THESIS

Condition based monitoring of steam traps

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2 JUNE 2016

Version 1.0

Research report

Research report for the graduation of maritime engineering

Condition based monitoring of steam traps.

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Date	: 2 June 2016
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Abstract

On board the vessels of Holland America Line a lot of attention is drawn to prevent the loss of energy. On board energy is produced in several ways by fuel. Therefor fuel is the biggest expense of a cruise ship. On board steam is used for heating purposes. The type of steam used for these heating purposes is saturated steam. To create the saturated steam a steam system is used that consumes fuel. This steam system can have energy losses, noticeable and unnoticeable. If the steam system has steam leaks this will result in a bigger expense on fuel.

Steam traps are an important part of the steam system. The function of a steam trap is to separate the condensate from the steam. Steam traps can leak steam unnoticed, if a steam trap leaks the boiler will have to produce more steam, this will result in higher fuel costs.

The goal of this research was to determine the condition of the steam traps by applying condition based maintenance on steam traps. The condition based monitoring methods used in this research were thermal imaging and ultrasound. The thermal image camera used was a FLIR E4, the ultrasound measuring tool was an Ultraprobe 15000.

Each steam trap was judged on the condensate outlet temperature, the working principle of the trap itself, and the decibel value of the ultrasound. If the temperature of the condensate was above 100 degrees Celsius this indicated steam. If the working principle of the trap was too fast, or the decibel value was above 40 this also indicated steam leakage though the trap.

An excel sheet which includes the 76 thermal measurements and the ultrasound measurements was created. Conclusions of the state of the steam trap according to the thermal image and ultrasound were made. A main conclusion was drawn by combining these to two conclusions.

Once the condition of the steam traps were determined the average steam loss was determined by using steam loss tables of Spirax Sarco and UE systems. The total amount of steam lost due to the leaking steam traps was 557,5 kg/hour according to Spirax Sarco, according to UE systems the amount of steam lost due to leaking traps was 1305 kg/hour. These steam losses are subjective, as the load in the steam system is not consistent.

The price of on ton steam was calculated. The price of one ton steam generated by the aft boiler on the MV Zuiderdam was 14,11 euro when running on MDO, running on HFO the price of one ton steam was determined on 9,24 euro.

The yearly expenses caused by leaking steam traps were achieved by assuming that the MV Zuiderdam has 250 port days in 2016, and the load configuration stays consistent during this period.

The total yearly expenses caused by leaking steam traps according to Spirax Sarco are 19662 euro's when running on MDO, and 12882 euro's when running on HFO. This resulted in an efficiency loss in the steam system of 11,9% on MDO and 12,2% on HFO.

According to UE systems the extra expenses caused by leaking steam traps were 47082 euro's while running on MDO, and 30847 euro's while running on HFO. This resulted in an efficiency loss in the steam system of 28,5% on MDO, and 29,1% on HFO.

It must be stated that the fuel prices are low at this moment. In 2013 the fuel prices were almost four times as high, this will make the expenses caused by leaking steam traps four times as high.

Preface

This research was a real eye opener for me. 7 months ago I had never heard of condition based maintenance, nor did I pay a lot of attention to steam traps. Now I know condition based maintenance has a real potential that is underused in the shipping industry, and that serious care should be given to steam traps.

I would like to thank Peter Boone and Marcel Rutgers of UE systems for giving me the opportunity to follow one of their ultrasound training courses, and for borrowing me the ultrasound measuring equipment.

This research came with a lot of work, I would like to thank Alex Hekker and Arie de Groot for guidance with this research.

Finally I would like to say I had a nice time and learning experience thanks to this research.

List of abbreviations

APA	: American Psychological Association
DB	: Decibel
DMS	: Data managing software
FFT	: Fast Fourier transformation
ECA	: Emmision control area
EGB	: Exhaust gas boilers
HFO	: Heavy fuel oil
KG	: Kilogram
MDO	: Marine diesel oil
MV	: Motor vessel
PN	: Pipe nominal
UE	: Ultrasound equipment

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1. Introduction

The Holland America Line is recognized worldwide as one of the biggest cruise ship lines in the cruise ship sector. The Holland America line fleet consists of fifteen vessels, offers 500 cruises around 415 ports in 98 countries in the world. (Holland America Line, 2015)

On board the vessels of Holland America Line a lot of attention is drawn to prevent the loss of energy. On board energy is produced in several ways by fuel. Therefor fuel is the biggest expense of a cruise ship.

On board steam is used for several heating purposes. The type of steam used for these heating purposes is saturated steam. To create the saturated steam a steam system is used that consumes fuel. This steam system can have energy losses, noticeable and unnoticeable. If the steam system has leaks this will result in a bigger expense on fuel.

Steam traps are an important part of the steam system. The function of a steam trap is to separate the condensate from the steam. Steam traps can leak steam unnoticed, if a steam trap leaks the boiler will have to produce more steam, this will result in higher fuel costs.

On board steam traps are not always monitored, a method to monitor steam traps while the steam system is operational is desired.

The goal of this thesis is to gather information with applied research that can lead to the solution of the unnoticeable leakages of steam traps in the steam system.

This thesis consists of several chapters. The second chapter, the theoretical framework, consists of literature that is required to start this research.

The third chapter, the research design, describes the method that was used to achieve the results in this research project.

The results are given in chapter four. In the fifth chapter there is a discussion about the results, and in chapter six the conclusions are drawn and the recommendations are made.

For this research a main question is drafted, this main question is as follows:

''How much can the efficiency of the steam system on board the MV Zuiderdam be improved, by performing condition based maintenance on steam traps?''

To answer this main question three sub question are drafted:

1. What are the conditions of the steam traps that are in use?
2. How much steam is lost due to the leaking steam traps?
3. What are the costs of the measured leaking steam traps?

2. Theoretical framework

In this chapter, the theoretical framework, existing literature is gathered to acquire background information needed for this research. The literature is required to answer the sub questions and eventually the main question of this research. This literature is gathered from databanks, internet and books. The literature is tested by the APA reference list.

2.1 The steam system

A steam system operates on a simple principle. In the boiler water is boiled under a certain pressure and temperature to create saturated steam. This steam is collected in the boiler, from there on it is transferred to heat exchangers. The heat exchanger makes the steam to condensate, when steam condensates heat of formation is created, this is used for heating purposes. Heat exchangers can work on different steam pressures. Therefor a pressure reduction valve can be placed in front of a heat exchanger. Not all steam will condensate in the heat exchanger, some steam will pass through to the condensate line. To ''trap'' this steam a steam trap is placed on the condensate line of a heat exchanger. The used condensate then returns to a condensate tank, a hotwell. This principle is displayed in figure two. The complete steam system can be found at (S van Hees, Bureau Veritas, 2006)

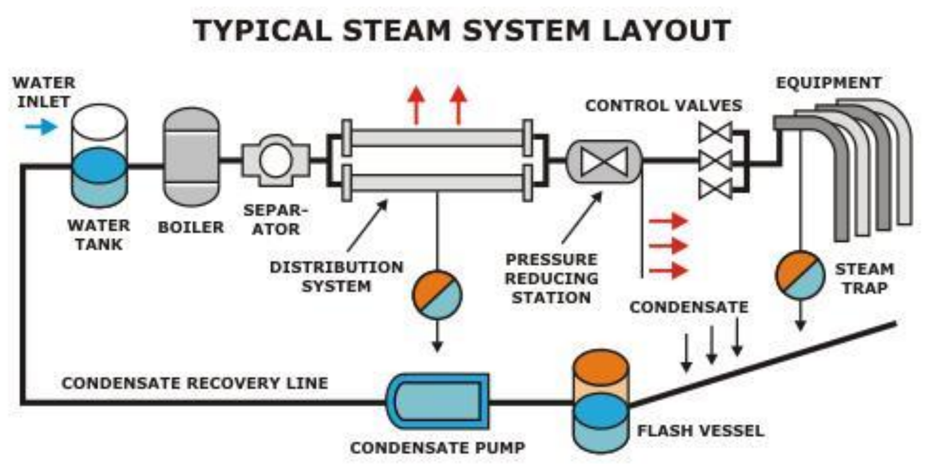

Figure 2 Schematic view of the steam systems principle - retrieved from (Wadeindustrial, 2011)

The boiler is an important part of the steam system, the fuel is burnt and the expenses are made here. The boiler should produce as much steam as possible under a certain pressure and temperature. (S van Hees, Bureau Veritas, 2006)

2.2 The energy losses in a steam system

No steam system is perfect, every steam system has its own energy losses, these can be noticeable or can go by unnoticed. Noticeable losses are losses which are accepted, for example a dryer that works on steam. Unnoticeable losses are a bigger problem. There are three main components that can lose energy unnoticeable in a steam system. These are:

1. Isolation losses
2. Steam valves
3. Steam traps

2.2.1 Isolation losses

A steam system is hot and therefor creates a lot radiant heat, radiant heat can be seen as an unwanted heat exchanger. To reduce the heat radiation the entire steam system is isolated. Isolation losses occur when isolation is removed and not put back in place, or if parts of the steam system are not isolated in the first place. Some examples where isolation losses occur are pressure reduction valves and expansion pipes. (Bain Bannon, BNP Media, 2013)

2.2.2 Steam valves

Valves are placed in each system in which mediums are transported. In steam systems steam valves are placed. In case a steam valve leaks this will result in higher fuel expenses.

2.2.3 Steam traps

45% of the burnt fuel in America is used for the production of steam. The biggest expenses in a steam system are leakages that go by unnoticed. These leakages mainly occur in steam traps. Incase steam traps fail this will result in a higher production of steam, efficiency loss and higher production costs. Steam traps therefor should be monitored regularly.

Several studies conclude that a lack of maintenance at steam traps can result in large energy losses, for instance, if a steam trap has a orifice of 3 mm and the steam pressure is 3,5 bar, the average steam loss is 13 kg of steam an hour. If the plant runs 24 hours a day, 50 weeks a year this will result in 1302 euro a year. This in only for one steam trap, a steam system can consist of hundreds of steam traps. In case the steam system consists of 100 traps, and 25% of the traps fail, this will result in 32000 euro of steam losses caused by steam traps. (Alan S Bandes, UE Systems, 2003) (Bruce Gorelick, Enercheck systems; Alan bandes, UE systems, 2010)

To give a clear picture on how these values are met a calculation to calculate the steam production can be calculated with the following formula:

$$Steam\ production\ \left(\frac{kg}{hour}\right) = \frac{Mass\ flow\ fuel\left(\frac{kg}{hour}\right) * Boiler\ efficiency\ * Calorific\ value\ \left(\frac{KJ}{Kg}\right)}{Heat\ of\ formation\ \left(\frac{Kj}{KgK}\right)}$$

The amount of tons steam that were generated can be divided by the fuel costs. This will give the price of one ton steam. The details of the calculations can be found at (S. van Hees, 2006).

The function of a steam trap is to remove condensate and other non-compressible gasses from the steam. (Gielessen BV, 2012) (Blok Gouda, 2014)

Steam traps can work on three different working principles, namely:

1. Thermostatic steam traps, work on the temperature difference of the liquid;
2. Thermodynamic steam traps, work on the dynamic difference of the liquid;
3. Mechanical steam traps, work on the difference in density of the liquid.

These different working principles know their own steam traps. Some examples of steam traps are:

- Ball float steam traps;
- Inverted bucket steam traps;
- Membrane steam traps;
- Bimetal steam traps;
- Venturi steam traps;
- Impulse and labyrinth steam traps.

The working principles of these traps are explained in appendix one.

2.3 The fail modes of steam traps

Each steam trap has its own fail modes, in this paragraph the fail modes of the different steam traps will be documented.

Ball float steam traps often leak around the outlet valve. The outlet valve is connected to the arm which is connected to the floater inside the trap. The outlet valve can leak because the mechanism can fail or the outlet valve is unable to close due to wear and dirt. If the ball float trap is equipped with air vent and this air vent fails, this also can result in steam leakages. In case the air vent fails air will flow inside the ball float trap. This air will make the steam trap fail in an open position, the position where steam can flow straight though the steam trap. (Spirax Sarco mechanical steam traps, 2015) (Joe Radle, Spirax Sanco, 2007)

Inverted bucket traps fail in open position, this can have three different causes, namely:

1. The inverted bucket trap loses its water seal, this can happen duo to wear inside the bucket;
2. Sudden changes in pressure;
3. In case the inverted bucket trap is installed incorrectly or has an overcapacity.

Inverted bucket traps don't get dirty easily, this is because the outlet valve is positioned at the top of the trap. (Joe Radle, Spirax Sanco, 2007)

Bimetal steam traps fail duo to leakages at the outlet valve. This is caused by the wear of the thread that connects the bimetal plates together. The steam trap can also fail in a closed position, this happens when the bimetal plates get dirty. Bimetal steam traps therefor are sensitive for dirt. (Joe Radle, Spirax Sanco, 2007)

Thermodynamic steam traps can fail because of wear on the disc inside the housing of the trap. Thermodynamic traps have opening and closing cycles, if the disc gets dirty the cycle will speed up. If the trap does not get overhauled the trap will eventually fail in an open position. The steam trap can also fail in an open position if the trap gets dirty, this is unlikely, because a small pressure wave is created each time the trap opens, this way the trap cleans itself. (Joe Radle, Spirax Sanco, 2007)

Membrane steam traps fail duo to leakages at the outlet valve next to the membrane. In case the membrane gets damaged or if the membrane loses its fluid the steam trap will fail in an open position. The membrane can lose its fluid duo to water hammer in the steam system. The steam trap can fail in a closed condition if the trap gets into contact with overheated steam. (Joe Radle, Spirax Sanco, 2007)

Impulse and labyrinth steam traps are sensitive for dirt, this can make the traps fail in a closed position.

The most common steam traps found on ships are ball float, thermodynamic and thermostatic traps.

According to David Gustafson, there are two main reasons why a steam trap can fail. The first reason is the dirt that gets trapped inside the steam trap, the dirt can cause a steam trap to leak. The second reason are the high peak pressures that occur inside steam traps. The high peak pressures can cause internal damage. A steam trap can fail in an open or closed condition. (David Gufstafson, Emerson Process management, 2015)

In case a steam trap fails in an open position the steam trap will leak saturated steam to the condensate return line. This results in a loss of steam, which will increase the fuel expenses duo to the higher demand of steam. (TLV, Steam Theory, waterhammer, 2016) (David Gufstafson, Emerson Process management, 2015)

In case a steam trap fails in a closed position or gets clogged by dirt the condensate will gather in front of the steam trap and in the heat exchangers. This condensate can cause several problems, namely:

1. Water hammer;
2. The thermodynamic efficiency drops;
3. Unwanted penetrated water.

2.3.1 Water hammer

Water hammer can be created in two different ways. The first way water hammer is created is due to a high velocity of steam passing through a bend in a pipeline. When steam passes at a high velocity through steam pipe corners condensation can occur. The steam then pushes the condensate through the pipe until the condensate can't go further and gathers, for example at a valve. After some time a large amount of condensate is gathered at the valve and the steam can't pass through the valve freely anymore. The pressure in the pipeline will increase, in case this pressure gets too high the pipeline can rupture. (David Gufstafson, Emerson Process management, 2015) (TLV, Steam Theory, waterhammer, 2016)

The second reason water hammer can occur is when steam finds its way to cold condensate. The specific volume of steam is more than 1000 times the specific volume of that of water. When the steam reaches the cold condensate some steam will condensate to increase the temperature of the cold condensate. This will create a vacuum. This vacuum is then filled with the condensate. Due to the vacuum the condensate will create a high velocity and will slam against the pipeline. This is hearable and immediate action should be taken when hearing water hammer. If water hammer is not treated the pipeline can rupture. (David Gufstafson, Emerson Process management, 2015) (TLV, Steam Theory, waterhammer, 2016)

The temperature therefor is an important factor for the production of water hammer. In figure three a test by TLV is displayed. The steam temperature was 100 degrees Celsius.

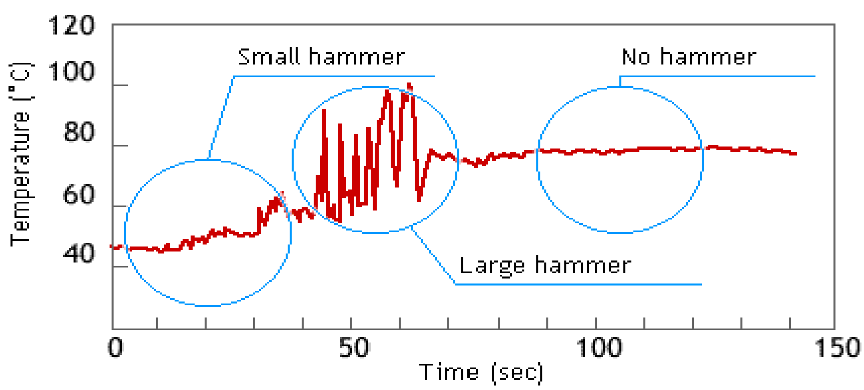

Figure 3 Water hammer at different condensate temperatures - retrieved from (TLV, Steam Theory, waterhammer, 2016)

From figure three it can be concluded that the most severe water hammer occurs when the condensate temperature falls 20 to 30 degrees under the steam temperature. (TLV, Steam Theory, waterhammer, 2016)

2.3.2 Thermodynamic efficiency

In case the condensate is not removed properly from the steam system the condensate will gather. The condensate will then flow to lower located places due to gravity, like heat exchangers. The unwanted water will flow back into the pipes of the heat exchangers. the condensate inside the heat exchanger will cause the heat exchange rate too decrease, this results in the loss of energy and will result in higher fuel expenses. (David Gufstafson, Emerson Process management, 2015)

2.3.3 Unwanted penetrated water

In overheated steam systems the condensate can emerge into the steam. Incase water is carried along with this steam it can cause damage to parts of the steam system, for example turbine blades of a steam turbine. (TLV, Steam Theory, waterhammer, 2016) (David Gufstafson, Emerson Process management, 2015)

A broken steam trap can only be detected with the eye in case the trap is experiencing severe steam leakage. The radian heat of the trap will be so high that steam plumes occur. If the hotwell is steaming steam traps are passing steam as well. Note that some steam systems have condensate coolers in front of the hotwell. (S van Hees, Bureau Veritas, 2006)

2.4 Condition based monitoring of steam traps

According to Spirax Sarco the lifetime of a steam trap is seven years, on average 7,5% of the steam traps will fail in year number eight. Incase steam traps are not monitored this will result in energy losses and higher fuel expenses. Therefor it is crucial to monitor steam traps. (Joe Radle, Spirax Sanco, 2007)

The definition of condition based monitoring is to acquire the state of an object without damaging it and the object is in service. Condition based monitoring knows many applications, each with their own benefits. The condition based monitoring applications usable for measuring steam traps are:

- Visually;
- Thermal image camera's;
- Ultrasound;
- Automatic (online) status control;
- Thermal and ultrasound combined.

