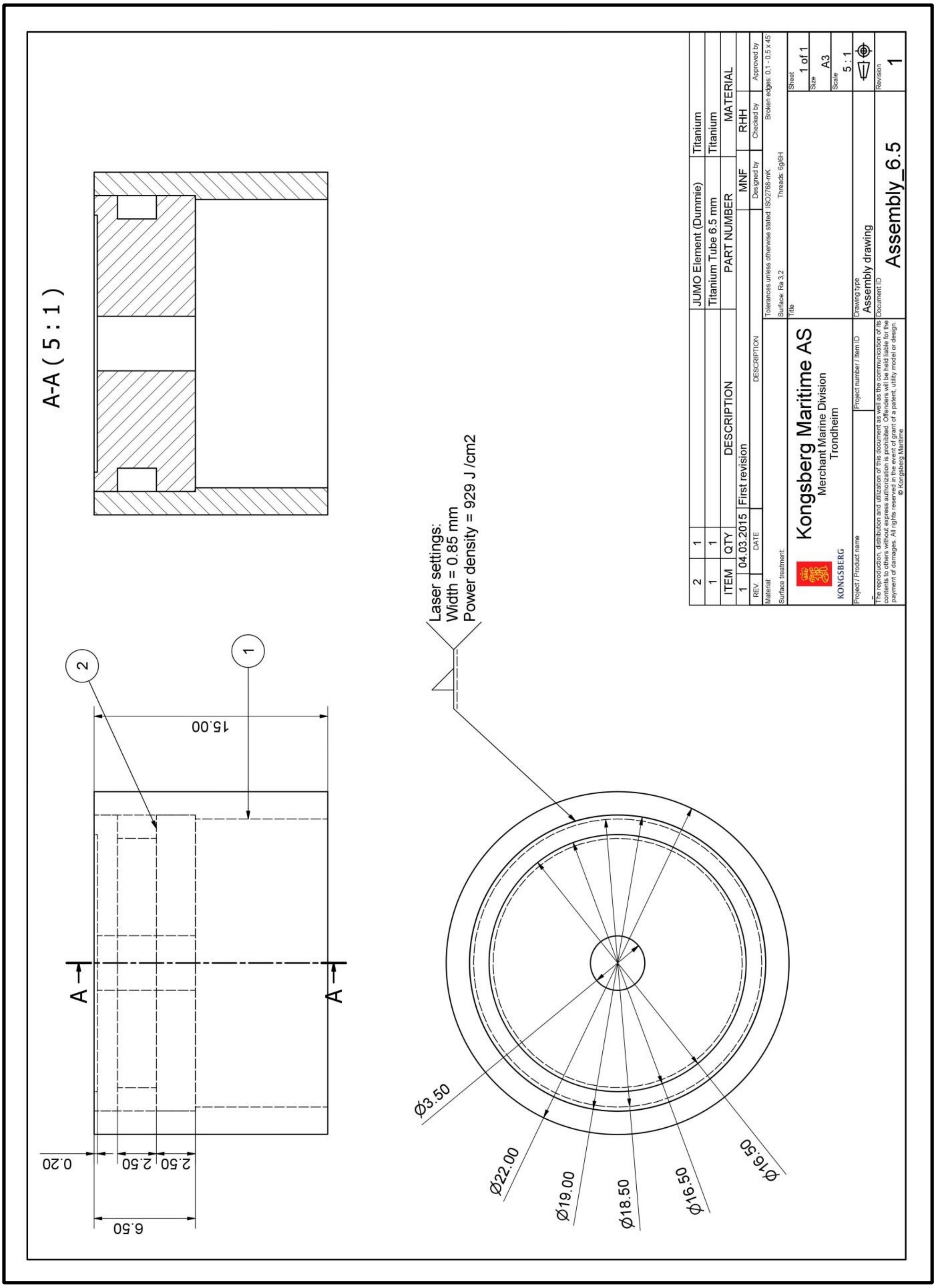


Figure 101: Test welding part, 6.5 mm

Appendix L: Mechanical Drawing – Test Welding 7.0

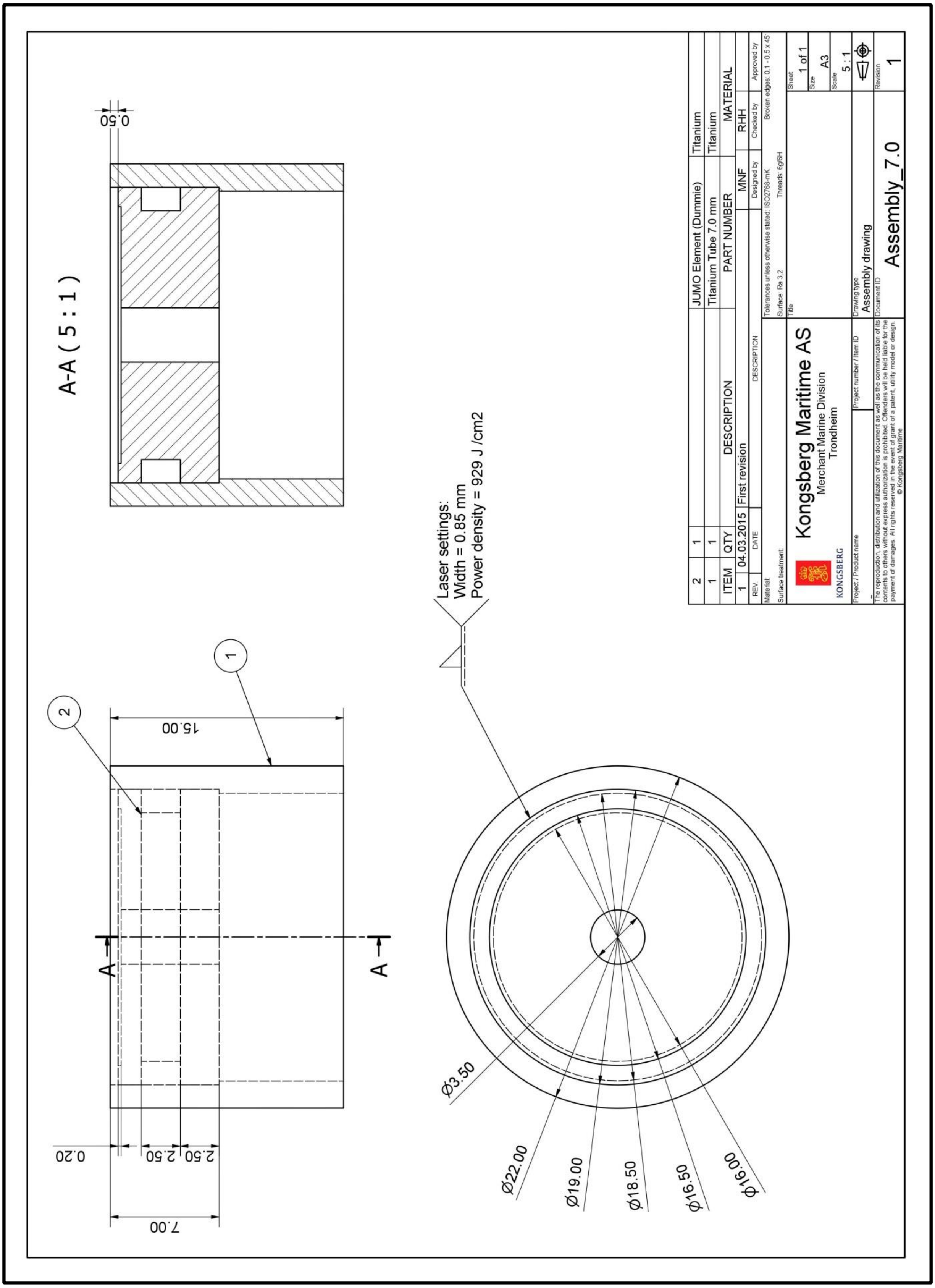


Figure 102: Test welding part, 7.0 mm

Appendix M: 1 Bar Sensor element JUMO

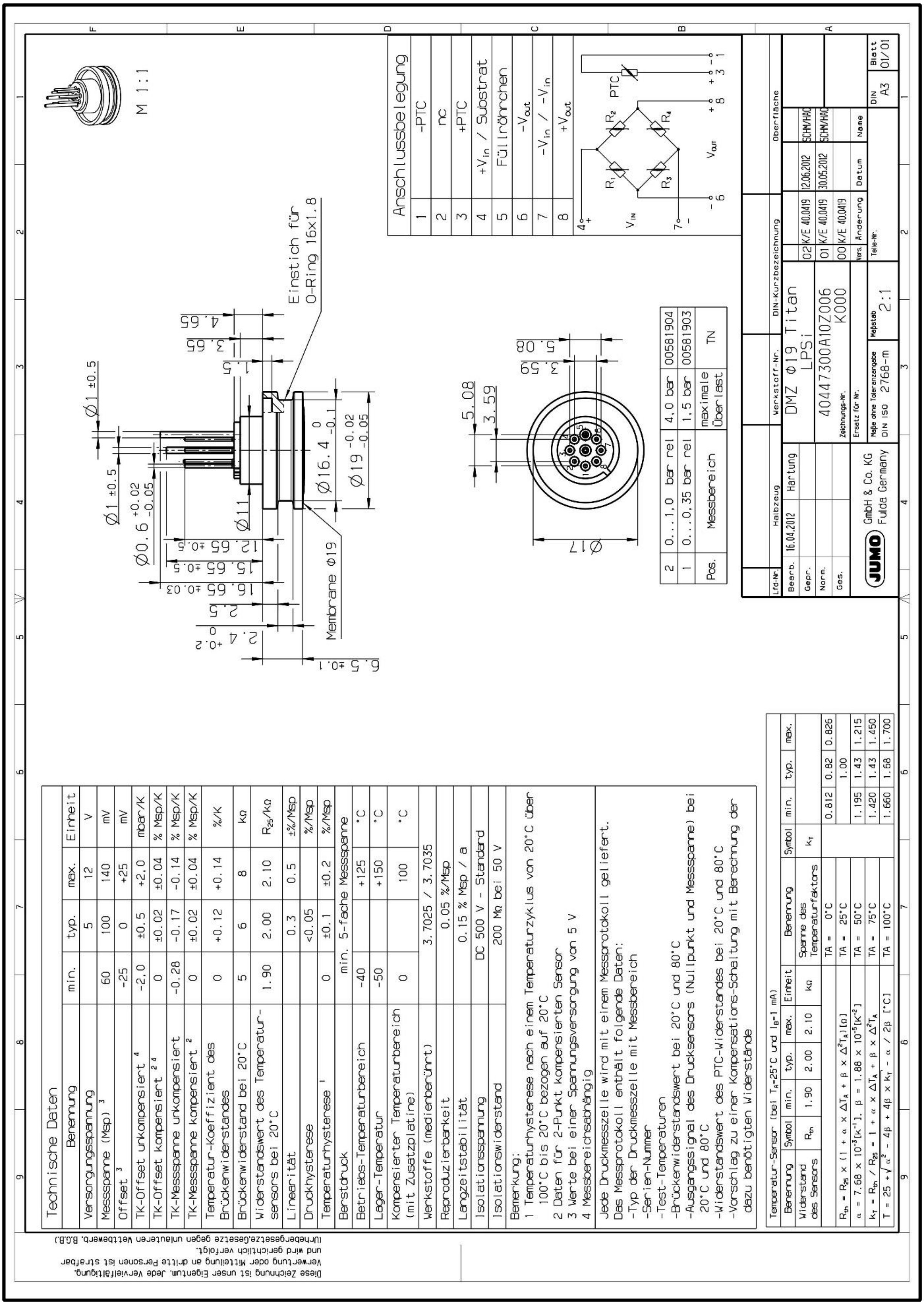


Figure 103: 1 bar element from JUMO

Appendix N: 5 Bar Sensor element JUMO

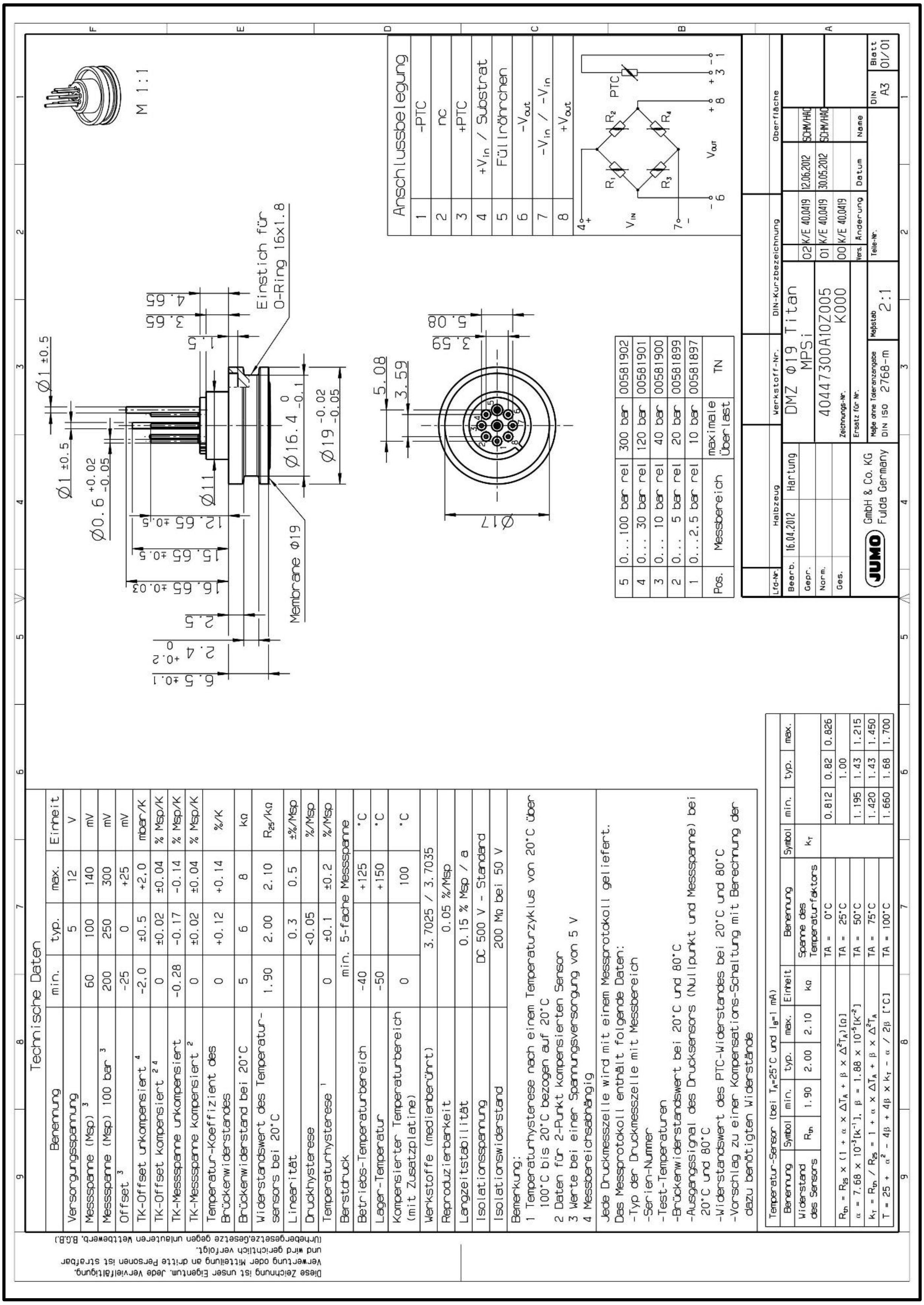


Figure 104: 5 bar element from JUMO

Appendix O: Measurement Prior and After Laser Welding

	R_{4-6}	R_{7-6}	R_{4-7}	R_{4-8}	R_{4-7}	R_{6-8}	V_{out} @5V
@ 1 bar							
#1 prior laser weld	4,63 kΩ	4,64 kΩ	4,63 kΩ	4,63 kΩ	6,17 kΩ	6,17 kΩ	0,14 mV
#1 after laser weld	4,63 kΩ	4,63 kΩ	4,63 kΩ	4,63 kΩ	6,17 kΩ	6,17 kΩ	-4,64 mV
#2 prior laser weld	4,58 kΩ	4,59 kΩ	4,58 kΩ	4,58 kΩ	6,11 kΩ	6,11 kΩ	0,13 mV
#2 after laser weld	4,55 kΩ	4,59 kΩ	4,58 kΩ	4,55 kΩ	6,11 kΩ	6,11 kΩ	-2,38 mV
#3 prior laser weld	4,56 kΩ	4,62 kΩ	4,61 kΩ	4,58 kΩ	6,15 kΩ	6,15 kΩ	0,13 mV
#3 after laser weld	4,58 kΩ	4,62 kΩ	4,61 kΩ	4,58 kΩ	6,15 kΩ	6,15 kΩ	-2,50 mV
#4 prior laser weld	4,55 kΩ	4,57 kΩ	4,58 kΩ	4,55 kΩ	6,11 kΩ	6,11 kΩ	0,13 mV
#4 after laser weld	4,56 kΩ	4,57 kΩ	4,58 kΩ	4,55 kΩ	6,11 kΩ	6,11 kΩ	4,60 mV
#5 prior laser weld	4,59 kΩ	4,64 kΩ	4,63 kΩ	4,60 kΩ	6,18 kΩ	6,18 kΩ	-3,71 mV
#5 after laser weld	4,63 kΩ	4,63 kΩ	4,63 kΩ	4,59 kΩ	6,18 kΩ	6,18 kΩ	-1,18 mV
@ 5 bar							
#1 prior laser weld	4,52 kΩ	4,56 kΩ	4,55 kΩ	4,53 kΩ	6,07 kΩ	6,07 kΩ	-7,65 mV
#1 after laser weld	4,55 kΩ	4,56 kΩ	4,55 kΩ	4,56 kΩ	6,07 kΩ	6,07 kΩ	-7,40 mV
#2 prior laser weld	4,56 kΩ	4,57 kΩ	4,54 kΩ	4,55 kΩ	6,06 kΩ	6,06 kΩ	-8,30 mV
#2 after laser weld	4,55 kΩ	4,56 kΩ	4,53 kΩ	4,54 kΩ	6,06 kΩ	6,06 kΩ	-8,30 mV
#3 prior laser weld	4,50 kΩ	4,53 kΩ	4,53 kΩ	4,51 kΩ	6,04 kΩ	6,04 kΩ	-6,83 mV
#3 after laser weld	4,52 kΩ	4,53 kΩ	4,53 kΩ	4,53 kΩ	6,04 kΩ	6,04 kΩ	-6,58 mV
#4 prior laser weld	4,48 kΩ	4,50 kΩ	4,51 kΩ	4,48 kΩ	6,00 kΩ	6,00 kΩ	4,24 mV
#4 after laser weld	4,48 kΩ	4,50 kΩ	4,50 kΩ	4,47 kΩ	6,00 kΩ	6,00 kΩ	4,43 mV
#5 prior laser weld	4,53 kΩ	4,53 kΩ	4,53 kΩ	4,54 kΩ	6,04 kΩ	6,04 kΩ	-4,01 mV
#5 after laser weld	4,53 kΩ	4,53 kΩ	4,53 kΩ	4,54 kΩ	6,04 kΩ	6,04 kΩ	-3,82 mV

Table 21: Measurement Prior and After Laser Welding:

Appendix P: Pressure Log: Laser Welded Transmitters (1 bar) before and after Coating

PRIOR COATING	Random sensor element 1	Random sensor element 2	AFTER COATING	Random sensor element 1 (T=15)	Ransom sensor element 2 (T=10)
0 bar	-4,91 mV	-2,58 mV	0 bar	-4,69 mV	-2,58 mV
0,25 bar	17,29 mV	18,66 mV	0,25 bar	17,56 mV	18,68 mV
0,50 bar	39,46 mV	39,86 mV	0,50 bar	39,76 mV	39,92 mV
0,75 bar	61,58 mV	61,15 mV	0,75 bar	61,92 mV	61,13 mV
1 bar	83,61 mV	82,28 mV	1 bar	84,00 mV	82,26 mV
0,75 bar	61,58 mV	61,14 mV	0,75 bar	61,92 mV	61,14 mV
0,50 bar	39,47 mV	39,96 mV	0,50 bar	39,77 mV	39,93 mV
0,25 bar	17,29 mV	18,72 mV	0,25 bar	17,57 mV	18,69 mV
0 bar	-4,91 mV	-2,55 mV	0 bar	-4,68 mV	-2,62 mV
0,25 bar	17,29 mV	18,72 mV	0,25 bar	17,57 mV	18,67 mV
0,50 bar	39,46 mV	39,96 mV	0,50 bar	39,76 mV	39,93 mV
0,75 bar	61,57 mV	61,14 mV	0,75 bar	61,91 mV	61,14 mV
1 bar	83,64 mV	82,26 mV	1 bar	83,99 mV	82,28 mV
0,75 bar	61,58 mV	61,14 mV	0,75 bar	61,91 mV	61,14 mV
0,50 bar	39,47 mV	39,96 mV	0,50 bar	39,76 mV	39,94 mV
0,25 bar	17,29 mV	18,72 mV	0,25 bar	17,57 mV	18.68 mV
0 bar	-4,91 mV	-2,56 mV	0 bar	-4,68 mV	-2,62 mV