A visual check on the steam traps is quite simple. In case steam plumes are coming of the trap the steam trap is leaking. If not, the steam trap should be working as it should, this is a very global gesture. A steam trap could still be leaking steam unnoticed. (SDT Ultrasound solutions, 2010) (Joe Radle, Spirax Sanco, 2007)

Thermal image cameras can detect a steam trap failed in a closed position, or a steam trap that is blocked. Thermal image cameras are limited in the detection of small steam leaks passing through the steam trap. This is due to the fact that the inlet and outlet temperature of the steam trap should be measured. Sometimes several steam traps connect to the same condensate retour line. This can create wrong conclusions. (SDT Ultrasound solutions, 2010) (Joe Radle, Spirax Sanco, 2007)

Ultrasound measurements on steam traps can detect the condensate and steam flow through a steam trap. Ultrasound is especially applicable for steam traps that work on the on/of principle. Steam traps that provide a continuous flow of condensate are often more difficult to measure. (Joe Radle, Spirax Sanco, 2007) (SDT Ultrasound solutions, 2010)

Automatic (online) status control, this is a system that digitizes the status of the steam traps. The big benefit of this system is that as soon as the steam traps fail, an alarm will be activated. The steam traps that fail can be replaced or overhauled in an early stage of failing. This system also increases the safety of the engineers that have to work in dangerous spaces to measure the steam traps. (Joe Radle, Spirax Sanco, 2007)

Thermal images and ultrasound both have their limitations when measuring steam traps. Incase both inspection methods are combined this will provide an excellent and reliable inspection method. The thermal image camera can detect if the steam trap is in service, and can determine the inlet and outlet temperatures of the steam & condensate mixture passing through the steam trap. With ultrasound the working principle of the steam trap can be checked. (Joe Radle, Spirax Sanco, 2007)

Thermal image cameras are easy to use. To get reliable ultrasound conclusions the inspector should have proper training before working with the ultrasound inspection tools.

But when should a steam trap be measured? For preventive maintenance the steam trap should be checked two times a year. In case the steam process stagnates, steam plumes are created or the feed water temperature increases steam traps could be failing and corrective maintenance is required. (S. van Hees, Bureau Veritas , 2006)

2.5 Ultrasound

Ultrasound uses ultrasonic sound waves that vibrate. Ultrasound knows a lot of applications and is used in many different industries. (De consult, 2015)

2.5.1 How does ultrasound work?

Ultrasound uses frequency's from 20 kHz to 100 kHz, not hearable for humans. Ultrasound is created via electric or magnetic fields. First the nets frequency is converted to a high frequent ultrasound (20-100 kHz), after this the high frequent ultrasound is converted via a converter to mechanical ultrasonic sound energy. The ultrasound sensor then sends this energy out of the measuring tool in a certain cycle. The signal that returns is converted into hearable frequency's for humans, this process is called heterodyning. The sound signals can now interpreted. (Sensor.nl, Ultrasoon geluid, 2015) (De consult, 2015) (Peter Boon, 2016)

2.5.2 Ultrasonic measurements in steam traps

Ultrasonic measurements in steam traps are accurate and precise. Because of these two characteristics a small steam leak can already be detected with ultrasound. There are many different types of steam traps, all with different working principles which generate different ultrasounds, therefor ultrasound measurements are not easy. To achieve reliable results proper training is required. (de Kegel, Hans, 2015)

Ultrasound can isolate large parts of background noises. This makes ultrasound ideal for loud environments, like power plants and engine rooms. The disadvantage of ultrasound measurements is that the temperature is not measured, and the temperature indicates if a steam trap is in use. Steam traps can only be measured with ultrasound when they are in use. A non-contact laser temperature meter can provide assistance while taking measurements with ultrasound. (Bruce Gorelick, Enercheck systems; Alan bandes, UE systems, 2010)

Each steam trap has its own characteristics in the generated ultrasound. An ultrasound measurement therefor can vary per steam trap type. Independent of the steam trap type an ultrasound measurement should always be taken from the outlet side of the steam trap. (UE systems, 2014)

Ultrasound on ball float steam traps

A ball float trap is seen as one of the hardest steam traps to measure with ultrasound. This is because the trap generates a continuous flow of condensate. If the trap is working as it should a continuous flow murmur should be detected, the DB value of the ultrasound should be deviating slightly. A Db value above 40 DB indicates the steam trap is passing steam. (Peter Boon, 2016)

In case the steam trap fails in an open position a loud sibilant sound can be detected with a high DB value. This is caused by the steam passing through the trap.

To detect if a steam trap is failed in a closed condition the inlet temperature should be measured at the trap. In case the inlet temperature is too low for the steam pressure the trap is failed in a closed position.

The most common problem with ball float traps and also the most hard part is to determine if the float leaks. In case the ball float leaks steam will pass through the outlet valve, this creates turbulence. This turbulence can then be detected with ultrasound measurement tools. Training and experience is required to achieve a reliable conclusion. (Peter Boon, 2016)

Ultrasound on inverted bucket traps

The inverted bucket trap works on the on/off principle, this means the trap is opening to transfer condensate or not. Because of this working principle the inverted bucket trap is excellent for ultrasound measurements.

In case the inverted bucket trap is failed in an open condition the trap will produce a continuous flow murmur like a ball float trap, the DB value will be high. Note that the trap works with a continuous condensate flow at low loads, the load therefore should be taken into account when measuring the trap.

An inverted bucket trap failed in a closed condition will produce no ultrasound. When no ultrasound is detected a thermal image camera could provide the necessary help. (S van Hees, Bureau Veritas, 2006) (Peter Boon, 2016)

Ultrasound on thermostatic steam traps. (Membrane, bimetal)

Thermostatic steam traps work on the on/off principle. The ultrasound created due to the on/off principle is the same as an inverted bucket. With ultrasound the trap should be heard opening and closing.

If the trap is failed in an open position the working principle will not be hearable any more. Also a continuous condensate/steam mixture should be detected. This will result in a fluctuating high DB value on the ultrasound measurement tool. (S van Hees, Bureau Veritas, 2006) (Peter Boon, 2016)

Ultrasound on thermodynamic steam traps

Thermodynamic traps work on an on/off principle. According to UE systems a thermodynamic trap opens 2-10 times a minute. Spirax Sarco states that a thermodynamic trap should open no more than 6 times a minute. The opening and closing of the thermodynamic trap can be detected with the ultrasound.

In case the thermodynamic trap opens too quick steam will escape with the condensate. The same can be concluded if the backpressure is 70% of the steam pressure. During an ultrasound measurement the amount of times the thermodynamic trap opens and closes in one minute should be measured.

If a thermodynamic trap fails in a closed position there will be no ultrasound detectable. A thermal image camera can provide the necessary help. (Peter Boon, 2016) (S van Hees, Bureau Veritas, 2006)

In table one all the steam trap workings principles, fail modes and expected ultrasounds are put together.

Table 1 Overview to be expected ultrasound in steam traps

Working principles, fail modes, and ultrasounds of steam traps				
Steam trap type	**Working principle**	**Fail modes**	**Ultrasound when working correctly**	**Ultrasound when working incorrectly**
Ball float	Continuous	Leakage, or fully open.	Fluctuating Db value under 40. Float can produce small background noise.	High sibilant noise producing 40 DB or more. The higher the Db the higher the steam leakage.
Inverted bucket	On/off	Fails open, or leaks	On/off cycle hearable. Ultrasound dies when trap is closed.	Continuous fluctuating sibilant noise. Can produce high DB values.
Thermostatic	On/off or continuous depending on the trap.	Fails open, or leaks	On/off cycle hearable, ultrasound dies when trap is closed.	Continuous fluctuating sibilant noise. Can produce high DB values.
Thermodynamic)	On/off	Cycle to quick, can fail open.	2-10 times a minute opening and closing of the trap.	High sibilant noise when failed open, trap cycle to fast.

3. Research design

In this chapter, the research design, the method used to perform this research will be described. The research design describes what kind of research takes place, the way the results are acquired and how the results will be analysed. The actions taken to achieve a valid and reliable research are explained as well.

3.1 The research method

This research is applied research. The research method used is qualitative experimental operational research (action research). (Baarda, 2014)

To acquire the condition of the steam traps and to answer the sub question: *'' What are the conditions of the steam traps that are in use?''*, the steam traps will be measured with ultrasound combined with thermal imaging. According to the theoretical framework this is the most reliable and valid method. The ultrasound measuring tool used is an Ultraprobe 15000 from UE systems, the thermal image camera used is a FLIR E4. To be able to work with an Ultraprobe an ISO-ASNT level one course from UE systems was completed.

Before the measurements can take place the steam users and the thereby steam trap locations will be located and documented, this is done by going through the steam system itself and its drawings. This process will take place in the first two months of the cadetship on board the MV Zuiderdam. While documenting the steam trap types and working principles are noted, this to acquire the to be expected ultrasound.

The ultrasonic equipment will be delivered to the ship on may the 3rd in Rotterdam, and will be off loaded in Kiel on may the 15th.

Once the equipment reaches the ship the measurements can start. Before measuring a steam trap with ultrasound an thermal image will be taken from the steam trap. This to acquire if the steam trap is in use and what the inlet and outlet temperature of the steam trap is.

After a thermal image is taken the ultrasound measurement will take place. The ''structure'' born inspection method will be used. The structure born method goes as follows:

1. Before starting measurements the Ultraprobe needs to be validated. The validation test method is described in appendix two.
2. Steam traps are measured at 25 kHz, adjust the frequency from the Ultraprobe and connect the contact module.
3. Place the Ultraprobe at the outlet side of the steam trap. Adjust the sensitivity until the working principle of the steam trap is heard clearly. The DB value can now be noted.
4. A fast Fourier transformation will be made and saved to the Ultraprobe, along with a normal picture of the steam trap.
5. The Db value, picture and FFT will be saved with a certain record number.

The condition of the steam trap can now be determined, and the sub question: *''What are the conditions of the steam traps that are in use?*, can be answered.

Only the steam traps that are in use can be measured. All the steam traps that are in use during the Baltic cruise will be measured. This will depend on the load of the steam system at the time itself.

Once determined which steam traps leak, the amount of steam that is lost has to be acquired.

To answer the sub question: *‘’How much steam is lost due to the leaking steam traps?’’,* steam loss tables are used, these can be found in appendix three. To remain objective in this research the average steam loss tables of Spirax Sarco and UE system are used and compared. On board the MV Zuiderdam Spirax Sarco manufactures the steam traps. Both Spirax Sarco and UE systems had steam specialists calculate the values in the steam tables. Note that these are subjective and only give an indication of the average steam loss.

To acquire the average steam loss the orifice diameter and steam pressure are required. The steam pressures can be found on the drawings and local gages, the average orifice diameter can be found in appendix three, if the pipe size is measured.

When all the steam losses due to leaking traps are documented the costs can be determined. To answer the sub question*: ‘’What are the costs of the measured leaking steam traps?’’,* the price of one ton of steam needs to be calculated. The calculations that are required can be found in the theoretical framework in paragraph 2.2.3.

When all the sub questions are answered the total loss of efficiency caused by the steam traps can be calculated. The main question of this thesis: *‘’How much can the efficiency of the steam system on board the MV Zuiderdam be improved, by performing condition based maintenance on steam traps?’’,* can be answered.

3.2 Data collection method

As described in chapter 3.1 the information will be gathered with the FLIR and the Ultraprobe. The data from the Ultraprobe is uploaded to the DMS software of UE systems. There the measurements can be analysed and interpreted. The photos of the FLIR do not require a software program.

Once the measurements are completed an excel sheet will be made with an overview of all the measurements, the costs of one ton steam, the steam leakages caused by the traps and the fuel costs created by the steam traps.

3.3 Validity and reliability

To achieve valid and reliable measurements it was chosen to combine ultrasound with thermal images, the conclusions of both inspection methods will be compared and one overall conclusion will be drawn for each trap. The measurements can be analysed with the DMS and Spectralyzer software, in case there is any doubt when drawing conclusions Marcel Rutgers and Peter Boone can be contacted. They are professional ultrasound specialists for UE systems in the Netherlands.

4. Research results

In this chapter, the research results, the results gained from the measurements will be explained. To achieve a clear view on the results gained from the measurements the excel sheet: ‘’Results steam traps MV Zuiderdam’’, should be read simultaneously.

4.1 Steam trap locations

Before the measurements could take place the steam traps were located. This was done by following the original drawings of the steam system of the MV Zuiderdam. All the steam traps were documented in a table. This table can be found in appendix four, or on page ‘’steam trap locations’’ in the excel sheet. By doing this the steam trap types and expected ultrasounds could be determined. 235 steam traps were located across the ship.

4.2 Thermal and ultrasound measurements

The measurements went according to the procedures explained in chapter 3.1. Only the steam traps that were in use during the research period could be measured. The MV Zuiderdam was sailing in an ECA area, this had as an result that the engines were running on MDO. The fuel tanks filled with MDO are not heated, along with the fuel modules. These steam traps therefor could not be measured.

Thermal camera measurements

To draw conclusions with thermal images it is stated that if the condensate outlet temperature is above 100 degrees Celsius, steam passes through the trap

Ultrasound measurements

Before the ultrasound measurements took place the Ultraprobe had to be validated. The results of the validations are displayed in appendix five.

Each steam trap had to be analysed in a certain way, this went as follows:

- Ball float steam traps were measured before and after the trap, the sound sample of the measurement after the trap was saved. Ball float traps have a continuous condensate flow, a smooth condensate flow with a low fluctuating DB value indicated that a trap was working okay. UE systems states that a ball float trap with a DB value over 40 will indicate steam, which indicates steam loss; (Peter Boon, 2016)
- Thermodynamic steam traps work on the on/off principle, which can clearly be heard with ultrasound. It is stated that thermodynamic traps that repeat there cycle no more than 10 times a minute work okay. If the thermodynamic trap opens more than ten times minute the trap was considered leak. A thermodynamic trap can fail open, when this happens a continuous fluctuating DB value can be detected, the ultrasound does not necessary have to be above 40 DB is this case. An open thermodynamic trap creates a fluctuating DB value with high DB peaks, the high peaks are steam that passes through the condensate line, the thermodynamic steam traps are measured on the outlet part of the trap.
- Locomotive steam traps use steam to pump out the condensate if the back pressure is too high. The pumping of the locomotive steam traps can be heard clearly with ultrasound. A locomotive steam trap is considered okay Incase a fluctuating DB value of 40 or less is detected on the condensate line just behind the steam trap. If the DB value is above 40 and the trap is not pumping, the trap is considered leak according to ultrasound.
- Thermostatic steam traps work on the on/off principle or continuous principle. The working principle and the condensate flow of the trap were analysed. A thermostatic steam trap is considered okay if the steam trap opens and closes as it should, or if the condensate only

consists of a low fluctuating DB value. The thermostatic traps were considered leak if the trap could not be heard closing and the condensate had a fluctuating DB value with high peaks, the high peaks in DB were considered steam;

The ultrasound measurements were uploaded to the software program DMS of UE systems. There the ultrasound could be analysed.

During the measurements the pipe size of the steam traps were measured to acquire the orifice size.

4.2.1 Results of the measurements

During the research 76 steam traps were discovered in use. To answer the sub question: *''What are the conditions of the steam traps that are in use?''*, the operational steam traps were measured and integrated in appendix six or the page ''measurements'' in the excel sheet. The measurement number, steam trap location, steam trap type, normal image, thermal image, temperatures, ultrasound with its DB value and the conclusions can be found here. It is recommended that the excel sheet is used to gain a more professional and clear view of the measurements. Note that the ultrasounds can only be listened to in the excel sheet by double clicking on the speaker icon.

The conclusion of each steam trap is that the steam traps leaks, yes or no. These conclusions are drawn of combining the thermal and ultrasound measurements together.

A summary of the results gained from the steam traps measurements can be found in table two.

Table 2, Summary of the results gained from steam trap measurements – retrieved from appendix six

Steam trap type.	***Times measured.***	***Times trap was found leaking.***
Ball float trap	13	2
Thermodynamic	9	5
Thermostatic	48	30
Bimetal	1	0
Locomotive	2	1
Inverted bucket	3	2

From the 76 steam trap measurements 40 steam traps were found leak, that's 52,6%.

4.2.2 Steam losses due to leaking steam traps

Now that the condition of the steam trap is determined the sub question: *''How much steam is lost due to the leaking steam traps?''*, can be answered. Spirax Sarco and UE systems both created average steam loss tables caused by steam traps. These tables can be found in appendix three. To use these tables the orifice size and steam pressure is required. The orifice size was gained by measuring the outside pipe diameter of the pipe the steam trap was connected to. By using (standard pipe sizes, 2016) the outside diameter was translated to the PN number, from where the orifice size was determined by using the table of Spirax Sarco.

The steam loss estimates according to Spirax Sarco and UE systems were acquired by using these tables. For example, measurement one, the thermodynamic trap from steam coil one of the fuel tank 3C, had an orifice size of 3 mm, the steam pressure was 9 bar, the steam trap was considered leak. According to the table of Spirax Sarco the average steam loss is twelve kg/hour. According to the steam tables of UE systems the steam loss is 30 kg/hour.

In appendix seven an overview of all the losses caused by the leaking traps is displayed. This overview can also be found in the excel sheet under the page: ''steam loss estimates''.

The steam losses an hour were multiplied by the running hours of the boiler. This to achieve the steam losses caused by the steam traps while the boiler in running during one day. As soon as the MV Zuiderdam is at sea the EGB's of the engines will provide the steam. This is free, as the EGB's run on waste recovery heat of the engines. The extra expenses of the fuel want to be calculated, the steam losses while the MV Zuiderdam is at sea are therefor neglected in this research.

4.3 The price of one ton steam

To achieve the price of one ton steam a calculation is made, this calculation was retrieved from the theoretical framework chapter 2.2.3. The following values were gained and used:

- An average calorific value of MDO and HFO is used, the calorific value for HFO is 41800 KJ/kg, for MGO 42700 KJ/Kg, the density of HFO is 996 kg/m3, MGO 880 kg/M3.
- The boiler efficiency was estimated on 89%;
- The fuel flow meter of the aft boiler indicated 250 litres of fuel an hour;
- The price of one ton HFO is 170 euro, MGO 300 euro (Bunkerworld, 2015);
- The boiler on the MS Zuiderdam produces an absolute steam pressure of 9 bar at 175 degrees Celsius, and has 10 running hours a port day;
- The heat of formation is 2030,7 Kj/KgK. (Steam tables, vapor training, 2012)

In figure four the calculation of the price of one ton steam is displayed. The steam production of the aft boiler is around 4600 kg/hour.

The price of one ton steam running on MDO was estimated on 14,11 euro. The price of one ton steam on HFO was estimated on 9,24 euro.

The calculation can also be found in the excel sheet. The calculation can be found under the page ''Calculation one ton steam''.

Calculation one ton steam	**MDO**	**HFO**	
Calorific value	42700	41800	Kj/Kg
boiler efficiency	89	89	%
Mass flow MDO to boiler	250	250	L/hour
Daily running hours / port hours boiler	10		
Daily fuel consumption	2500	2500	Liters/day
Average MDO density	880	996	Kg/m3
Fuel consumptoin	2,2	2,49	M3 / day
Costs of one M3 fuel	300	170	Euro
Fuel costs total	660	423,3	Euro/day
heat of formation (9bar, 175 C°)	2030,7	2030,7	Kj/kgK
Steam production	4678,6	4579,9	Kg/hour
Steam production total	46,8	45,8	Ton
Price one ton steam	**14,11**	**9,24**	Euro

Figure 4 The price of one ton steam

4.4 The expenses caused by leaking steam traps

Now that the price of one ton steam and the amount of steam lost caused by the leaking steam traps is determined the sub question: *''What are the costs of the measured leaking steam traps?'',* can be answered. To determine the costs it is stated that the MV Zuiderdam will stay in this current load configuration in each port day and that the steam traps are operational during the running hours of the boiler, these are subjective values. According to the itinerary the Zuiderdam has 250 port days in 2016.

Appendix eight displays the calculations to achieve the expenses caused by leaking steam traps, the calculations are simple. The amount of steam that is lost per hour is multiplied by the running hours in port, divided by 1000 gives the amount of steam that is lost in tons. The price per ton steam was already calculated in chapter 4.3, the total costs per day are multiplied by the port days to achieve the extra fuel expenses caused by leaking steam traps in one year. These calculations were made in the excel sheet, under the page ''expenses and efficiency losses''. A copy of the table can be found in appendix eight.

5. Discussion

In this chapter, the discussion, the measurements and results will be criticised.

5.1 Thermal and Ultrasound measurements criticism

While the steam trap conditions according to the thermal camera were determined it was stated that if the condensate outlet temperature was above 100 degrees Celsius, the steam trap would leak steam. This can be misleading, as some steam traps connect to the same condensate line, a steam trap that works fine could be determined failed due to this statement.

Thermodynamic steam traps and locomotive steam traps also use steam for the working principle of the trap itself, this leads to a small amount of steam leaking away. The condensate outlet temperature therefor could be slightly higher at thermodynamic and locomotive traps while working correctly. This way a thermal image could determine the wrong result.

Ultrasound measurements require a certain amount of experience and expertise, this was not the case when the measurements took place. To counter react this argument a lot of the same steam traps, with the same working principle were measured. The steam traps were compared to each other, this way a leaking trap could be determined.

Ultrasound is very accurate, this is good for determining the working principles of the steam traps, but also other internal background noises created from the machinery can cause confusion.

So how reliable are the measurements taken? Combining two measurement strategies eliminated false results of either ultrasound or thermal measurements. By measuring same steam traps types the reliability of the results will increase.

Ball float, thermodynamic and thermostatic steam traps were measured enough times to make a valid comparison. Inverted bucket, locomotive and bimetal traps were only measured a couple of times. This made it harder to determine the condition of the steam traps, therefor it can be stated that these measurements are less valid.

According to the measurements 52,2% of the steam traps measured were leak. This high percentage is caused due to the small thermostatic steam traps leakages. The condition of the most important big steam traps were okay. That 52.2% of the steam traps were considered leak can therefore give a wrong indication of the condition of the steam traps on the MV Zuiderdam.

5.2 Steam lost due to the leaking steam traps criticism.

The exact amount of steam lost due to leaking steam traps is a question unanswered. Spirax Sarco and UE systems both have a different view on the steam losses caused by steam traps and the results are far apart. It was stated that the MV Zuiderdam stayed in this load configuration for the entire year, this is false. As the load consistently changes in the steam system. Some steam users do not use steam the entire day. In the research it is stated that the steam users are all operational during the running hours of the boiler.

The reliability and validity of the steam tables used cannot be proved. This can lead to lower steam losses caused by the traps than calculated. This can also have a positive side, in which case the steam losses are higher than the steam table indicates.

It is important to state that the steam losses calculated in this research are subjective, and can differ from the actual steam losses caused by the steam traps.

6. Conclusions and recommendations

In this chapter, chapter six, the conclusions from the results are drawn and recommendations are made.

6.1 Fuel saving conclusions

To determine the fuel that can be saved in the boiler, the total amount of steam loss a day in tons is multiplied by price of one ton of steam. In appendix eight the expenses of each leaking steam trap is calculated in this manner. It was stated that the boiler runs ten hours during a port day, and that the MV Zuiderdam has 250 port days in 2016. The steam users run the same time as the port running hours of the boiler.

The steam losses of each steam trap were calculated to the costs. This was done in appendix eight, or can be found in the excel sheet under the page ''expenses and efficiency losses'''.

According to Spirax Sarco

According to Sarco 5,575 tons of steam is lost in each port day due to leaking steam traps. This results in a total of 78,65 euro of extra expenses a day while the boiler is running on MDO, on HFO the extra expenses are 51,53 euro's. On a yearly basis this comes down to 19662 euro's on MDO and 12882 euro's on HFO.

According to UE systems

According to UE systems 13,335 tons of steam is lost in each port day due to leaking steam traps. This results in a total of 188,33 euro of extra fuel expenses while running on MDO, on HFO the extra fuel expenses are 123,39 euro's. On a yearly basis this comes down to 47082 euro's on MGO and 30847 euro's on HFO.

To calculate the efficiency loss caused by the steam traps, the total amount of fuel burned by the boiler is calculated. The boiler uses 2,2 tons of MDO, or 2,49 tons of HFO a day. With 250 port days the boiler yearly uses 550 tons of MDO or 622,5 tons of HFO. This results in a total of 165000 euro's on MDO or 105825 euro's on HFO. Figure five gives and overview of the expenses.

To answer the main question of this thesis*: ''How much can the efficiency of the steam system on board the MV Zuiderdam be improved, by performing condition based maintenance on steam traps?'',* the expensed caused by leaking steam traps are divided by the total fuel costs a year.

The total efficiency lost due to the leaking steam traps according to Spirax Sarco is 11,9% on MDO, and 12,2% on HFO.

The total efficiency lost due to leaking steam traps according to UE systems is 28,5% on MDO, and 29,1% on HFO.

These losses are only for the MV Zuiderdam, Holland America Line consists of fifteen vessels. The total fuel savings could increase significantly.

Yearly costs due to leaking traps			
	MDO	HFO	
Spirax Sarco estimate	19662	12882	Euro/year
UE Systems estimate	47082	30847	Euro/year
Total fuel costs boiler	165000	105825	Euro/year

Efficiency loss			
	MDO	HFO	
Spirax Sarco estimate	11,9	12,2	%
UE Systems estimate	28,5	29,1	%

Figure 5 Expenses and efficiency losses

6.2 Recommendations

It is recommended that the leaking thermostatic, thermodynamic and ball float steam traps are replaced or overhauled. As these measurements have been done on several steam traps and create a reliable result.

According to the measurements the locomotive steam trap located at the condensate retour line from the crew and passengers hot water heater, leak a lot of steam an hour. One locomotive steam trap is on stand-by next to the two steam traps that are in use. It is recommended that the aft locomotive steam trap is switched with the forward locomotive steam trap. Only two measurements could be done on locomotive steam traps, this can make these measurements less reliable, but switching over the steam traps is free.

Further investigation regarding condition based monitoring of steam traps in the shipping industry is recommended. The measurements show a potential of fuel saving without investing a lot of money. Maintaining a good condition of the steam traps do not only result in fuel savings, but also keeps the steam system clear from banging that can cause severe internal damage.

The calculations in this research are all subjective, to achieve more valid calculations it is recommended to hire a professional condition based monitoring company to make an inspection of the steam traps in use, and give advice on the regarding matter.

The older the age of the ship, the more steam traps will fail. It is recommended that the older ships of Holland America Line apply condition based monitoring on the steam traps in use.

To achieve maximum results with condition based monitoring on steam traps on board ships it is recommended that the measurements take place when the ship is outside an ECA area and running on HFO. This way tanks are heated, and fuel modules and HFO separators all are in use. In normal conditions this will be the load configuration. These steam traps are the most important when sailing outside ECA areas.

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Appendices

Appendix one: Working principles of different steam traps.

The ball float steam trap

The ball float steam trap, an mechanical steam trap, works on the difference in density of the steam and condensate. These steam traps are mainly placed after heat exchangers with a large capacity. A ball float trap can only be installed horizontal or vertical.

Working principle.

The working principle is based on the ball float inside the steam trap. The float is connected to a connection rod which is connected to the outlet valve. Figure six explains that the condensate and steam mixture is entered on the top side of the trap, the ball float will start to float. When the ball float starts to float the outlet valve will open, condensate will be removed and drained back to the hotwell. When steam enters the trap its will gather above the ball float, the steam will push the ball float further downwards and the outlet valve will close. (Condenspot.nl, 2015)

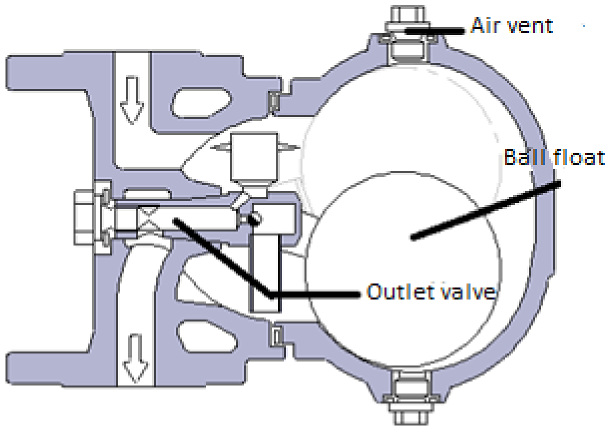


Figure 6 Ball float trap – retrieved from (Condenspot.nl, 2015)

The ball float steam trap comes close to an ideal steam trap. The Ball float steam trap will start removing condensate as soon as condensate is generated, despite the pressure difference. Other advantages of ball float steam traps are:

- The ball float trap removes the condensate on steam temperatures, therefor the ball float trap is mainly used on places where large amounts of heat exchange take place;
- Can manage light and heavy condensation, does not suffer from sudden pressure- and load changes;
- Can remove air and other non-comprisable gases in case an air vent is placed on the trap;
- Has a big capacity for its size. (Spirax Sarco mechanical steam traps, 2015) (Sleeptros , 2009) (S. van Hees, 2006)

The ball float steam trap also has its disadvantages. In case the steam trap is exposed to freezing temperatures the steam traps ball float can get damaged, this will cause the steam trap to leak. The steam trap can get damaged easily, in case the trap is placed in a harmful environment the trap should be protected in some kind. The ball float is modified for a certain pressure difference. In case the pressure difference is exceeded the steam trap will fail in a closed position and no condensate will be removed. Water hammer can cause the ball float to lose its buoyancy. (Spirax Sarco mechanical steam traps, 2015) (Condenspot.nl, 2015)

Inverted bucket steam trap

The inverted bucket steam trap, an mechanical steam trap, works according to the inverted bucket principle. The steam trap has only two moving parts, the connecting rod that opens the outlet valve and the inverted bucket. (Hydrotemp, 2014)

Working principle

The inverted bucket trap is equipped with an ''inverted bucket'', this bucket is connected to the connection rod which operates the outlet valve. In figure 7 the working principle is displayed. The steam and condensate mixture enters in the bottom of the trap. In case only condensate enters the trap the inverted bucket will remain seated and the outlet valve will stay closed. When steam enters the trap the steam will gather in the bucket and will push the bucket upwards. The inverted bucket then pushes the outlet valve closed. As soon as the steam is condensated the inverted bucket will sink and the outlet valve will open again. (Spirax Sarco mechanical steam traps, 2015) (Condenspot.nl, 2015)

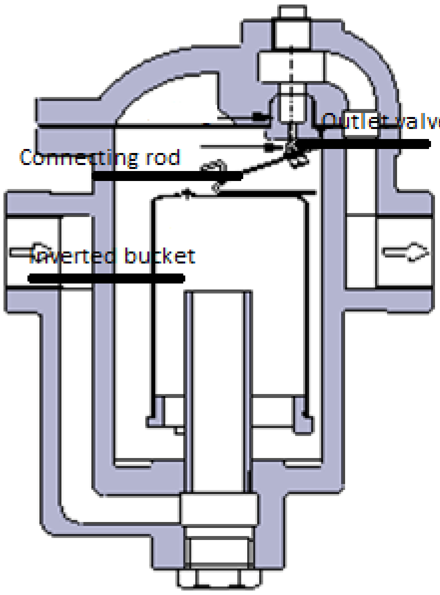


Figure 7 inverted bucket trap - retrieved from (Condenspot.nl, 2015)

The inverted bucket trap can handle high pressures and therefor is commonly placed in steam systems that operate with high pressures. Other advantages of inverted bucket traps are:

- The inverted bucket is open and therefor can withstand water hammer well;
- Can be placed in superheated steam systems;
- Does not get dirty easily;
- Only has two moving parts, this ensures the steam trap will not get stuck. (Hydrotemp, 2014) (Spirax Sarco mechanical steam traps, 2015)

In case the flow of condensate is too low the volume inside the steam trap can boil dry, this can result in internal damage to the steam trap. Other disadvantages are:

- These types of steam traps only come with a small air vent. Only a small amount of non-compressible gasses can be removed from the system;
- At all times condensate should remain inside the steam trap, this to maintain the water seal inside the inverted bucket. The water seal can break in case of a sudden pressure drop. The sudden pressure drop causes the condensate to flash into steam above the inverted bucket, the inverted bucket is now pressed down and failed in an open position;
- In applications with superheated steam the steam trap will lose its water quicker, a non-return valve should always be placed in front of the inverted bucket trap in superheated steam systems;
- The steam trap can be damaged when exposed to freezing temperatures;
- The trap is adjusted for a certain differential pressure, in case this differential pressure is exceeded the trap will fail in an closed position, and the trap will stop removing condensate. (Spirax Sarco mechanical steam traps, 2015) (Condenspot.nl, 2015)

Bimetal steam traps

The bimetal steam trap, a thermostatic trap, is used in tracing lines, heat exchangers or steam lines. (Thermostatic steam traps, Spirax Sanco, 2015)

Working principle

Figure eight shows that the core of the steam trap is made of a thread which consists of bimetal plates. The bimetal plates are two metals welded together, each with a different expand coefficient. The thread with the bimetal plates is connected to the outlet valve. When condensate and steam enters the trap the steam gathers in the top side of the trap, the steam pushes the bimetal plates down. The steam also increases the temperature of the bimetal plates, the plates will expand and open the outlet valve. Both forces will find a balance and create the position of the outlet valve.

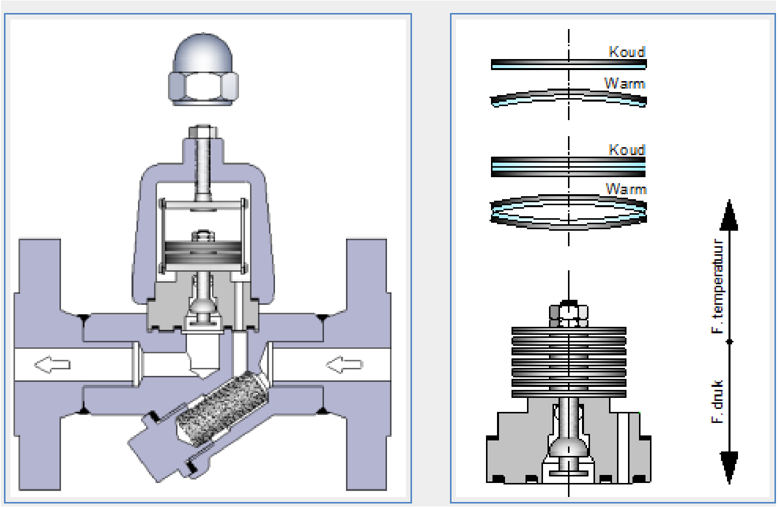


Figure 8 Bimetal steam trap – retrieved from (Condenspot.nl, 2015)

This way the steam is trapped and the condensate is removed from the system. The moment when the outlet valve closes completely can be adjusted with the valve clearance. The valve clearance and steam pressure define the condensate outlet temperature. (Thermostatic steam traps, Spirax Sanco, 2015) (Condenspot.nl, 2015)

Bimetal steam traps are compact, but still can remove a large amount of condensate. Other advantages of bimetal steam traps are:

- During start up the trap is cold, the valve will be fully open, air and non-compressible gasses can be removed easily;
- Freezing temperatures do not affect bimetal steam traps;
- Water hammer, high pressures and corrosive condensate do not affect bimetal traps
- Maintenance is easy, and bimetal traps have a large operational area.

To prevent water hammer a bimetal steam trap should come with a cooling pipe of at least three meters in front of the steam trap. Therefor the bimetal steam trap is unsuitable for steam systems where the condensate has to be reused as quickly as possible. Bimetal steam traps do not react quickly to changes in pressure, as the bimetal plates need time to expand. (Thermostatic steam traps, Spirax Sanco, 2015)

Venturi steam traps

Venturi steam traps work on a different principle than all other steam traps. The venturi steam traps don't see the difference in steam or condensate. Consequently, venturi steam traps can only be placed on locations where the load and steam pressure remains constant. On board vessels this will never be the case, as the steam systems load fluctuates. Figure nine displays a venturi steam trap. (Condenspot.nl, 2015)

Working principle

The working principle is simple, a predesigned hole only lets condensate trough at a specific steam pressure. In case the flow of condensate gets high the condensate will gather in front of the hole. When the condensate flow is low steam can pass through the hole as well, that's why a constant pressure is required for venturi steam traps.