Table 22: Transmitters (1 bar) testing before and after Coating

Appendix Q: Mechanical Drawing of New Housing Part

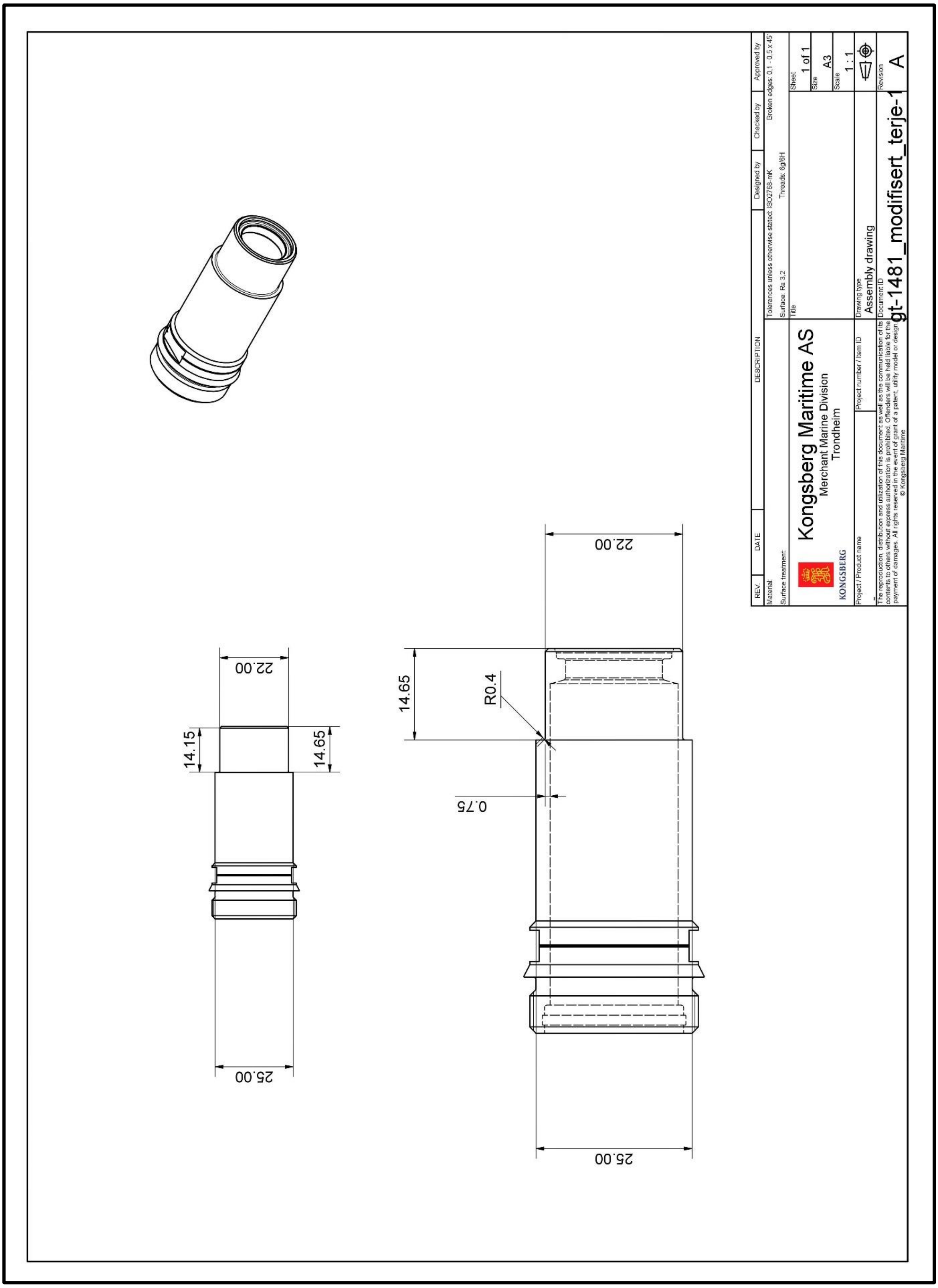


Figure 105: Modified housing part

Appendix R: Mechanical Drawing of Assembled Prototype

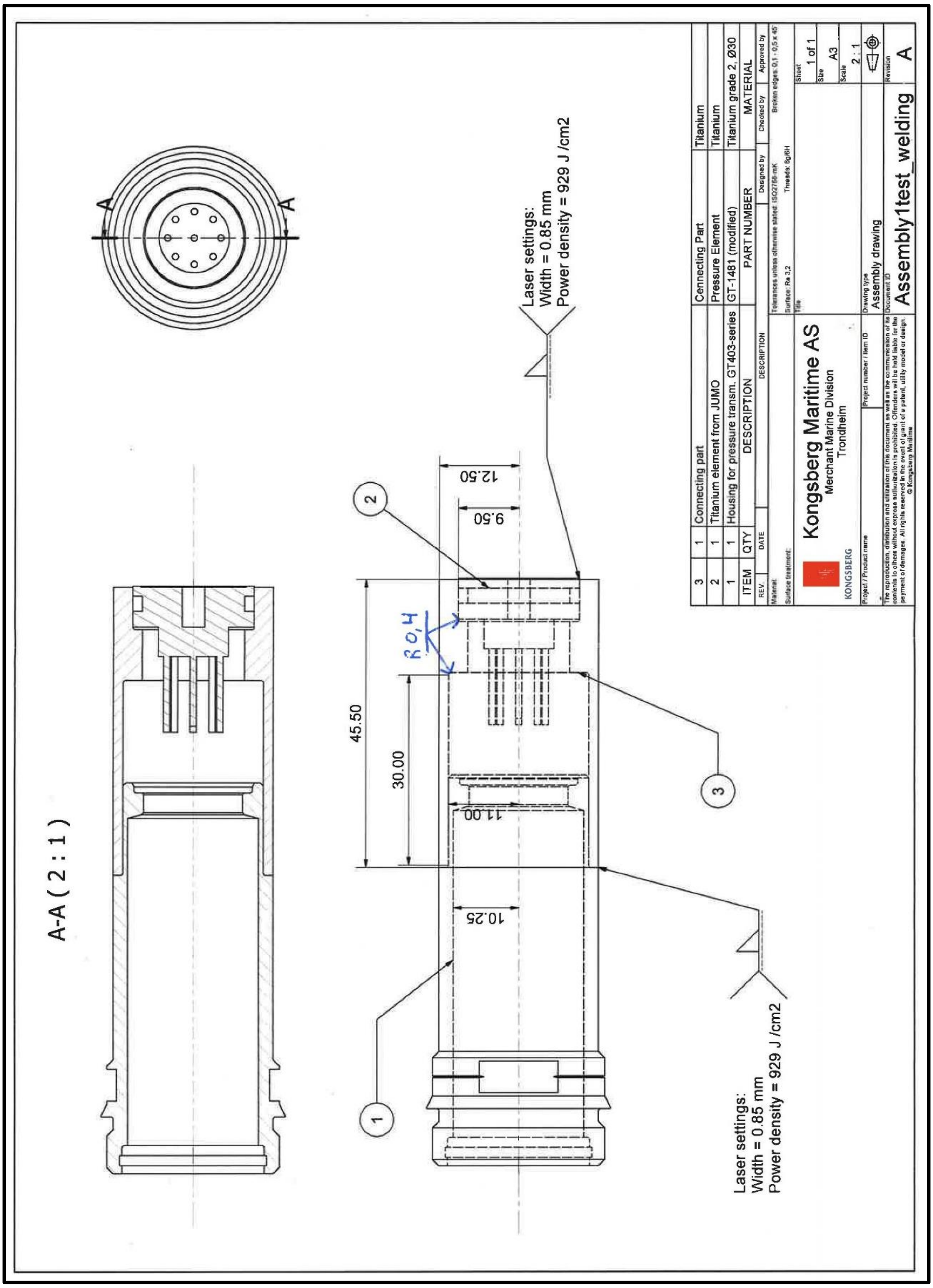


Figure 106: Assembled Prototype

Appendix S: Results 1 bar Sensor Elements

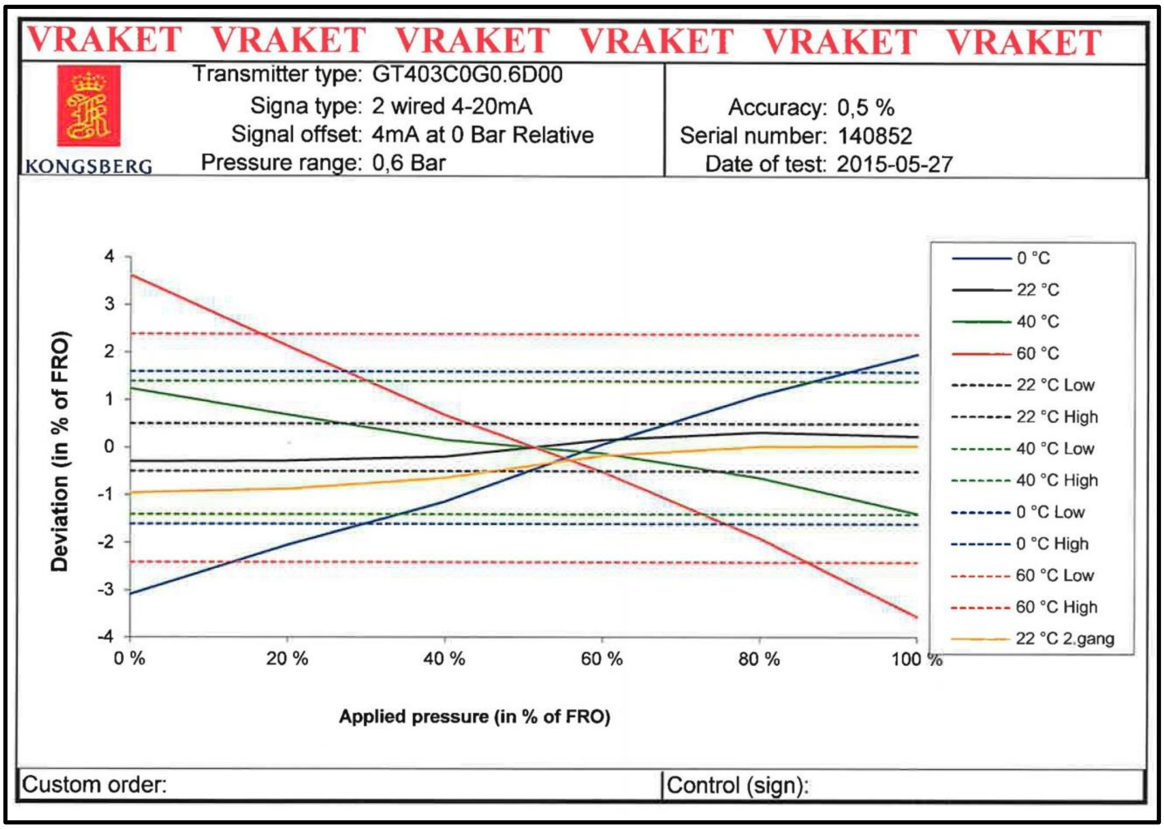


Figure 107: Result sensor number 140852

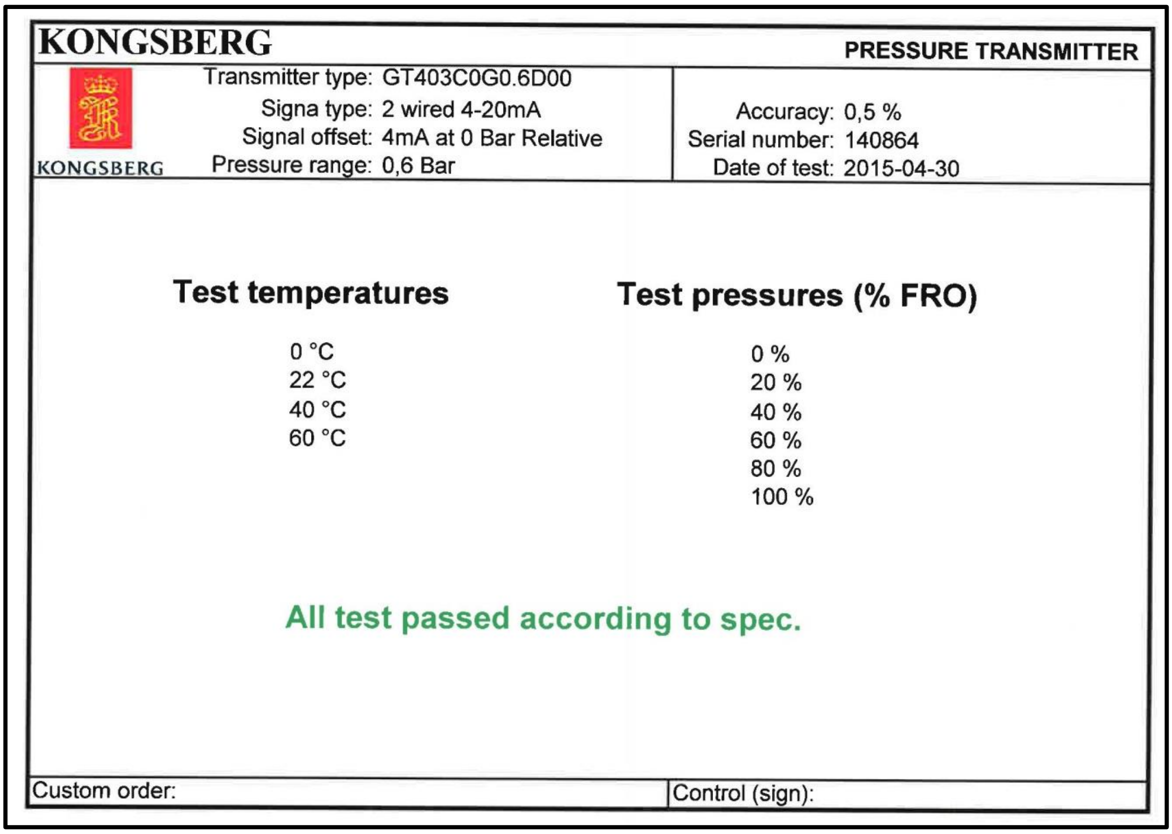


Figure 108: Result sensor number 140864

KONGSBERG PRESSURE TRANSMITTER

KONGSBERG

Transmitter type: GT403C0G0.6D00 Signa type: 2 wired 4-20mA Signal offset: 4mA at 0 Bar Relative Pressure range: 0,6 Bar	Accuracy: 0,5 % Serial number: 140866 Date of test: 2015-04-29

Test temperatures	Test pressures (% FRO)
0 °C	0 %
22 °C	20 %
40 °C	40 %
60 °C	60 %
	80 %
	100 %

All test passed according to spec.