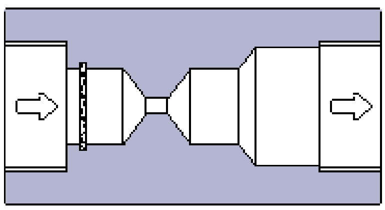


Figure 9 Venturi steam trap - retrieved from (Condenspot.nl, 2015)

The steam trap has as advantage that there are no moving parts inside the trap, nevertheless the venturi steam traps knows more disadvantages that advantages. The steam trap can only be used in a constant system, and the predesigned hole gets dirty easily, this will block the steam trap. (Thermodynamic Steam traps, Spirax Sanco, 2015)

Membrane steam trap

A membrane steam trap, a thermostatic steam trap, is mainly used in locations where a lot of air and other non-compressible gasses have to be removed from the system. (Sleeptros , 2009)

Working principle

This type of steam trap works on its membrane located inside the housing. The membrane is filled with a certain fluid, the fluid's boiling point lies ten degrees Celsius under that of water. When the fluid inside the membrane boils the membrane will float and push the outlet valve closed, this occurs when steam enters the trap. As soon as the steam is condensated the temperature of the fluid inside the membrane will drop and the membrane will open the outlet valve. When starting up the steam system the membrane will be cold, air and other non-compressible gasses can be removed easily. Figure ten shows a typical membrane steam trap from Spirax Sarco. (Condenspot.nl, 2015)

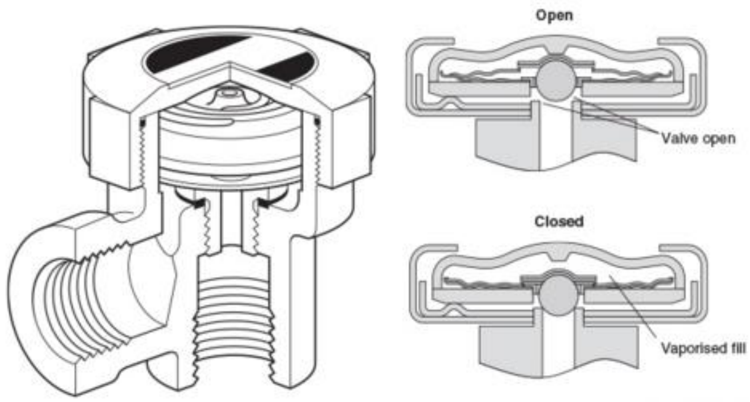


Figure 10 Membrane steam trap - retrieved from (Condenspot.nl, 2015)

A membrane steam trap is a light steam trap with a big capacity for its size. Other advantages the membrane steam traps offer are:

- Freezing temperatures do not affect the steam trap;
- Maintenance can be performed easily. (Thermostatic steam traps, Spirax Sanco, 2015)

Water hammer and corrosive condensate can damage older types of membrane steam traps. Newer versions are made from stainless steel, to avoid corrosion. Thermostatic steam traps only work in case the condensate's temperature falls under the steam temperature. (Thermostatic steam traps, Spirax Sanco, 2015)

Traditional thermodynamic steam trap

Thermodynamic steam traps are used in several different steam systems. They are especially used in steam systems where dry steam is required. The working principle rests on Bernoulli's law, which states: ''An increase of speed in the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy''. (Sleeptros , 2009)

Working principle

Figure eleven shows a typical thermodynamic trap with its working principle. There is only one moving part in the steam trap, the disc (outlet valve). During start up the pressure in the system will rise, the disc will move upwards. The cold condensate and non-compressible gasses can be removed in this manner. This process continuous until steam enters and warm condensate enters the trap, the mixture first enters the chamber under the disc. The volume of the steam is greater than the volume of the condensate, in this way the velocity under the traps disc will increase, this creates a negative pressure which wants to pull the disc downwards. At the same moment the temperature above the disc rises, which causes some steam to flash. The saturated steam will push the disc down, the condensate flow is stopped. After a while the flashed steam will condensate and the disc will open again. (Thermodynamic Steam traps, Spirax Sanco, 2015) (Condenspot.nl, 2015)

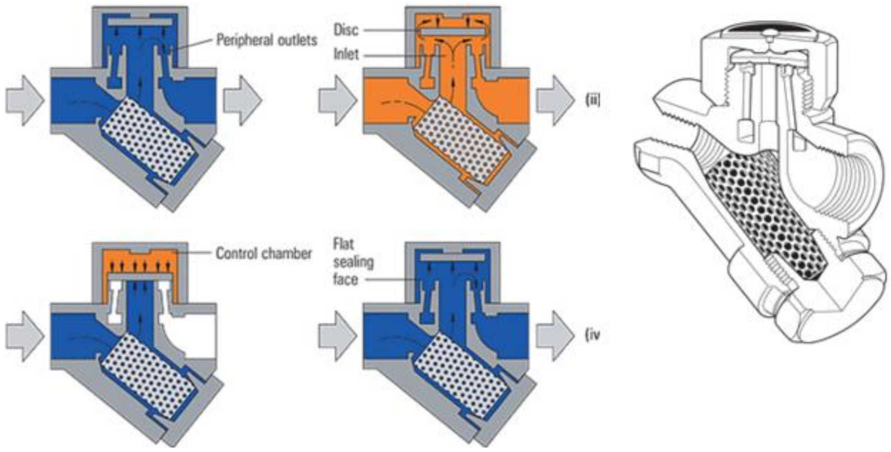


Figure 11 Thermodynamic steam trap - retrieved from (Thermodynamic Steam traps, Spirax Sanco, 2015)

The thermodynamic trap is robust, and has a large capacity for its size. Other advantages are:

- Thermodynamic steam traps can be applied in steam systems with high pressures and superheat without creating water hammer;
- Don’t suffer from freezing temperatures;
- The disc is the only moving part in the steam trap, this makes the trap easy for maintenance.
- Every 20-40 seconds the disc will open, this creates a ‘’click’’ sound, thermodynamic traps are therefor easy to test.

The thermodynamic steam trap also has disadvantages, thermodynamic traps do not work well with small differential pressures. The differential pressure needs to be high enough to increase the speed of the condensate and create a negative pressure on the bottom side of the disc. Other disadvantages are:

- Due to the high amount of air and non-compressible gasses that need to be removed during start up the disc can fail in an closed position. Newer versions of thermodynamic traps are equipped with a so called air disc, this disc removes this problem;
- The steam trap makes noise when opening, when placing the steam trap the location has to be taken into account;
- With the condensate a small amount of steam is used for the working principle of the trap, this results in a small loss of steam. (Thermodynamic Steam traps, Spirax Sanco, 2015) (Condenspot.nl, 2015)

Impulse- and labyrinth steam traps

Thermodynamic impulse- and labyrinth steam traps work on the same principle as the traditional thermodynamic trap. Figure twelve displays an impulse steam trap on the left side, on the right side an labyrinth steam trap can be found.

The impulse steam traps have a large operational work area, can work with superheated steam and high steam pressures. If impulse traps work with low steam pressures the steam trap will pass steam and will produce noise. Impulse steam traps fail to work in case the back pressure is 40% of the inlet pressure. (Thermodynamic Steam traps, Spirax Sanco, 2015)

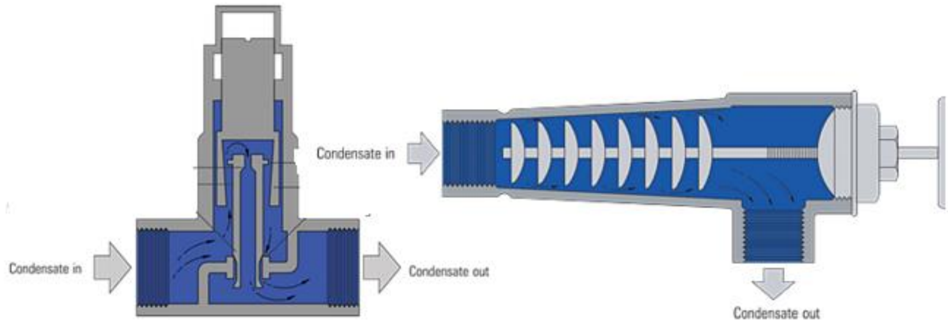


Figure 12 Impulse and labyrinth steam traps - retrieved from (Thermodynamic Steam traps, Spirax Sanco, 2015)

The labyrinth steam trap is small for its capacity. There are no moving parts inside the trap. The labyrinth trap therefor will not get stuck or fail. A disadvantage of the labyrinth trap is that the trap has to be adjusted when the load in the steam system changes. (Thermodynamic Steam traps, Spirax Sanco, 2015)

Appendix two: validation test method Ultraprobe 15000.

Below the validation test method from UE systems can be found, retrieved from (UE systems, 2016).

ue SYSTEMS INC
The ultrasound approach

APPENDEX A
Sensitivity Calibration

Ultrasonic Tone Generator Method
Ultraprobe 15000

It is advisable to check the sensitivity of your instrument before proceeding with your inspection. To assure reliability keep a record of all your sensitivity validation tests and be sure to keep your Warble Tone Generator charged.

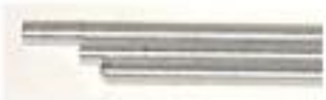
Procedure:

1. Create a chart or use the one below:

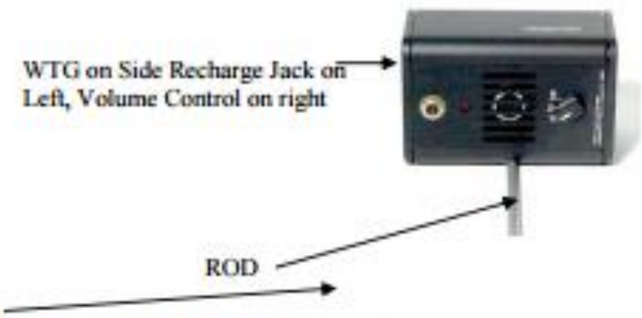
Sensitivity Validation						
Scanning Module	Date	Serial #	Rod used	TG setting	Frequency	DB
Contact Module	Date	Serial #	Not Applicable	TG setting	Frequency	DB
			Not Applicable			

A. For the Scanning Module, insert it into the front end of the instrument.

2. Select 40 kHz as the test frequency and note "40" in the Frequency box for the Scanning Module in the Sensitivity Validation Chart
3. Plug in the Headphones and adjust the ear pieces so that they are opened up and place them on the test table
4. In your kit select the longest of the Stethoscope extension probe rods.



5. Place an "L" in the Rod used box of your Sensitivity Validation Chart
6. Place the Tone generator on the side with the front facing you.



7. Place the rod in the middle of the transducer are (as above)
8. Select a volume level on the Warble Tone Generator (Low or High).
9. Note the level (L or H) in the TG box of the Sensitivity Validation chart.

10. Turn the Ultraprobe 15,000 on its' side so that it will rest flat on the test table with the handle facing you and the Scanning Module facing the Tone Generator.
11. Slide the Ultraprobe gently so that the front faceplate touches the Rod and that the rod is touching the face plate while touching the side of the Scanning Module. Align the Scanning Module so that the center of the module is facing the center of the Tone Generator Transducer (see below).

12. Adjust the sensitivity until the intensity bar graph is at mid-line and displays the decibel level.
13. Note and record the decibel reading in the dB box of your Sensitivity Validation chart.

B. For the Contact (Stethoscope) Module, insert the Module into the Front End of the Instrument:

1. Select 40 kHz as the test frequency and note "40" in the Frequency box for the Contact Module in the Sensitivity Validation Chart
2. Plug in the Headphones and adjust the ear pieces so that they are opened up and place them on the test table
3. Place the Warble Tone Generator flat facing up with the recharge jack facing you at 90°.
4. Select a volume level on the Warble Tone Generator (High or Low).
5. Note the level (H or L) in the TG box of the Sensitivity Validation chart.
6. With the handle facing you, align the tip of the contact probe with the recharge jack and allow the probe to rest on the jack. **DO NOT PRESS DOWN!**

(NOTE: NEVER USE THE ALUMINUM EXTENSION PROBE RODS THEY WILL SHORT OUT THE BATTERY OF THE WTG)

7. Adjust the sensitivity until intensity bar graph is at mid-line
8. Note and record the decibel in the dB box of your Sensitivity Validation chart.

For all tests:
Whenever you perform a Sensitivity Validation Test, review the data in the Sensitivity Validation chart and repeat the test using the same rod/module, frequency, and Warble Tone Generator volume setting.

Look for a change in the decibel reading. A change of greater than 6 dB will indicate a problem.

Appendix three: Steam loss tables.

Spirax Sarco and UE systems both had steam specialists calculate the losses of leaking steam traps. Both Spirax Sarco and UE systems made a table with the average steam losses in case a steam trap leaks. To determine the steam loss the orifice diameter and steam pressure is required. Table three displays the average steam losses according to Spirax Sarco. Table four is the steam loss table according to UE systems, the table found was in Lb/hour, for the purpose of this research the table was transformed to kg/hour.

Table 3 Spirax Sarco steam loss estimates – retrieved from (Spirax Sarco, 2006)

Table 1 Typical steam wastage and annual costs due to leaking steam traps

Trap size	Average orifice size in steam traps (mm)	Steam loss (kg/h)			Typical annual cost £000s		
		6 bar g	14 bar g	32 bar g	6 bar g	14 bar g	32 bar g
DN15	3.0	8	19	43	13	32	72
DN20	5.0	24	53	119	40	89	200
DN25	7.5	55	121	270	92	203	453
DN40	10.0	98	214	478	164	359	802
DN50	12.5	152	335	747	255	562	1 254

Table 4 UE systems estimated steam losses – retrieved from (UE systems, 2014)

Orifice Diameter	3,44(bar)	5,2(bar)	6,89(bar)	8,62(bar)	10,35(bar)
	Steam leakage (kg/h)				
0,8 mm	0,84	1,17	1,5	1,82	2,15
1,6 mm	3,36	4,67	5,99	7,3	8,57
2,4 mm	7,57	6,99	13,47	16,42	19,32
3,2 mm	13,52	18,73	23,95	29,62	34,38
4 mm	21,09	29,26	37,22	45,36	53,52
4,8 mm	30,39	42,18	53,98	65,77	77,11
5,6 mm	41,37	57,15	73,48	89,36	105,23
6,4 mm	53,98	74,84	95,71	116,57	137,44
7,1 mm	68,49	94,8	121,11	147,42	174,18
7,9 mm	84,37	117,03	149,69	182,34	215
8,7 mm	102,06	141,52	180,98	220,45	259,91
9,5 ,mm	121,56	168,28	215,46	262,18	309,35
10,3 mm	142,43	197,77	252,65	307,99	362,87
11,1 mm	165,56	229,52	305,72	356,98	420,93
11,9 mm	190,06	263,08	336,57	410,05	483,08
12,7 mm	215,91	299,37	382,83	466,29	549,75

Appendix four: Steam trap locations

Steam traps MS Zuiderdam	Steam Traps in the engine room			Steam traps outside the engine room		
	Total ball float steam traps	14		Total ball float steam traps	3	
	Total thermodynamic steam traps	140	(97 tracing)	Total thermostatic steam traps	33	
	Total locomotive steam traps	21		Total thermodynamic steam traps	20	(not working)
	Total steam traps engine room	175		Total traps outside engine room	56	

Number	Area	Location	Condensate retour from	Steam trap Type	Working	Comments
1	Vacuum Collecting Room	Under grating Laundry heater	Laundry	Locomotive	NO	Laundry heater is removed
3	Vacuum Collecting Room	Next to laundry hot water pump	Laundry	Thermodynamic	NO	Laundry heater is removed
4	Vacuum Collecting Room	Behind Permeate tank 3 Portside	Potable water tanks	Thermodynamic	YES	Low temperature
5	Grey Water Room	Next to portable water 2C	Potable water tanks	Thermodynamic	YES	Low temperature
7	Potable Water Room	In front of GSP	Fuel oil tank 1 SB	2x Thermodynamic	YES	High temperature
9	Potable Water Room	PS potable water room	Fuel oil tank 1 PS	2x Thermodynamic	YES	High temperature
12	Potable Water Room	next to watertight door D3	Potable water tanks	3x Thermodynamic	YES	Only one of the three traps are in use.
11	Potable Water Room	Under PS hot water de-Chlorination unit	-	Thermodynamic	NO	Low temperature
16	Potable Water Room	Galley condensate retour station 1	Hot water Galley	3x Locomotive	YES	Only two are in use, one standby
19	Potable Water Room	Galley condensate retour station 2	Hot water Galley	3x Locomotive	YES	Only one is un use, two standby
20	Forward Sewage Room	Next to potable water 3C & GW pump	-	Thermodynamic	NO	-
22	AC Room	FWD bulkhead in front of AC 1	-	2x Thermodynamic	NO	High temperature
28	AC Room	FWD bulkhead in front of AC 1	two steam heaters portside	6x Locomotive	YES	Not all are in use. Covered in Isolation
36	AC Room	FWD bulkhead in front of AC 4	two steam heaters starboard sid	8x Locomotive	YES	Not all are in use. Covered in Isolation
38	Evaporator Room	Next to Service tank 4C	Fuel oil service tank 4C	2x Thermodynamic	YES	High temperature
40	Evaporator Room	Next to settling tank 4PS	Fuel oil settling tank 4P	2x Thermodynamic	YES	High temperature
41	Evaporator Room	In front of starboard side EVAP	Evaporator number 1	Thermodynamic	YES	High temperature
42	Evaporator Room	In front of portside EVAP	Evaporator number 2	Thermodynamic	YES	High temperature
43	Evaporator Room	Next to Settling tank 4P	sludge tank 18P	Thermodynamic	YES	-
49	Evaporator Room	Next to portside EVAP	Tracing lines	6x thermodynamic	YES	Low temperatures, not all in use
54	Evaporator Room	next to starboard EVAP, aft bulkhead	Tracing lines	5x thermodynamic	YES	Low temperatures, not all in use
59	Evaporator Room	Next to WTD D7	Tracing lines	5x thermodynamic	YES	Low temperatures, not all in use
60	Forward Main engine Room	Next to horizontal boiler	Pre heat module DG 4-5	Ball float trap	YES	-
61	Forward Main engine Room	Under horizontal boiler, next to blowdown	Horizontal boiler	Thermodynamic	YES	-
62	Forward Main engine Room	Next to horizontal boiler, PS hull	Horizontal boiler	Thermodynamic	YES	-
64	Forward Main engine Room	Under gratings next to GT and DG5	Fuel oil tank 2SB	2x Thermodynamic	YES	High temperature
66	Forward Main engine Room	Under gratings next to DG4 PS	Fuel oil tank 2PS	2x Thermodynamic	YES	High temperature
67	Forward main engine Room	In front of FW cooling pump	HFO overflow tank	Thermodynamic	YES	-
74	Forward main engine Room	In fron of GT, next to enersyn tank.	Tracing lines	7x thermodynamic	YES	Low temperatures, not all in use

74	Forward main engine Room	In fron of GT, next to enersyn tank.	Tracing lines	7x thermodynamic	YES	Low temperatures, not all in use
88	Forward main engine Room	Next to Portside sea chest	Tracing lines	14x thermodynamic	YES	Low temperatures, not all in use
89	Forward Purifier room SB	HFO/MDO Fuel module	HFO/MDO fuel module	Ball float trap	YES	
90	Forward Purifier room SB	Fuel oil seperator 1	Fuel oil seperator 1	Ball float trap	YES	-
91	Forward Purifier room SB	Fuel oil seperator 2	Fuel oil seperator 2	Ball float trap	YES	-
106	Forward Purifier room SB	FWD bulkhead near entrance	Tracing lines	15x thermodynamic	YES	Low temperatures, not all in use
107	Forward purifier room PS	under grating next to sludge pump 3	Sludge tank 19P	Thermodynamic	YES	-
108	Forward purifier room PS	Forward boiler Module	Forward boiler Module	Ball float trap	YES	
109	Forward Purifier room PS	Lubrication oil purifier 4	Lubrication oil purifier 4	Ball float trap	YES	-
110	Forward Purifier room PS	Lubrication oil purifier 5	Lubrication oil purifier 5	Ball float trap	YES	-
125	Forward Purifier room PS	Aft purifier room	Tracing lines	15x thermodynamic	YES	Low temperatures, not all in use
126	Aft Main engine room	Behind hotwell	Hotwell	Thermodynamic	YES	-
130	Aft main engine room	Next to SW pump	Tracing lines	4x thermodynamic	YES	Low temperatures, not all in use
131	Aft Main engine room	Next to foam drum	Tracing lines	Thermodynamic	YEs	-
149	Aft Main engine room	Portside corner	Tracing lines	18x Thermodynamic	YES	Low temperatures, not all in use
151	Aft Main engine room	In between DG 2 & DG3	Fuel tank 3C	2x Thermodynamic	YES	-
153	Aft Main engine room	In between DG1 & DG2	Fuel tank 3P	2x Thermodynamic	YES	-
155	Aft Main engine room		Fuel tank 3SB	2x Thermodynamic	YES	-
156	PS aft purifier room	HFO/MDO Fuel module aft	HFO / MDO fuel module	Ball float trap	YES	-
157	PS aft purifier room	Fuel oil seperator 4	fuel oil seperator 4	Ball float trap	YES	-
158	PS aft purifier room	Fuel oil seperator 5	fuel oil seperator 5	Ball float trap	YES	-
159	PS aft purifier room	Lubrication oil purifier 1	Lubrication oil purifier 1	Ball float trap	YES	-
160	PS aft purifier room	Lubrication oil purifier 2	lubrication oil purifier 2	Ball float trap	YES	-
161	PS aft purifier room	Lubrication oil purifier 3	lubrication oil purifier 3	Ball float trap	YES	-
162	PS aft purifier room	Boiler fuel module Aft	boiler fuel module aft	Ball float trap	YES	-
164	Auxiliary room AFT C- DECK	in front of service tank 5C	Fuel service tank 5C	2x Thermodynamic	YES	-
166	Auxiliary room AFT C- DECK	In front of settling tank 5P	Fuel settling tank 5P	2x Thermodynamic	YES	-
173	Auxiliary room AFT C- DECK	Near daily oily bilge pumps, fwd bulkhead	Tracing lines	7x thermodynamic	YES	Hot tracing lines
174	Auxiliary room AFT D- DECK	Renovating oil tank	Renovating oil tank	Thermodynamic	YES	-
175	Auxiliary room AFT D- DECK	Bilge water tank 15C	BWT 15C	Thermodynamic	YES	-

Steam traps outside Engine room

Number	Area	Location	Condensate retour from	Steam trap Type	Working	Comments
176	Deck 8 fwd machinery space	Deck 8 fwd machinery space	Hydro pool heater	Ball float	YES	-
177	Deck 8 mid machinery space	Deck 8 mid machinery space	Lido pool heater	Ball float	YES	-
178	Deck 8 aft machinery space	Deck 8 aft machinery space	Outside swimming pool heater	Ball float	Yes	-
179- 186	Galley deck two food warmers	Unit one to eight	food warmers	Thermostatic	YES	-
187-192	Galley deck three food warmers	Units one to six	food warmers	Thermostatic	YES	-
193-197	Lido food warmers	2 units	food warmers	Thermostatic	YES	-
198-199	Taco grill food warmers	1 unit	food warmers	Thermostatic	YES	-
199-215	Dish washers	Deck 2,3 & crew galley	Dish washers	Thermostatic	YES	-
- 235 (+/-)	Ac stations	All AC stations have one trap	AC station	Thermodynamic	NO	if in use condensate goes to scupper, not back in system.

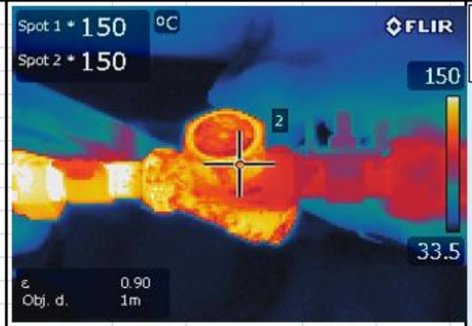
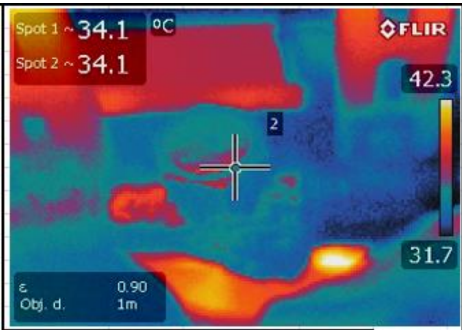
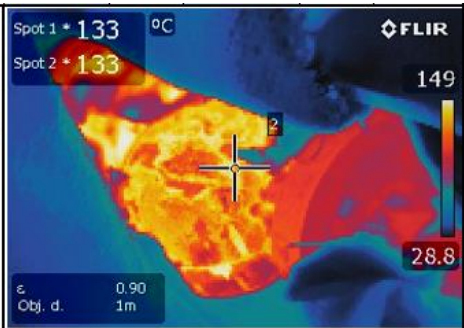
Appendix five: Validation tests Ultraprobe 15000.

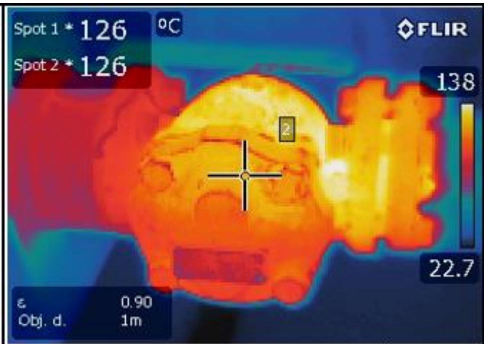
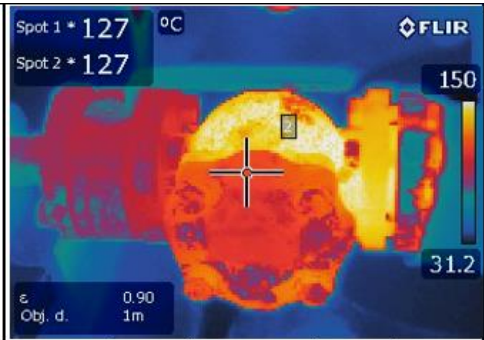
The validation tests from the Ultraprobe can also be found in the excel sheet, under the page ''validation tests Ultraprobe 15000''. The first day the Ultraprobe indicated 42 and 92 DB. In case the Ultraprobe deviated more than six DB from these values the values would be considered false. During the measurements the Ultraprobe was considered reliable.

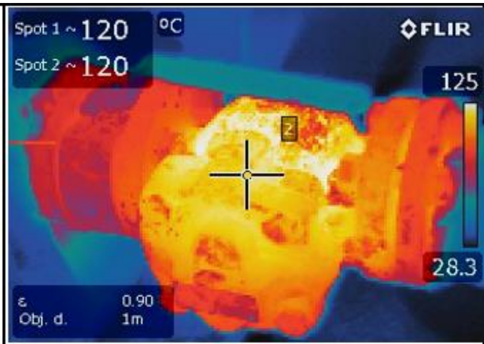
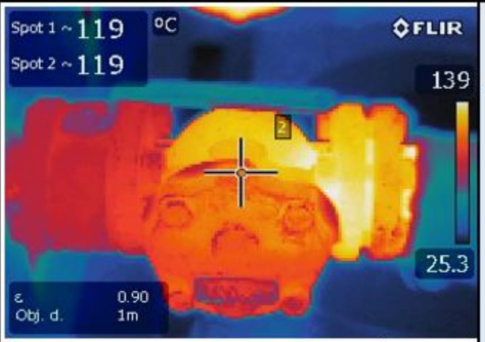
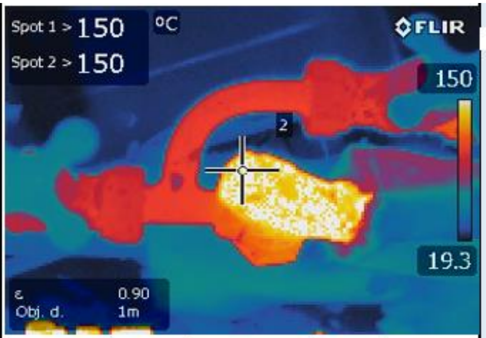
Table 5 Validation tests Ultraprobe 15000

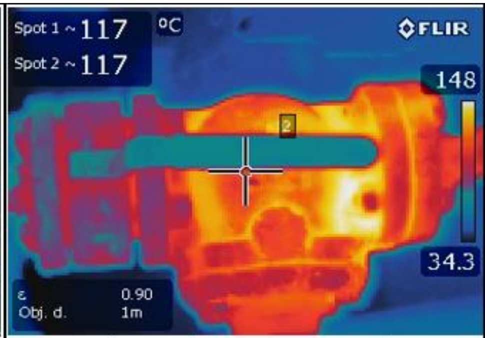
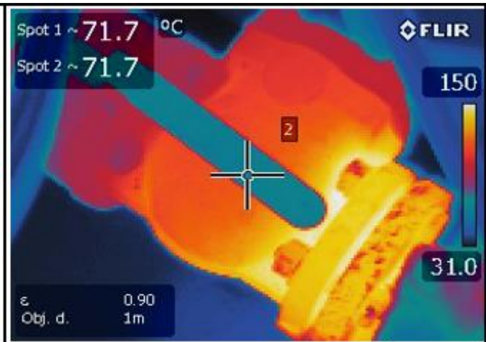
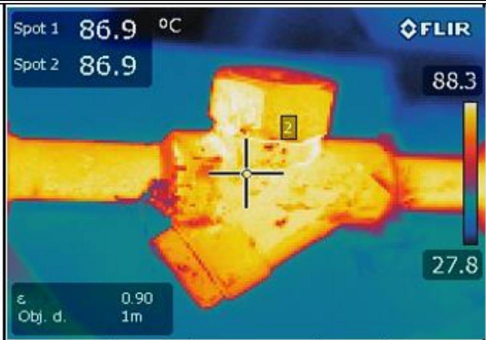
Validation tests Ultraprobe 15000						
	Date	Serial nr#	Stick used	tone generator frequency	Frequency	DB
Contact module	4-5-2016	104219	Long	low	40	**42**
Scan module	4-5-2016	160121	Long	low	40	**92**
Contact module	5-5-2016	104219	Long	low	40	**41**
Scan module	5-5-2016	160121	Long	low	40	**91**
Contact module	6-5-2016	104219	Long	low	40	**42**
Scan module	6-5-2016	160121	Long	low	40	**92**
Contact module	7-5-2016	104219	Long	low	40	**41**
Scan module	7-5-2016	160121	Long	low	40	**92**
Contact module	8-5-2016	104219	Long	low	40	**43**
Scan module	8-5-2016	160121	Long	low	40	**91**
Contact module	9-5-2016	104219	Long	low	40	**44**
Scan module	9-5-2016	160121	Long	low	40	**92**
Contact module	10-5-2016	104219	Long	low	40	**41**
Scan module	10-5-2016	160121	Long	low	40	**91**
Contact module	11-5-2016	104219	Long	low	40	**43**
Scan module	11-5-2016	160121	Long	low	40	**92**
Contact module	12-5-2016	104219	Long	low	40	**44**
Scan module	12-5-2016	160121	Long	low	40	**91**
Contact module	13-5-2016	104219	Long	low	40	**43**
Scan module	13-5-2016	160121	Long	low	40	**90**

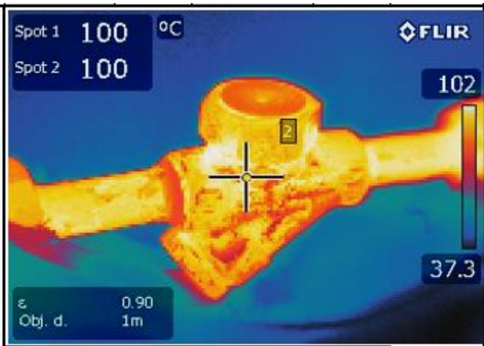
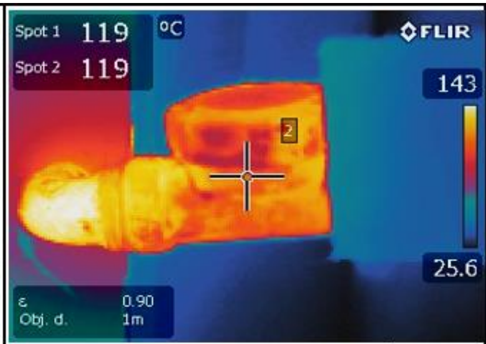
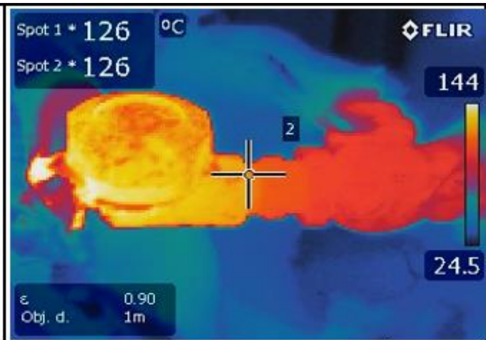
Appendix six: Thermal and ultrasound measurements with their conclusions

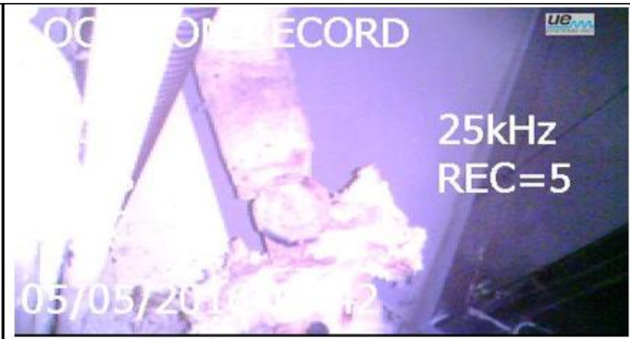
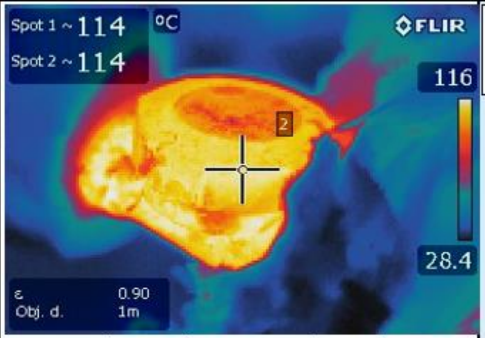
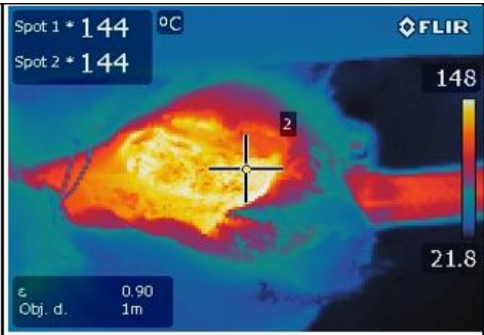
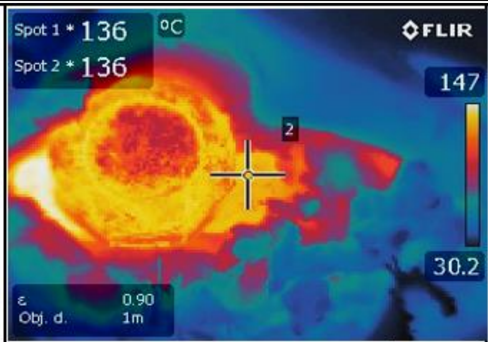
Measurement nr & location	Normal picture	Thermal image	Ultrasound	Conclusion
1 **Fuel coil 3C, coil one.** (Thermodynamic)	 **DB value** 40 (DB not on picture)	 **Inlet temp** > 150 C° **Outlet temp** 110 C°	Fuel 3C steam coil 1 #10 (2).wav	Steam trap opening and closing, but to fast. Spirax Sarco says a thermodynamic trap opening more than 6 times a minute will result in steam leakage. Trap opens and closes around 20 times a minute. according to ultrasound trap not oke. Thermal image shows trap working but leaking, condensate outlet 110 C°. **Steam trap leaking.**
2 **Fuel coil 3C, coil two.** (Thermodynamic)	 **DB value** - (DB from background noise)	 **Inlet temp** - **Outlet temp** -	Fuel 3C steam coil 2.wav	Sound on Ultraprobe is background noise from engine. Steam trap is located next to Dg3. No flow through pipe detectable with ultrasound. Thermal confirmes, no flow through coil. Explains why fuel tank 3C does not heat up so quickly. **No steam reaches trap.**
3 **Aft fuel module.** (Ball float trap)	 **DB value** 55	 **Inlet temp** 149 C° **Outlet temp** 125 C°	Aft fuel module.wav	Very high fluctuating DB sound. Ultrasound above 40 DB on ball float trap indicates steam leakage. Steam passing through. Trap not okay according to ultrasound. Thermal immage shows steam trap full of steam, outlet temperature to high. **Steam trap leaking.**