Custom order:	Control (sign):

Figure 109: Result sensor number 140866

KONGSBERG PRESSURE TRANSMITTER

KONGSBERG

Transmitter type: GT403C0G0.6D00 Signa type: 2 wired 4-20mA Signal offset: 4mA at 0 Bar Relative Pressure range: 0,6 Bar	Accuracy: 0,5 % Serial number: 140867 Date of test: 2015-04-29

Test temperatures	Test pressures (% FRO)
0 °C	0 %
22 °C	20 %
40 °C	40 %
60 °C	60 %
	80 %
	100 %

All test passed according to spec.

Custom order:	Control (sign):

Figure 110: Result sensor number 140867

KONGSBERG **PRESSURE TRANSMITTER**

KONGSBERG

Transmitter type:	GT403C0G0.6D00		
Signa type:	2 wired 4-20mA	Accuracy:	0,5 %
Signal offset:	4mA at 0 Bar Relative	Serial number:	140865
Pressure range:	0,6 Bar	Date of test:	2015-04-29

Test temperatures	Test pressures (% FRO)
0 °C	0 %
22 °C	20 %
40 °C	40 %
60 °C	60 %
	80 %
	100 %

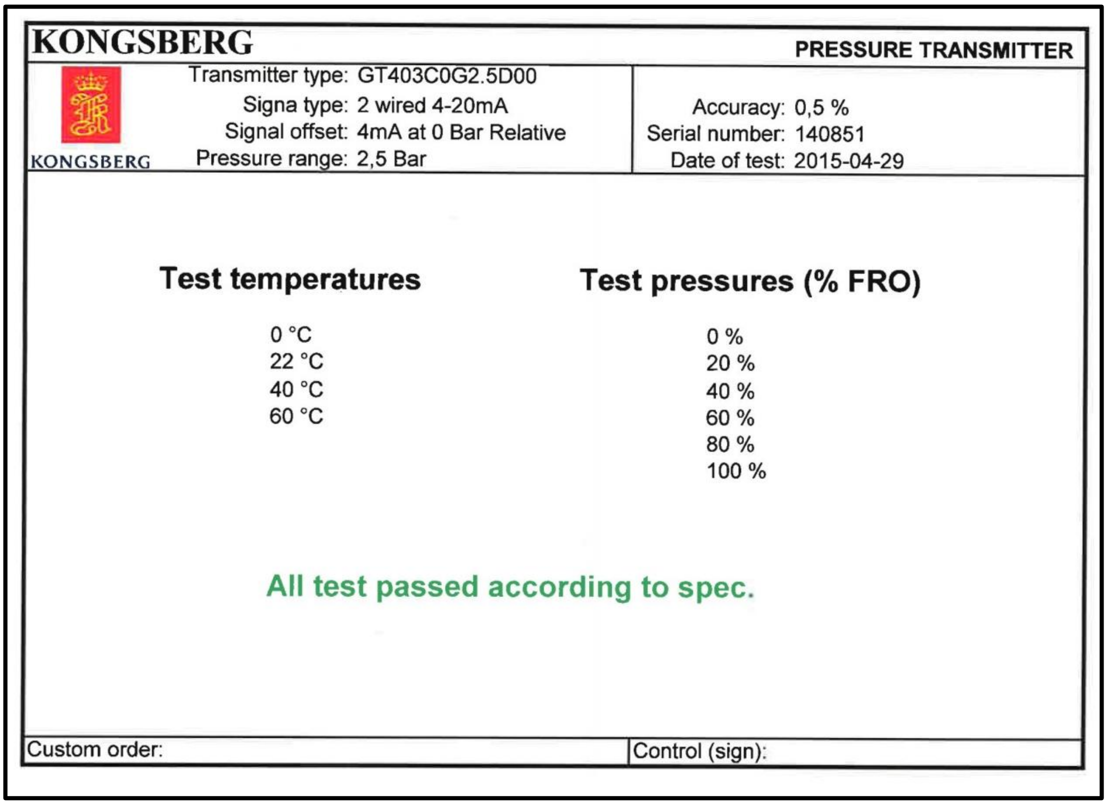
All test passed according to spec.

Custom order:

Control (sign):

Figure 111: Result sensor number 140865

Appendix T: Results 5 bar Sensor Elements


KONGSBERG
PRESSURE TRANSMITTER

KONGSBERG

Transmitter type: GT403C0G2.5D00
Signa type: 2 wired 4-20mA
Signal offset: 4mA at 0 Bar Relative
Pressure range: 2,5 Bar

Accuracy: 0,5 %
Serial number: 140851
Date of test: 2015-04-29

Test temperatures

0 °C
22 °C
40 °C
60 °C

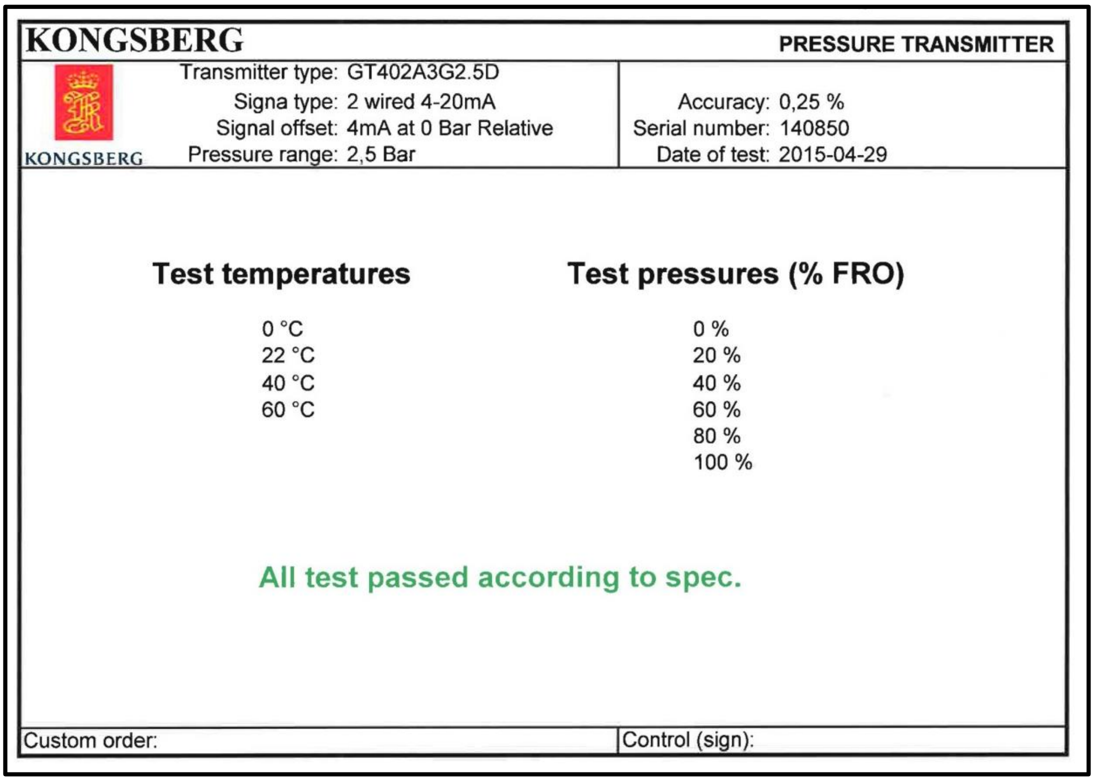
Test pressures (% FRO)

0 %
20 %
40 %
60 %
80 %
100 %

All test passed according to spec.

Custom order:
Control (sign):

Figure 112: Result sensor number 140851


KONGSBERG
PRESSURE TRANSMITTER

KONGSBERG

Transmitter type: GT402A3G2.5D
Signa type: 2 wired 4-20mA
Signal offset: 4mA at 0 Bar Relative
Pressure range: 2,5 Bar

Accuracy: 0,25 %
Serial number: 140850
Date of test: 2015-04-29

Test temperatures

0 °C
22 °C
40 °C
60 °C

Test pressures (% FRO)

0 %
20 %
40 %
60 %
80 %
100 %

All test passed according to spec.

Custom order:
Control (sign):

Figure 113: Result sensor number 140850

KONGSBERG **PRESSURE TRANSMITTER**

KONGSBERG

Transmitter type: GT403C0G2.5D00
Signa type: 2 wired 4-20mA
Signal offset: 4mA at 0 Bar Relative
Pressure range: 2,5 Bar

Accuracy: 0,5 %
Serial number: 140869
Date of test: 2015-04-30

Test temperatures

0 °C
22 °C
40 °C
60 °C

Test pressures (% FRO)

0 %
20 %
40 %
60 %
80 %
100 %

All test passed according to spec.

Custom order:

Control (sign):

Figure 114: Result sensor number 140869

KONGSBERG **PRESSURE TRANSMITTER**

KONGSBERG

Transmitter type: GT403C0G2.5D00
Signa type: 2 wired 4-20mA
Signal offset: 4mA at 0 Bar Relative
Pressure range: 2,5 Bar

Accuracy: 0,5 %
Serial number: 140853
Date of test: 2015-04-29

Test temperatures

0 °C
22 °C
40 °C
60 °C

Test pressures (% FRO)

0 %
20 %
40 %
60 %
80 %
100 %

All test passed according to spec.

Custom order:

Control (sign):

Figure 115: Result sensor number 140853

KONGSBERG | **PRESSURE TRANSMITTER**

KONGSBERG

Transmitter type: GT403C0G2.5D00	
Signa type: 2 wired 4-20mA	Accuracy: 0,5 %
Signal offset: 4mA at 0 Bar Relative	Serial number: 140868
Pressure range: 2,5 Bar	Date of test: 2015-04-30

Test temperatures	**Test pressures (% FRO)**
0 °C	0 %
22 °C	20 %
40 °C	40 %
60 °C	60 %
	80 %
	100 %

All test passed according to spec.