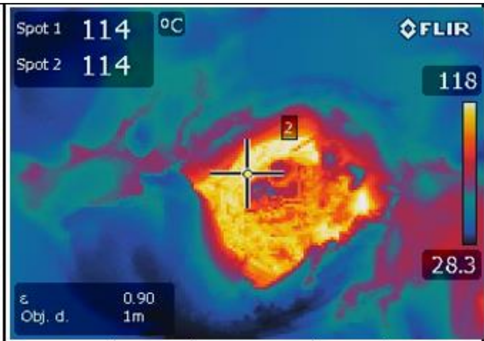
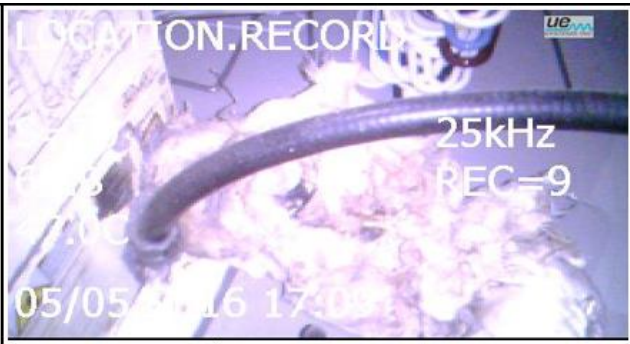
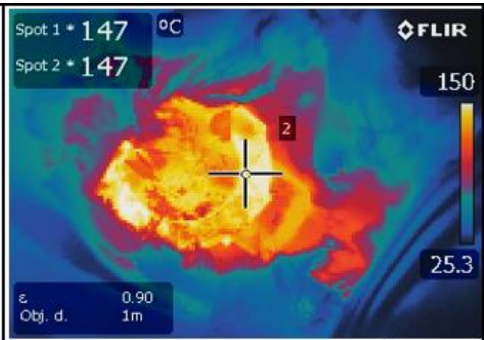
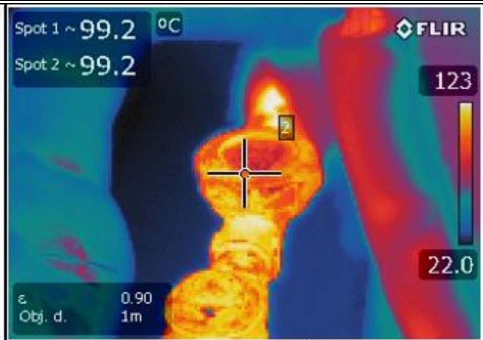
4	**lubricating purifier one.** (ball float trap)		DB value: 24		Inlet temp: 128 C°	Outlet temp: 100 C°	Lubrication oil purifier one.wav	low ultrasound noise, ticking is purifier itself. Smooth condensate flow can be detected. Fluctuating DB sound, trap okay according to ultrasound. Thermal image shows trap is trapping steam, condensate outlet is around 100 C°. **Steam trap working okay.**
5	**lubricating purifier two.** (ball float trap)		DB value: 34		Inlet temp: 138 C°	Outlet temp: 100 C°	Lubrication oil purifier two.wav	Hard to hear condensate flow due to background noise purifier, condensate flow DB low. Fluctuating DB sound, trap okay according to ultrasound. Thermal image shows trap is working correct, trap is not passing steam, condensate outlet around 100 C° **Steam trap working okay.**
6	**lubricating purifier three.** (Ball float trap)		DB value: 29		Inlet temp: > 150 C°	Outlet temp: 100 C°	Lubrication oil purifier three.wav	Hard to hear condensate flow due to background noise. Condensate flow Db low. Fluctuating Db sound, trap oke according to ultrasound. Thermal image shows trap is working oke. Condensate oulet around 100 C°. Trapping steam **Steam trap working okay.**

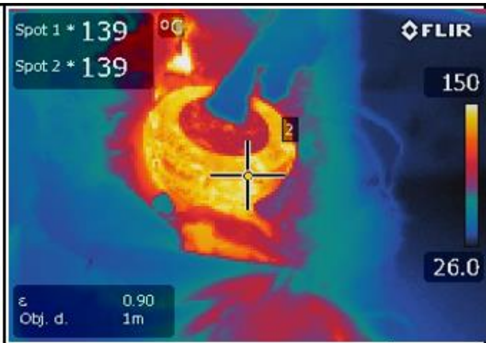
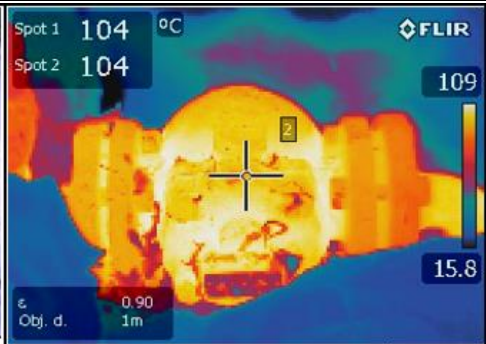
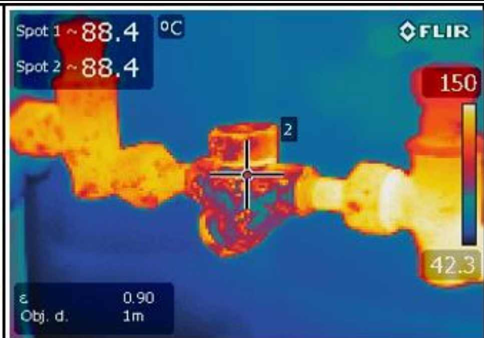
7 **Lubricating purifier four.** (ball float trap)	 **DB value** 27	 **Inlet temp** 125 C° **Outlet temp** 100 C°	Lubrication oil purifier four.wav	Smooth condensate flow detectable with ultrasound. Low fluctuating DB sound, trap working okay according to ultrasound. Thermal image shows trap is working okay. condensate outlet around 100 C°. Trapping steam. **Steam trap working okay.**
8 **Lubrication oil purifier five.** (ball float trap)	 **DB value** 34	 **Inlet temp** 139 C° **Outlet temp** 100 C°	Lubrication oil purifier five.wav	Smooth condensate flow detectable with ultrasound. Low fluctuating DB sound, trap working okay according to ultrasound. Thermal image shows trap is trapping steam. condensate outlet around 100 C°. **Steam trap working okay.**
9 **Sludge tank 19P coil.** (thermodynamic)	 **DB value** 31	 **Inlet temp** >150 C° **Outlet temp** 120 C°	Sludge tank 19P coil.wav	Constant steam flow trough trap, not closing anymore. According to ultrasound trap failed in open position, passing steam. Trap not okay. Thermal image shows condensate oulet around 120 C°. Trap passing steam. Trap upside down.. waterhammer can be felt on condensate line. **Steam trap leaking.**

10 **Fuel oil purifier one.** (Ball float trap)	 **DB value** 28	 **Inlet temp** 148 C° **Outlet temp** 100	Fuel oil purifier one.wav	Low fluctuating DB detectable with ultrasound. Steam trap working oke according to ultrasound. Thermal image shows trap is trapping steam. Condensate outlet 100 C° **Steam trap working okay.**
11 **Fuel oil purifier two** (Ball float trap)	 **DB value** 44	 **Inlet temp** >150C° **Outlet temp** 105 C°	Fuel oil pur 2 #20.wav	Higher DB value detected with ultrasound. Trap slightly leaking steam according to ultrasound. Thermal shows condensate outlet around 105 C° **Steam trap leaking.**
12 **Fuel tank 3SB coil one.** (thermodynamic)	 **DB value** 20 (photo taken before measurement)	 **Inlet temp** 88 C° **Outlet temp** 88 C°	Fuel tank 3SB coil one.wav	Ultrasound indicates trap is not closing, stays open. Condensate flow was low, still steam is detectable in condensate outlet. Thermal image shows equal temperature. Note that the condensate is only around 90 C°. **Steam trap leaking.**

13 **Fuel tank 3SB coil two.** (thermodynamic)	 **DB value** 20 (photo taken before measurement)	 **Inlet temp** 102 C° **Outlet temp** 102 C°	Fuel tank 3Sb coil two.wav	Ultrasound indicates steam trap is open, not closing as it should. Constant steam flow detected through condensate. Thermal image shows the equal inlet and outlet temperature. Steam is leaking trough trap. **Steam trap leaking.**
14 **Laundry forenza clothes press one.** (thermostatic)	 **DB value** 46 (photo taken before measurement)	 **Inlet temp** 140 C° **Outlet temp** 100 C°	Laundry, Florenza clothes press one.wav	Strange ultrasound noise, trap closing as it should. But steam is leaking when trap opens, high db. Noise can be the boiling of the liquid inside the trap. Thermal image shows outlet temperature around 110 C°. **Steam trap leaking.**
15 **Laundry, forenza clothes press two, trap one.** (thermostatic)	 **DB value** 20	 **Inlet temp** 126 C° **Outlet temp** 100 C°	Laundry, Florenza clother press two, trap one.wav	Some part of the forenza machine can be heard during the recording. Smooth flow of condensate detected with ultrasound. Thermal image shows trap is working oke. Condensate outlet around 100 C°. Note that the trap was isolated, thermostatic traps don't work when isolated, removed isolation. **Steam trap working okay.**

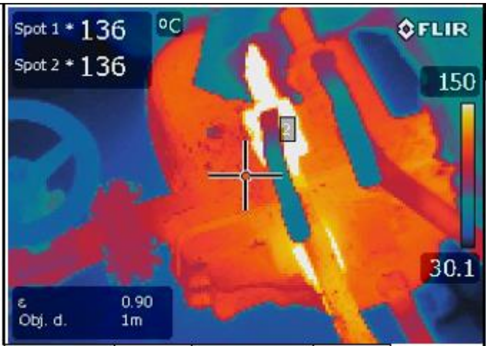
16 Laundray forenza clother press two, trap two. (thermostatic)	 DB value: 41	 Inlet temp: 116 / Outlet temp: 110 C°	Laundry, Florenza clother press two, trap two.wav	Parts of the machinery disturb measurement. In background constant steam flow detected, high db value. Thermal image shows outlet temperature 110 C°. Steam is leaking. Trap was isolated, static traps don't work while isolated. **Steam trap leaking.**
17 Laundry, forenza pants press. (thermostatic)	 DB value: 49	 Inlet temp: 140 C° / Outlet temp: 125 C°	Forenza pants press.wav	Parts of the machinery disturb measurement. In background constant steam flow detected, high db value. Thermal image shows outlet temperature 125 C°. Steam is leaking. Trap was isolated, static traps don't work while isolated. **Steam trap leaking.**
18 Laundry, florenza pants press, steam to condensate line. (thermostatic)	 DB value: 18	 Inlet temp: 150 C° / Outlet temp: 125 C°	Laundry, florenza pants press two..wav	Ultrasound detected trap is closed as it should, low db value. Thermal image shows condensate outlet around 125 C°. However, trap is closed and connected to the same line as trap 17. **Steam trap working okay.**

19	Laundry, FLorenza Steamer, trap one. (thermostatic)		DB value: 7		Inlet temp: 114	Outlet temp: 105 C°	Florenza steamer.wav	Ultrasound detects trap is closed. Only background noise can be heared on soundfile. Machinery was not in use, so trap should be closed. Thermal image shows condensate retucrn line is around 105 C°, this can be due to other trap connected to line. **Steam trap working okay.**
20	Laundry, Florenza steamer, trap two. (thermostatic)		DB value: 19		Inlet temp: 150 C°	Outlet temp: 105 C°	Florenza steamer two.wav	Ultrasound detects calm condensate flow. Trap seems to work oke. But sometimes a small high sound and high db were detected. Trap slightly passes steam Thermal image shows condensate is 105 C°, steam slightly passing from trap. **Steam trap leaking.**
21	Florenza pants press two, trap one. (thermostatic)		DB value: 38		Inlet temp: 124 C°	Outlet temp: 120 C°	Florenza pants press two, trap one.wav	Vibrating object disturds ultrasound measurement, condensate flow still detected. Trap not closing. Trap is leaking. Thermal image shows outlet temperature of 120 C°. Trap is leaking. **Steam trap leaking.**

22 **Florenza pants press two, trap two** (thermostatic)		**DB value** 72		**Inlet temp** 150 C° **Outlet temp** 140 C°	Florenza pants press two, trap two.wav	Very high DB value with ultrasound. Trap fully open, continuously passing steam. Trap broken. Thermal image shows outlet temperature around 140 C°. Trap is broken. **Steam trap leaking.**
23 **Aft pre-heat module** (ball float trap)		**DB value** 20		**Inlet temp** 109 C° **Outlet temp** 100 C°	Aft pre-heat module.wav	Ultrasound detects smooth condensate flow with a low db value. Trap working okay. Thermal image shows steam is being trapped inside the stream trap. Condensate outlet temperature around 100 C°. **Steam trap working okay.**
24 **Hotwell** (thermodynamic)		**DB value** 35		**Inlet temp** 150 C° ? **Outlet temp** 100 C°	Hotwell.wav	A nice example of how a thermodynamic steam trap should work. WIth ultrasound clearly detectable that steam trap opens and closes smoothly. Thernal image shows inlet temperature of 150 C°. This is not possible. Hotwell around 80-85 C°. This thermal image is considered false. **Steam trap working okay.**

<table>
<tr><td>25

Condensate retour from Hot water heaters, middle one. (Locomotive)</td><td>

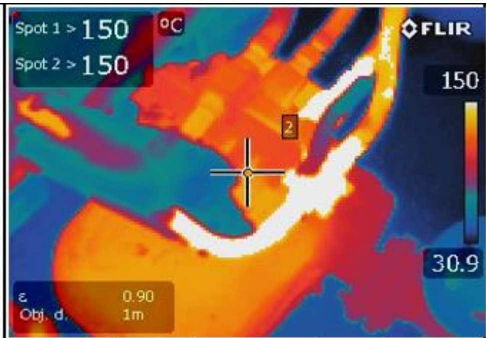
DB value | 22</td><td>

Inlet temp | 130 C° | Outlet temp | 105 C°</td><td>Middle locomotive trap portable water room.wav</td><td>Trap was pumping out condensate during ultrasound measurement. A little amount of steam is pushed out with the condensate, thats normal. Trap working oke.

Thermal image shows condensate outlet around 105C°. this due to pump out the steam trap.

Steam trap working okay.</td></tr>
<tr><td>26

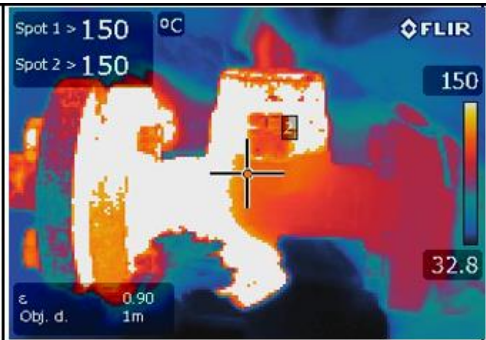
Condensate retour from Hot water heaters, most aft trap. (Locomotive)</td><td>

DB value | 51</td><td>

Inlet temp | 120 C° | Outlet temp | 111 C°</td><td>Locomotive trap potable water room, aft one..wav</td><td>Ultrasound detects steam leaking due to constant high db noise. Trap is leaking.

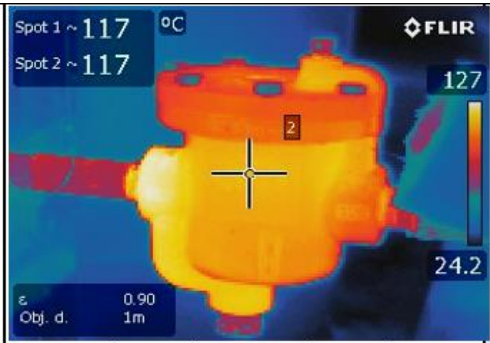
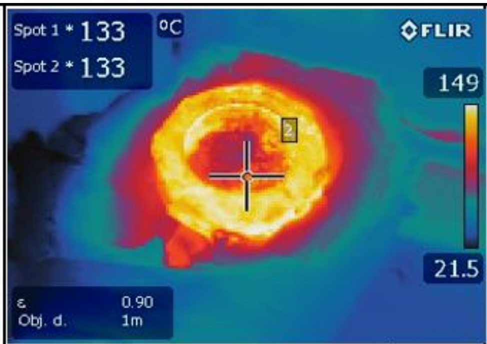
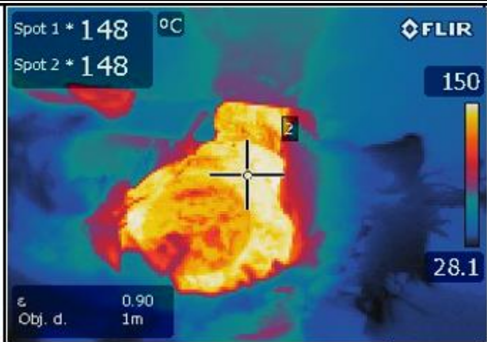
Thermal image confirms, condensate oulet 110 C°. Slight steam leakage is normal. But this trap is DB higher than a simular trap next to it.
Opened and closed the locomotive steam, DB dropped. Locomotive steam inlet valve passing.
Steam trap leaking.</td></tr>
<tr><td>27

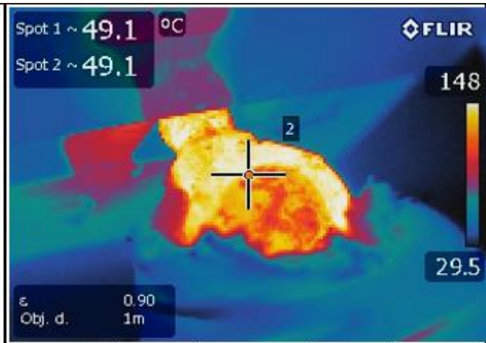
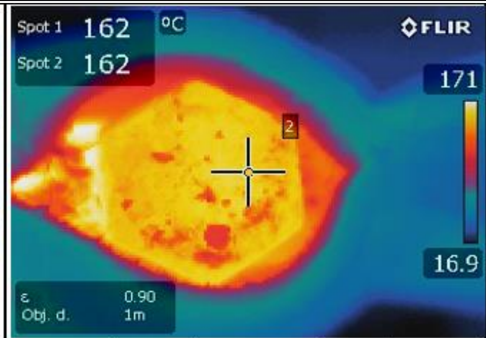
Laundry, linen machine. (Bimetal)</td><td>

DB value | 21</td><td>

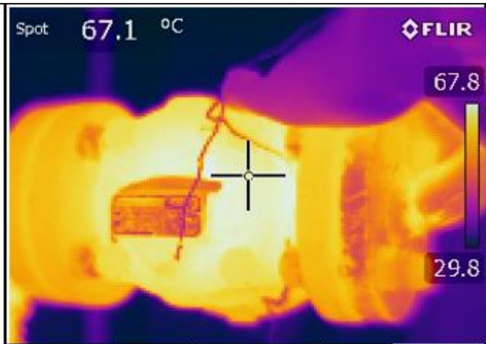
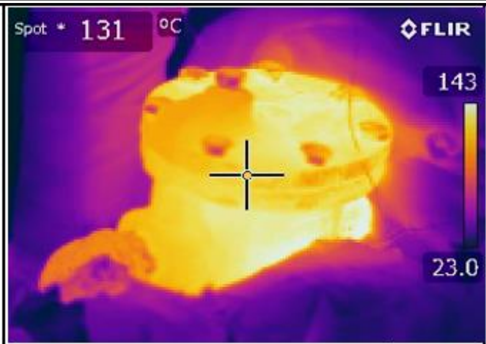
Inlet temp | > 150 C° | Outlet temp | 105 C°</td><td>Linen machine laundry.wav</td><td>With ultrasound can be concluded that the trap is working, but opening and closing to fast.