Custom order:

Control (sign):

Figure 116: Result sensor number 140868

Appendix U: Certificate 1 bar Sensor Elements

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer: Kongsberg Maritime AS
Address: Haakon VII's gt 4, N-7005 Trondheim
Sensor type: GT403C0G0.6D00
Pressure range: 0 to 0,6 Bar Relative
Accuracy 0,05 %FRO in the range 0 to 60°C
Sensor serial no: 140865
Date of calibration: 2015-05-27

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	0,0 %	20,0 %	40,0 %	60,0 %	80,0 %	100,0 %
0°C	-0,93	-1,08	-1,23	-1,28	-1,39	-1,53
22°C	-1,27	-1,38	-1,51	-1,66	-1,79	-1,86
40°C	-1,79	-1,76	-1,87	-1,89	-1,91	-1,85
60°C	-1,96	-2,12	-2,26	-2,39	-2,53	-2,71

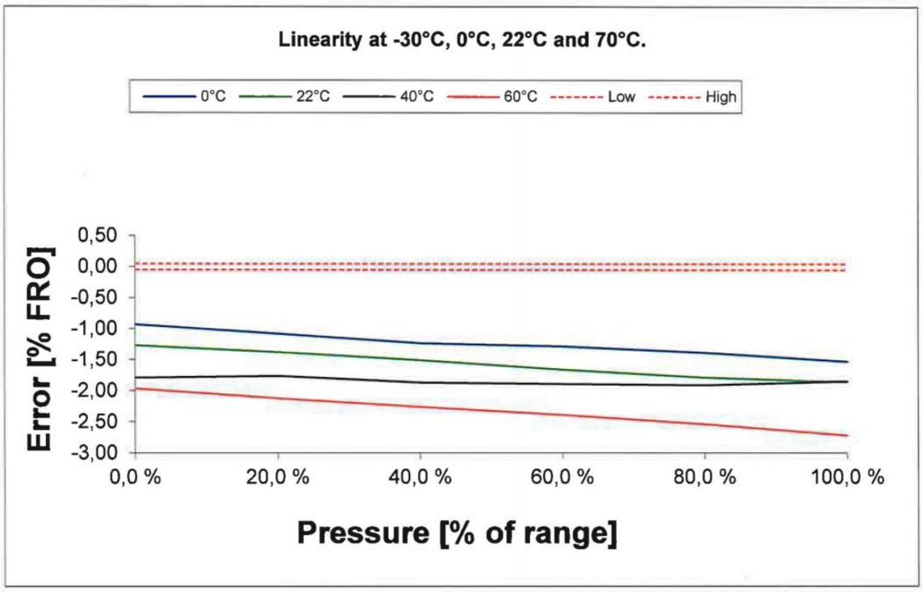


Figure 117: Calibration certificate for sensor number 140865

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer:	**Kongsberg Maritime AS**
Address:	**Haakon VII's gt 4, N-7005 Trondheim**
Sensor type:	**GT403C0G0.6D00**
Pressure range:	**0 to 0,6 Bar Relative**
Accuracy	**0,05 %FRO in the range 0 to 60°C**
Sensor serial no:	**140866**
Date of calibration:	**2015-05-27**

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	**0,0 %**	**20,0 %**	**40,0 %**	**60,0 %**	**80,0 %**	**100,0 %**
0°C	-0,58	-0,53	-0,62	-0,70	-0,75	-0,87
22°C	-0,73	-0,92	-1,06	-1,16	-1,17	-1,29
40°C	-1,38	-1,34	-1,43	-1,50	-1,47	-1,41
60°C	-1,73	-1,81	-2,00	-2,13	-2,20	-2,30

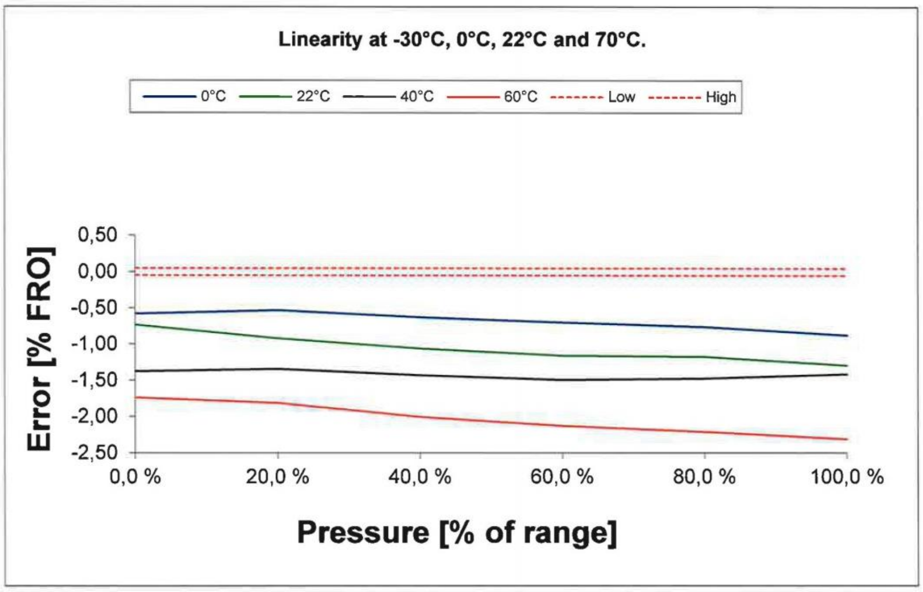


Figure 118: Calibration certificate for sensor number 140866

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer:	**Kongsberg Maritime AS**
Address:	**Haakon VII's gt 4, N-7005 Trondheim**
Sensor type:	**GT403C0G0.6D00**
Pressure range:	**0 to 0,6 Bar Relative**
Accuracy	**0,05 %FRO in the range 0 to 60°C**
Sensor serial no:	**140864**
Date of calibration:	**2015-05-27**

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	**0,0 %**	**20,0 %**	**40,0 %**	**60,0 %**	**80,0 %**	**100,0 %**
0°C	0,07	0,03	-0,15	-0,35	-0,40	-0,49
22°C	-0,09	-0,20	-0,30	-0,38	-0,44	-0,40
40°C	-0,31	-0,36	-0,44	-0,44	-0,42	-0,34
60°C	-0,01	-0,22	-0,36	-0,50	-0,66	-0,64

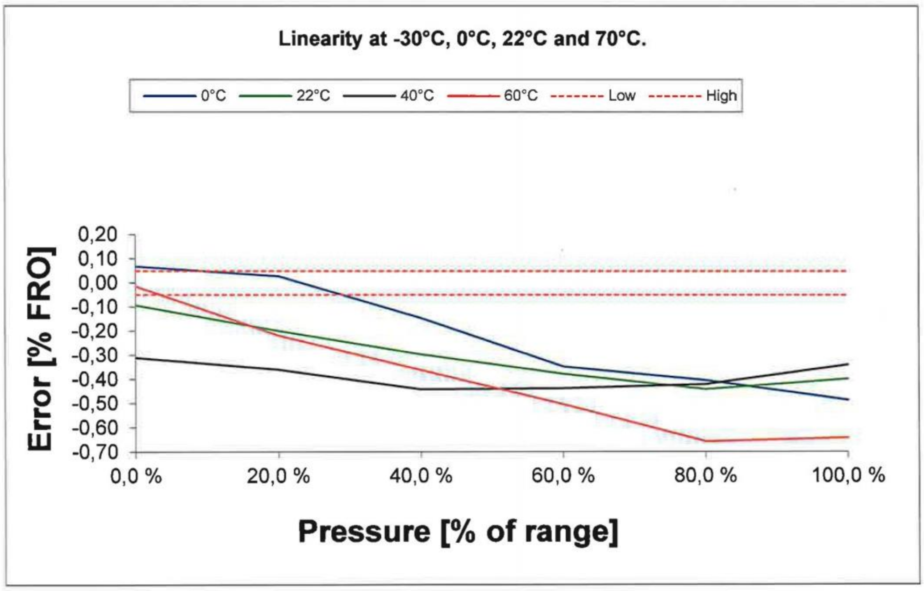


Figure 119: Calibration certificate for sensor number 140864

Appendix V: Certificate 5 bar Sensor elements

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer:	**Kongsberg Maritime AS**
Address:	**Haakon VII's gt 4, N-7005 Trondheim**
Sensor type:	**GT403C0G2.5D00**
Pressure range:	**0 to 2,5 Bar Relative**
Accuracy	**0,05 %FRO in the range 0 to 60°C**
Sensor serial no:	**140853**
Date of calibration:	**2015-05-26**

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	**0,0 %**	**20,0 %**	**40,0 %**	**60,0 %**	**80,0 %**	**100,0 %**
0°C	-0,31	-0,04	0,12	0,20	0,28	0,49
22°C	0,29	0,19	0,06	0,00	-0,05	0,09
40°C	0,19	0,11	0,10	0,10	0,16	0,36
60°C	0,32	0,11	-0,02	-0,12	-0,33	-0,33

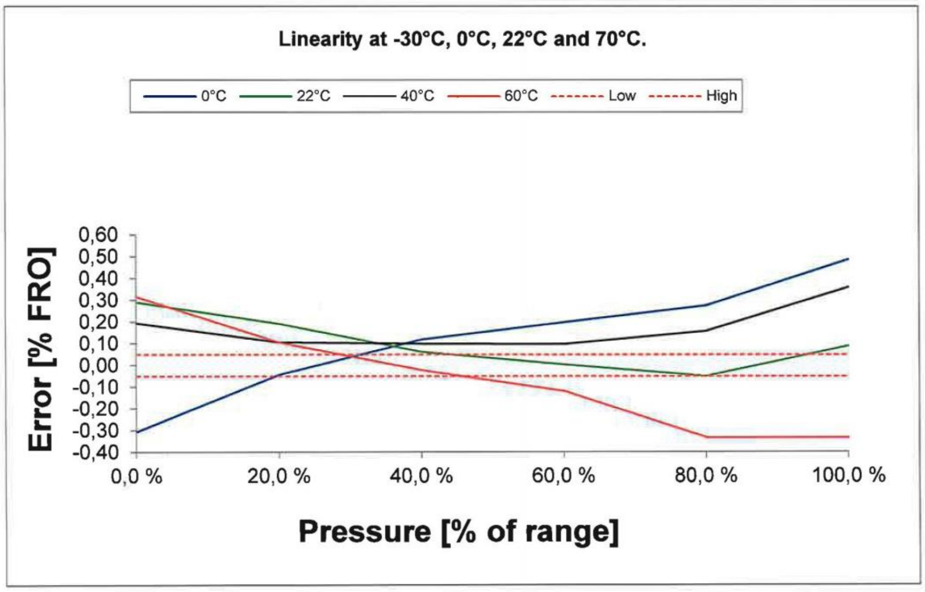


Figure 120: Calibration certificate for sensor number 140853

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer: Kongsberg Maritime AS
Address: Haakon VII's gt 4, N-7005 Trondheim
Sensor type: GT403C0G2.5D00
Pressure range: 0 to 2,5 Bar Relative
Accuracy 0,05 %FRO in the range 0 to 60°C
Sensor serial no: 140868
Date of calibration: 2015-05-26

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	0,0 %	20,0 %	40,0 %	60,0 %	80,0 %	100,0 %
0°C	0,10	-0,07	-0,17	-0,23	-0,28	0,08
22°C	0,10	-0,06	-0,17	-0,21	-0,26	-0,14
40°C	-0,04	-0,07	-0,08	0,00	0,04	0,33
60°C	0,15	-0,01	-0,11	-0,22	-0,41	-0,31

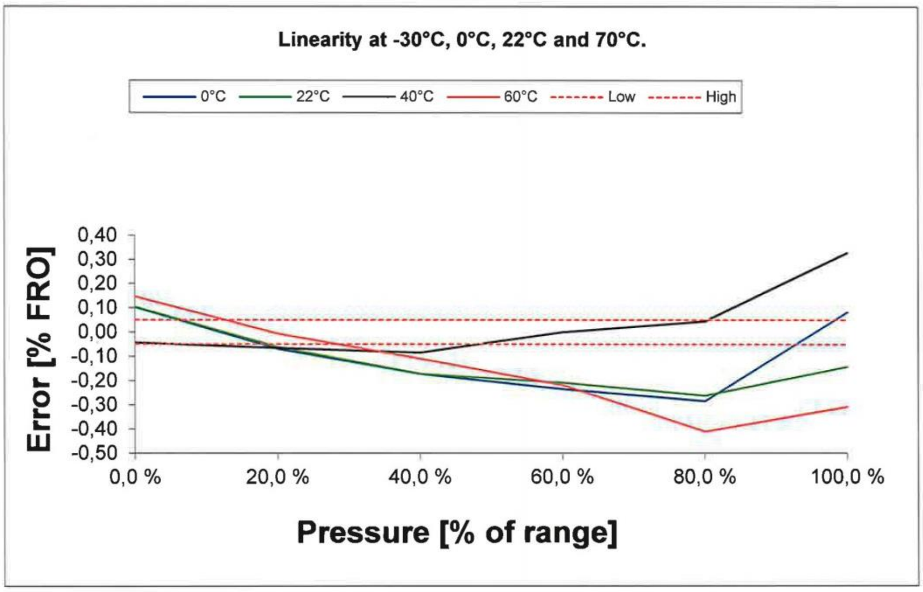


Figure 121: Calibration certificate for sensor number 140868

Calibration certificate
Pressure sensor
FAT

KONGSBERG

Manufacturer:	**Kongsberg Maritime AS**
Address:	**Haakon VII's gt 4, N-7005 Trondheim**
Sensor type:	**GT403C0G2.5D00**
Pressure range:	**0 to 2,5 Bar Relative**
Accuracy	**0,05 %FRO in the range 0 to 60°C**
Sensor serial no:	**140869**
Date of calibration:	**2015-05-26**

Deviation table [%FRO] (%FRO = % of Full Range Output)

	Applied pressure [% FRO]					
Temperature	0,0 %	20,0 %	40,0 %	60,0 %	80,0 %	100,0 %
0°C	-0,01	-0,07	-0,12	-0,21	-0,18	0,09
22°C	-0,03	-0,11	-0,19	-0,27	-0,25	-0,16
40°C	-0,20	-0,17	-0,17	-0,11	-0,01	0,22
60°C	-0,04	-0,10	-0,24	-0,32	-0,49	-0,48

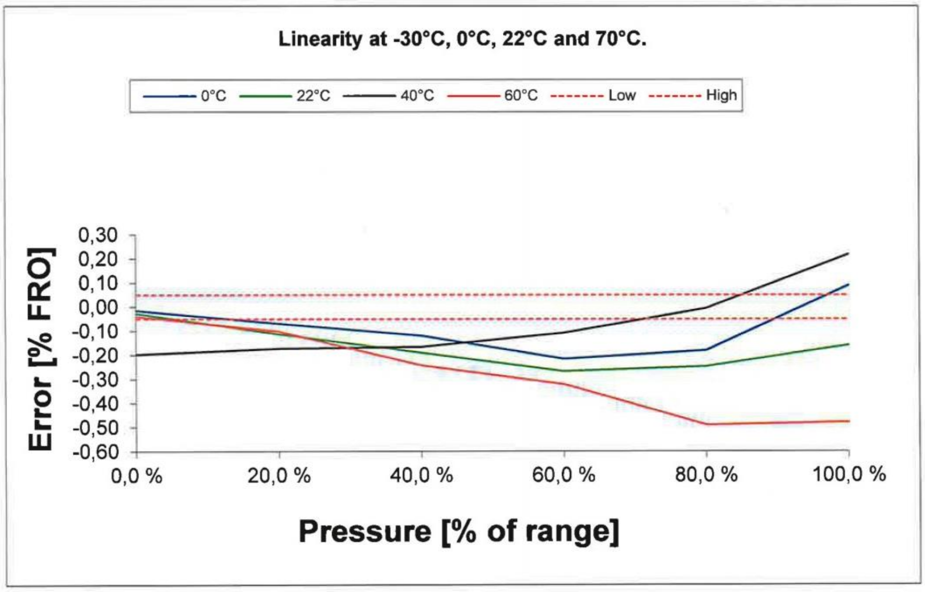


Figure 122: Calibration certificate for sensor number 140869