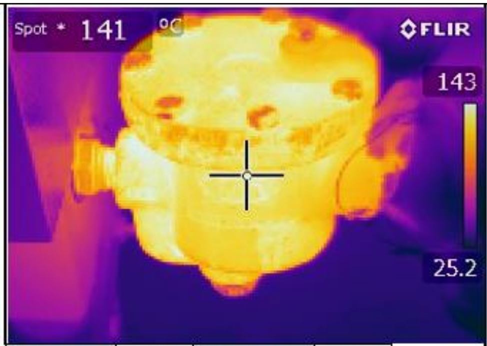
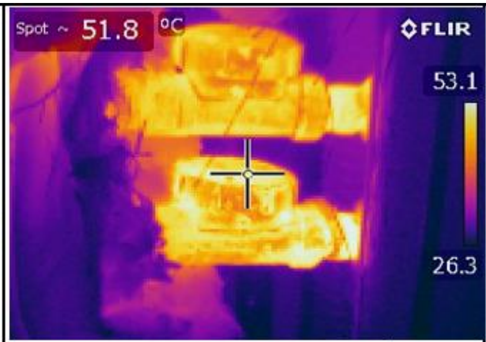
Thermal image shows trap is working and trapping, but condensate outlet around 105 C°, for a bimetal trap this is normal.
Note: trap was isolated. bimetal trap does not function when isolated. Isolation removed.
trap working okay after isolation was removed.</td></tr>
</table>

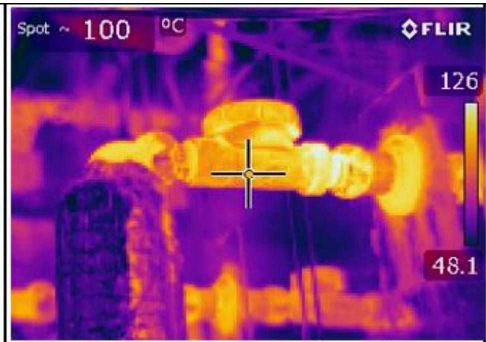
28 **Laundry, Dryer. (two dryers that work with steam are onboard, one was measured.** (Inverted bucket trap)	 **DB value** 26	 **Inlet temp** 127 C° **Outlet temp** 100 C°	Inverted bucket trap dryer.wav	Trap is functioning as it should. With ultrasound trap can be heard opening and closing smoothly. Thermal image shows trap trapping steam. Condensate oulet around 100C°. **Steam trap working okay.**
29 **Forenza shirt steamer, trap one.** (thermostatic)	 **DB value** 46 (picture taken before measurement)	 **Inlet temp** 150 C° **Outlet temp** 115 C°	Forenza shirt steamer trap one.wav	With ultrasound a smooth condensate flow is detected. Db value is quite high, also waterhammer can be heared. This is from the other traps connected to the same condensate line. Thermal image shows trap outlet temperature around 115 C°. This due to leakage other traps. **Steam trap working okay.**
30 **Forenza shirt steamer, trap two.** (thermostatic)	 **DB value** 52	 **Inlet temp** 150 C° **Outlet temp** 125 C°	Forenza shirt steamer trap two.wav	Constant high db condensate / steam flow detected with ultrasound. Waterhammer can be heared and felt on the condensate retour line. Thermal image shows very hot condensate outlet, around 125 C°. Trap was Isolated, static traps do not work when isolated. **Steam trap leaking.**

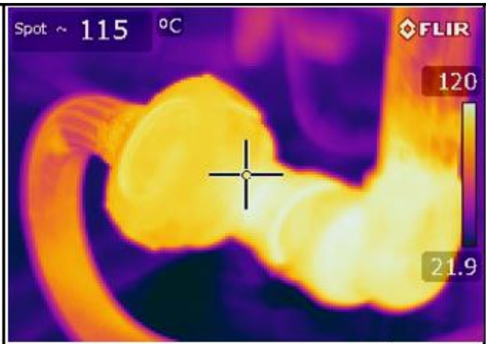
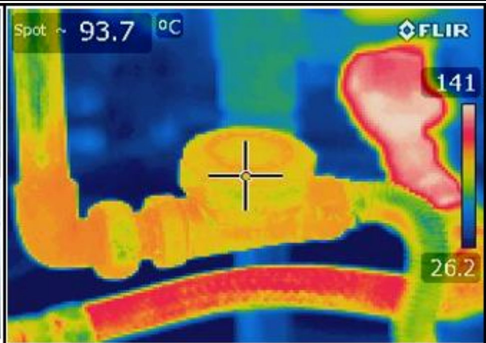
31 **Forenza shirt steamer, trap 3.** (thermostatic)	 **DB value** 42	 **Inlet temp** 150 C° **Outlet temp** 125C°	Forenza shirt steamer trap three.wav	Ultrasound detects steam passing at the trap, Db value is too high. Trap still closing but leaking. Thermal image shows condensate oulet around 125C°. The trap is located next to the second trap that is leaking heavely. So temperature can be misleading. **Steam trap leaking.**
32 **Starboard evaporator.** (ball float trap)	 **DB value** 27	 **Inlet temp** 90C° **Outlet temp** 80C°	Starboard evaporator (2).wav	Smooth condensate flow detected with ultrasound, low db value for a ball float trap. Thermal image shows equal temperature throughout the trap. No conclusions can be drawn from thermal image. **Steam trap working okay.**
33 **Steam to condensate line evap two.**	 **DB value** 41	 **Inlet temp** 170 C° **Outlet temp** 150 C°	Steam to condensate line evap 2.wav	With ultrasound steam passing trough trap detected, Db value to high. Thermal image shows boiling trap. Outlet steam trap around 150C°. Why is this steam trap in operating? Pushing steam directly too condensate return line. Trap was isolated. Trap in bad state due to rust. **Steam trap leaking.**

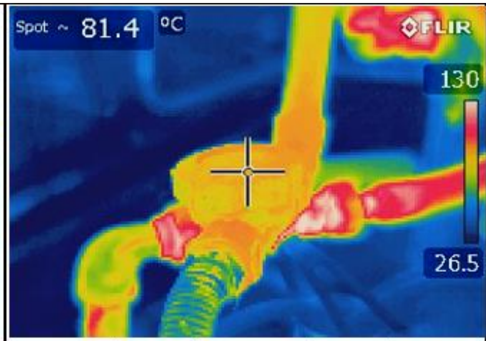
34	**HFO settling tank 4P, coil one.** (thermodynamic)	 DB value: 52	 Inlet temp: 127 C° / Outlet temp: 120 C°	HFO settling tank 4P coil one.wav	Constant condensate and steam flow detected with ultrasound. DB value very high. Trap not closing. Thermal image shows trap is a constant temperature. Not trapping steam. Trap was isolated. **Steam trap leaking.**
35	**HFO settling tank 4P, coil two.** (thermodynamic)	No picture taken DB value: -	No picture taken Inlet temp: - / Outlet temp: -	No ultrasound taken	2nd coil was found of. No db noise only background noise. Low temperature. **Coil off.**
36	**Aft swimming pool** (ball float trap)	 DB value: 24	 Inlet temp: 80C° / Outlet temp: 120 C°	Aft swimming pool normal condition.wav Aft swimming pool, closed drain & steam.wav	A smooth condensate flow is detected with ultrasound. Hard waterhammer can be heared. The oulet temperature at the trap was 120 C°. Also the drain of the trap was open. **A small steam valve to the condensate line was fully open. Passing steam directly to condensate line. Steam was closed, waterhammer stopped, temperature dropped. Trap working okay.**

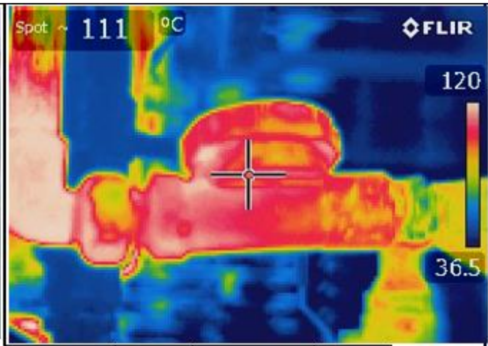
37 **Lido midship pool** (ball float trap)	No picture taken **DB value** 7	No thermal picture taken **Inlet temp** 30C° **Outlet temp** 110 C°	No ultrasound detected	Heater & trap were off. Condensate retour line was 110 C°; Again a crossover line from the steam inlet to the condensate line was found open. Loud waterhammer on the condensate line. **Cross over valve was closed. Waterhammer on the condensate line stopped and line cooled off. Why was this valve open?**
38 **Hydro pool** (ball float trap)	No picture taken **DB value**	 **Inlet temp** 70 C° **Outlet temp** 70 C°	No ultrasound detected	Heater was on, but steam trap was found cold at first. A small condensate drain just before the steam trap was open. All condensate was being directly drained to a gray water tank. **Closed drain, steam trap got hot, trap working okay.**
39 **Laundry, Veit steamer** (inverted bucket trap)	 **DB value** 33	 **Inlet temp** 140C° **Outlet temp** 105C°	Veit steam er, inverted bucket.wav	With ultrasound a smooth condensate flow is detected, still small high peaks in db, indicates small steam leakage. Thermal image shows trap is working and trapping steam. But is passing slightly due to condensate outlet of around 105 C°. **Steam trap leaking.**

40 **Laundry, veit steamer two** (inverted bucket trap)	 **DB value** 37	 **Inlet temp** 140 C° **Outlet temp** 115 C°	Veit steamer two, inverted bucket.wav	Condensate flow with steam is detected with ultrasound. tickling noise can be vibrating obejct elsewere. Thermal image shows trap is hot and leaking, condensate outlet around 115 C°. **Steam trap leaking.**
41 **Laundry, trap next to steam inlet veit steamer.** (thermostatic)	 **DB value** 18	 **Inlet temp** 150 C° **Outlet temp** -	Static trap next to steam inlet veit steamer.wav	Smooth condensate flow with low db detected with ultrasound. Due to isolation not alot can be concluded from the thermal image. Should have been removed. **Steam trap working okay.**
42 **Forenza clothes stamp two, top trap.** (thermostatic)	 **DB value** 19	 **Inlet temp** 120 C° **Outlet temp** 110 C°	Forenza clothes stamp two, trap one (top).wav	Smooth condensate flow detected with ultrasound, but sometimes has high peaks. Indicates steam. Thermal image shows equal temperature. Trap is not working anymore. **Steam trap leaking.**

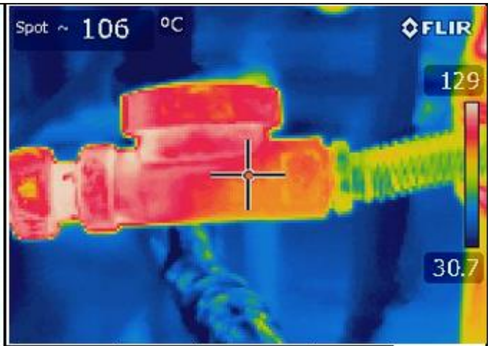
43 **Forenza clothes stamp two, bottom trap.** (thermostatic)	 **DB value** 44 (DMS shows 44 Db)	 **Inlet temp** 130 C° **Outlet temp** 115 C°	Forenza clothes stamp two, trap one (bottem).wav	Continuous high db value condensate flow filled with steam detected with ultrasound. Themal image shows equal temperature troughout trap. Bottem trap is hotter, this can indicate a higher load, as both traps leak. **Steam trap leaking.**
44 **Lido warm buffet (english breakfast)** (thermostatic)	 **DB value** 43	 **Inlet temp** 126 C° **Outlet temp** 120 C°	Lido buffet, top static trap.wav	With ultrasound continious steam flow detected when steam is open. Trap not responding. Thermal image shows equal temperature over trap. Steam is passing. **Steam trap leaking.**
45 **Lido buffet, english breakfast.** (thermostatic)	 **DB value** 24	Infrared picture not possible, hot steam lines blocking view **Inlet temp** - **Outlet temp** -	Lido buffet, bottem trap.wav Lido buffet condensate line, when opening steam.wav	Continious condensate filled with steam detected with ultrasound. db value a lot lower than top trap. Thermal image could not be taken. **An extra measurement was taken of the condensate line when steam is being openen. After a couple of seconds steam is passing trough it.** **Steam trap leaking.**

46 Galley deck three, unit five, (thermostatic)	 DB value 49	 Inlet temp 120 C° Outlet temp 110 C°	Deck three galley, unit five..wav	Constant steam flow detected just after the static trap. Trap fully open. Ultrasound has a high db value. Thermal image shows almost equal temperature. condensate outlet around 110 C°. **Steam trap leaking.**
47 Galle deck 3 unit 6. (thermostatic)	 DB value 40 (picture taken before measurement)	 Inlet temp 140 C° Outlet temp 110 C°	Galley deck 3, unit 6..wav	Ultrasound detects a constant high db value. Trap failed in open position. Thermal image shows condensate outlet around 110 C°. Thermal image can be misleading, as condensate line is made from isolation material. **Steam trap leaking.**
48 Galley deck 3 unit 4 (thermostatic)	 DB value 25 (picture taken before measurement)	 Inlet temp 100 C° Outlet temp 95 C°	Galley deck three, unit four.wav	Constant condensate flow with low db detected with ultrasound. No steam detected in condensate. Thermal image shows trap is around 100 C°. Oulet around 95C°. Not leaking steam. Note: steam flow low, measurement may not be accurate. **Steam trap working okay.**

49	Galley deck 3, unit 3 (thermostatic)	 DB value: 39 (picture taken before measurement)	 Inlet temp: 90 C° / Outlet temp: 80C°	Galley deck three, unit three.wav	Ultrasound detecs trap is opening and closing. Working as it should. Smooth condensate flow detected. Thermal image shows trap outlet temperature around 80C°. Note: trap was measured at a low load. **Steam trap working okay.**
50	Galley deck 3, unit 2 (thermostatic)	 DB value: 39 (picture taken before measurement)	 Inlet temp: 130 C° / Outlet temp: 110C°	Galley deck three, unit two.wav	Constant condensate flow wit steam detected with ultrasound. Trap not closing. Thermal image shows trap outlet temperture around 110 C°. Steam is passing. **Steam trap leaking.**
51	Galley deck 3, unit 1. (thermostatic)	 DB value: 52 (picture taken before measurement)	 Inlet temp: 120 C° / Outlet temp: 110 C°	Galley deck three, unit one.wav	Constant condensate flow filled with steam detected with ultrasound. Constant high db value. Trap not closing. Thermal image shows trap has a condensate outlet around 110 C°. Steam is leaking through trap. **Steam trap leaking.**

52 **Galley deck two, unit one.** (thermostatic)	 **DB value** 51	 **Inlet temp** 120 C° **Outlet temp** 110 C°	Galley deck two, unit one.wav	With ultrasound condensate flow with steam detected. Trap is not closing. High db value. Thermal image shows outlet temperature around 110 C°. Trap not working. **Steam trap leaking.**
53 **Galley deck two, unit two.** (thermostatic)	 **DB value** 34 (picture taken before measurement)	 **Inlet temp** 105 C° **Outlet temp** 100 C°	Galley deck two, unit two.wav	Trap is opening and closing. Low db value with ultrasound. Still steam is leaking though trap when closing. Thermal image shows trap temperature equal. **Steam trap leaking.**
54 **Galley deck two, unit three.** (thermostatic)	 **DB value** 34	 **Inlet temp** 115 C° **Outlet temp** 100 C°	Galley deck two, unit three.wav	Smooth condensate flow detected with ultrasound. Db value okay. Thermal image shows condensate oulet around 100 C°. **Steam trap working okay.**

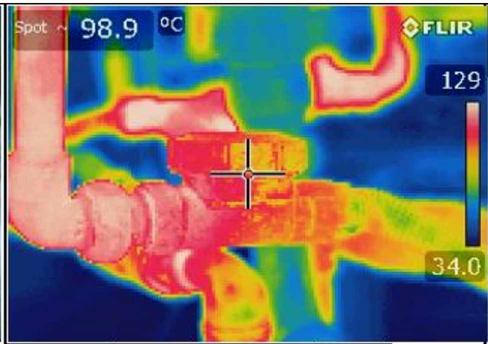
<table>
<tr>
<td>55
Galley deck two, unit 6.
(thermostatic)</td>
<td>

DB value | 33 | (picture taken before measurement)</td>
<td>

Inlet temp | 120 C° | Outlet temp | 105 C°</td>
<td>Galley deck two, unit six.wav</td>
<td>Condensate flow with low db detected with ultrasound. Trap opening and closing, but steam can be heared.

Thermal image shows trap is trapping steam. Condensate outlet around 105 C°

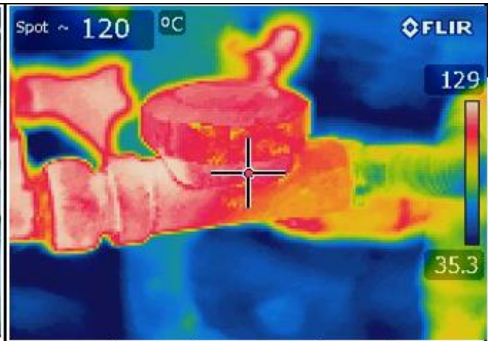
Steam trap leaking.</td>
</tr>
<tr>
<td>56
Galley deck two, unit eight.
(thermostatic)</td>
<td>

DB value | 26</td>
<td>

Inlet temp | 130 C° | Outlet temp | 100 C°</td>
<td>Galley deck two, unit eight.wav</td>
<td>Smooth condensate flow deteced with ultrasound. No steam detected in condensate flow. Trap is opening and closing as it should.

Thermal image shows trap is trapping steam, condensate outlet around 100 C°.

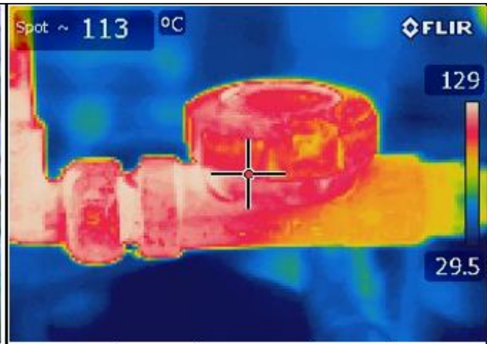
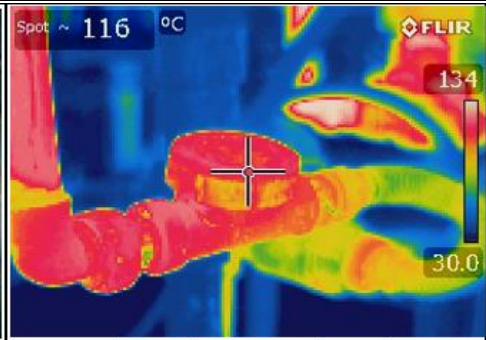
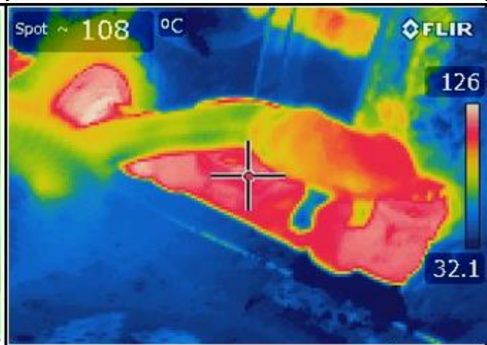
Steam trap working okay.</td>
</tr>
<tr>
<td>57
Galley deck two, unit seven.
(thermostatic)</td>
<td>

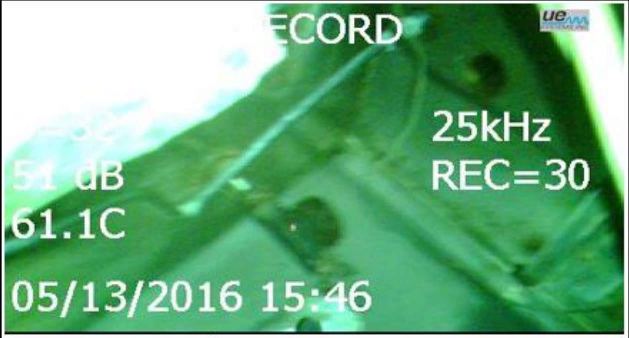
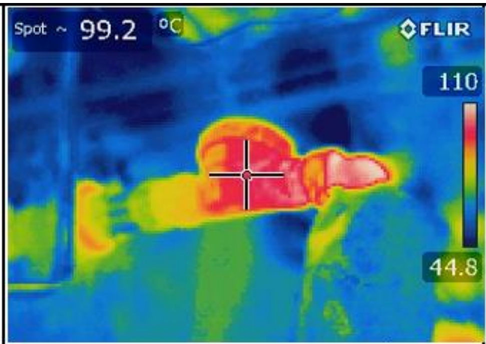
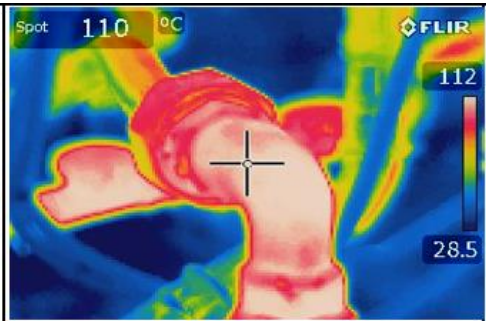
DB value | 54</td>
<td>

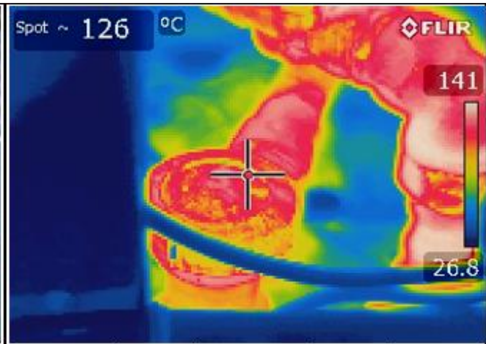
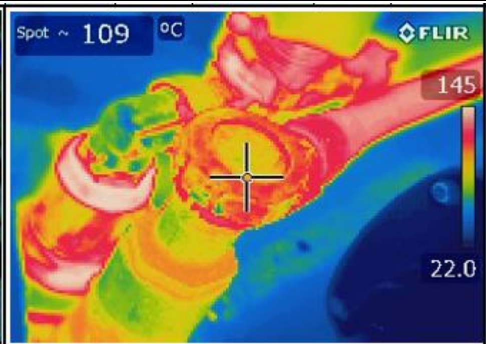
Inlet temp | 129 C° | Outlet temp | 115 C°</td>
<td>Galley deck two,unit seven.wav</td>
<td>Constant high db condensate filled with steam detected with ultrasound. Steam can be heared passing.

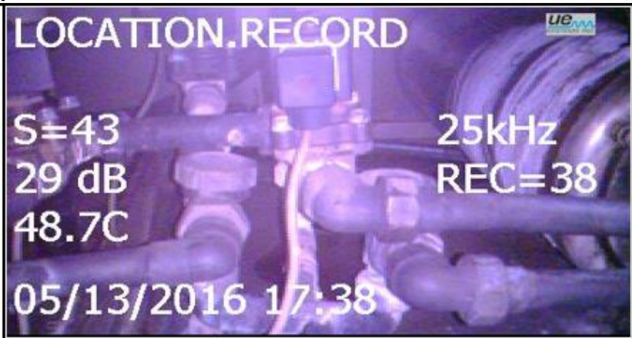
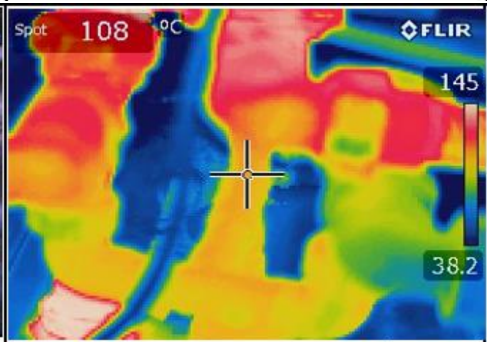
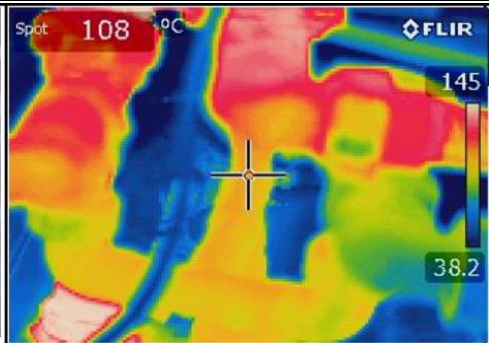
Thermal image shows condensate outlet around 115 C°.

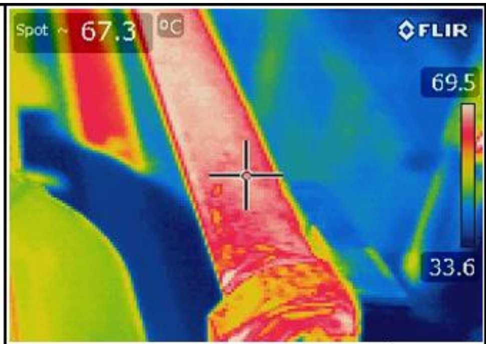
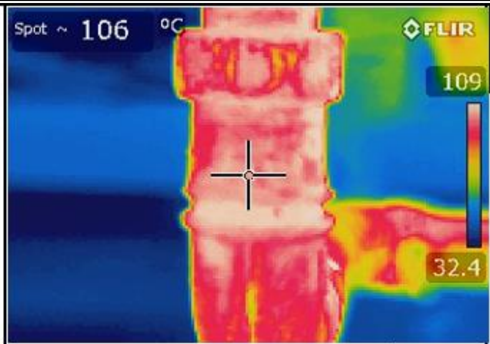
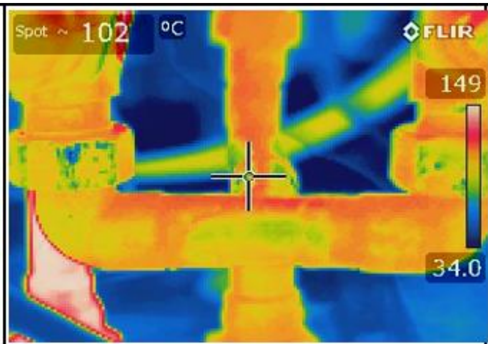
Steam trap leaking.</td>
</tr>
</table>

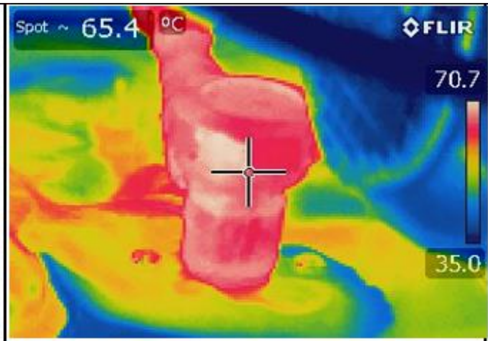
58 **Galley deck two, unit five.** (thermostatic)	 **DB value** 59	 **Inlet temp** 130 C° **Outlet temp** 110 C°	Galley deck two, unit five.wav	Steam constantly passing thourg trap. Trap not doing anything according to ultrasound. Thermal image shows trap trapping steam. Condensate outlet around 100 C°. Further on the condensate line the temperature was 110 C. Image considered invalit. **Steam trap leaking.**
59 **Galley deck two, unit four.** (thermostatic)	 **DB value** 51 (picture taken before measurement)	 **Inlet temp** 120 C° **Outlet temp** 110 C°	Galley deck two, unit four.wav	Constant high db value condensate flow. Trap not closing, steam passing through trap. Thermal image shows condensate outlet temperature around 110 C°. **Steam trap leaking.**
60 **Po buffet warmer, lower trap.** (thermostatic)	 **DB value** 49	 **Inlet temp** 120 C° **Outlet temp** 115 C°	Petty officers buffet warmer, lower trap.wav	With ultrasound a constant high db value can be heared. Trap not closing, failed open. Thermal image shows condensate outlet around 115 C°. **Steam trap leaking.**

61 **Po buffet warmer, top trap.** (Thermostatic)	 **DB value** 51	 **Inlet temp** 110 C° **Outlet temp** 110 C°	Petty officers buffet warmer, top trap.wav	Very high db value determined with ultrasound. Trap not closing, waterhammer on condensate line. Thermal image shows inlet and outlet temperature around 110 C°. **Steam trap leaking.**
62 & 63 **Crew galley buffet warmers.** (2x thermostatic)	 **DB value** 40	 Condensate line from the 2 thermostatic traps. **Inlet temp** 140 C° **Outlet temp** 110 C°	Crew galley buffet warmers (2x static).wav	Condensate line measured, quite far from the steam traps. A condensate / steam flow was determined. Thermal image shows condensate outlet around 110 C°. **Steam trap leaking.**
64 **Crew dish washer, trap one.** (thermostatic)	 **DB value** 35 (db on picture in incorrect)	 **Inlet temp** 80 C° **Outlet temp** 120 C°	Crew dish washer, trap one..wav	Condensate flow with steam detected with ultrasound. Db value although, is not so high. Thermal shows condensate line 120 C°. This is due to the leakage of the other steam traps connected to the same condensate line. Note: waterhammer can be felt on the condensate line. **Steam trap working okay.**

65 **Crew dish washer, trap two,** (Thermostatic)	 **DB value** 48	 **Inlet temp** 140 C° **Outlet temp** 120 C°	Crew dish washer, trap two.wav	Constant high db value detected with ultrasound. Trap is failed open. Not functioning any more. Thermal shows condensate outlet around 120 C°. Note: waterhammer can be felt and heared on condensate line. **Steam trap leaking.**
66 **Crew dish washer, trap three.** (thermostatic)	 **DB value** 53	 **Inlet temp** 145 **Outlet temp** 120 C°	Crew dish washer, trap three..wav	Very high constant db value detected with ultrasound. Trap is open, trap not trapping any steam. Thermal shows condensate outlet around 120 C° Note: waterhammer can be heared and felt on the condensate line. **Steam trap leaking.**
67 **Galley dishwasher deck 2, against wall, Trap one.** (thermostatic)	 **DB value** 50	 **Inlet temp** 110 C° **Outlet temp** 110 C°	Galley dishwasher deck two, against wall trap two..wav	Condensate with steam determined with ultrasound. High db value. Trap is not closing Thermal image shows inlet and outlet temperature equal. **Steam trap leaking.**

68	Galley dishwasher deck 2, against wall. trap two, (thermostatic)		DB value: 35	Picture was to blurred, was discarded.	Inlet temp:	Outlet temp:	Galley dishwasher deck two, against wall trap two.wav	With ultrasound condensate flow with high db value detected. Indicates small steam leakage. Thermal image was discarded. **Steam trap leaking.**
69	Galley dishwasher deck 2, against wall, trap three. (thermostatic)		DB value: 29		Inlet temp: 140 C°	Outlet temp: 100 C°	Deck 2 dishwasher against wall, trap 3 & 4 line..wav	Smooth condensate flow determined with ultrasound. low db value. Thermal image is blurred. condensate oulet was around 100 C° **Steam trap working okay.**
70	Galley dishwasher deck 2, against wall, trap four. (thermostatic)		DB value: 29		Inlet temp: 140 C°	Outlet temp: 100 C°	Deck 2 dishwasher against wall, trap 3 & 4 line..wav	Smooth condensate flow determined with ultrasound. low db value. Thermal image is blurred. condensate oulet was around 100 C° **Steam trap working okay.**

71 + 72 **Condensate retour line from dishwasher deck two, smaller one.** Traps were blocked, condensateline was measured. (2x thermostatic)	No picture taken **DB value**	 **Inlet temp** - **Outlet temp** 70 C°	Condensate retour line dishwasher deck 2 small one.wav	With ultrasound smooth condensate flow detected, no steam was in condensate line. Thermal shows condensate outlet around 70 C°. **Steam trap working okay.**
73 **Deck three dishwasher, has one trap. Trap blocked, condensate line measured.** (thermostatic)	 **DB value** 40	 **Inlet temp** - **Outlet temp** 110 C°	Deck three dishwasher, condensate retour.wav	With ultrasound a condensate flow with steam is determined. Condensate line measured cause trap was not accesible. Thermal image shows condensate outlet around 110 C°. **Steam trap leaking.**
74 + 75 **Lido main dish washer. Coil one.** (2x thermostatic)	 **DB value** 32	 **Inlet temp** 120 C° **Outlet temp** 100 C°	Lido main dishwasher coil one (2x static).wav	Traps opening and closing. Condensate flow detected, sometimes with a small steam particles inside. Acceptable. Thermal image shows condensate outlet around 100 C°. **Steam traps working okay.**

76 **Lido main dish washer. Coil two.** (thermostatic)			Lido main dish washer, coil two..wav	Ultrasound detects a high db value, this is false. A small steam leak was found next to the steam trap that caused the high db value. thermal image shows outlet temperature oke. **Steam trap working okay.**
	DB value 30	**Inlet temp** 70 C° **Outlet temp** 70 C°		

Appendix seven: Steam losses due to leaking traps

Measurement nr	location	Trap type	Pipe diameter	Orifice size (mm)	Pressure (bar)	inlet temp (C˚)	outlet temp (C˚)	DB value	Leaking	Spirax Sarco steam loss estimate (kg/h)	UE systems steam loss estimate (kg/h)
1	Condensate return HFO 3C, coil one	Thermodynamic	DN15	3	9	150	110	40	YES	12	30
2	Condensate return HFO 3C, coil two	Thermodynamic	DN15	3	9	-	-	-	OFF	-	-
3	Aft fuel module	Ball float	DN25	7,5	9	150	125	55	YES	82,5	165
4	Lubrication oil purifier one	Ball float	DN20	5	9	128	100	24	NO	-	-
5	Lubrication oil purifier two	Ball float	DN20	5	9	140	100	34	NO	-	-
6	Lubrication oil purifier three	Ball float	DN20	5	9	150	100	29	NO	-	-
7	Lubrication oil purifier four	Ball float	DN20	5	9	125	100	27	NO	-	-
8	Lubrication oil purifier five	Ball float	DN20	5	9	140	100	34	NO	-	-
9	Sludge tank 19P coil	Thermodynamic	DN15	3	9	150	120	31	YES	12	30
10	Fuel oil purifier one	Ball float	DN20	5	9	150	100	28	NO	-	-
11	Fuel oil purifier two	Ball float	DN20	5	9	148	105	44	YES	20	70
12	Fuel tank 3SB, coil one	Thermodynamic	DN15	3	9	88	88	20	Unsure	12 (if leaking)	30 (if leaking)
13	Fuel tank 3Sb, coil two	Thermodynamic	DN15	3	9	102	102	20	YES	12	30
14	Laundry, forenta clothes press one	Thermostatic	DN15	3	6	140	100	46	YES	8	20
15	Laundry, forenta clothes press two, trap one	Thermostatic	DN15	3	6	126	100	26	NO	-	-
16	Laundry, forenta clothes press two, trap two	Thermostatic	DN15	3	6	116	100	41	YES	8	20
17	Laundry, forenta pants press, trap one	Thermostatic	DN15	3	6	140	125	49	YES	8	20
18	Laundry, forenta pants press, steam to condensate line	Thermostatic	DN15	3	6	150	125	18	NO	-	-
19	Laundry, forenta steamer, trap one	Thermostatic	DN15	3	6	113	105	7	NO	-	-
20	Laundry, forenta steamer, trap two	Thermostatic	DN15	3	6	150	105	19	YES	8	20
21	Forenta pants press two, trap one	Thermostatic	DN15	3	6	124	120	38	YES	8	20
22	Forenta pants press two, trap two	Thermostatic	DN15	3	6	150	140	72	YES	8	20
23	Aft pre heat module	Ball float	DN25	7,5	9	109	100	20	NO	-	-
24	Hotwell coil	Thermodynamic	DN15	3	9	-	100	35	NO	-	-
25	Crew & passengers hot water locomotive trap, middle one	Locomotive	DN40	10	9	130	105	22	NO	-	-
26	Crew & passengers hot water locomotive trap, aft one	Locomotive	DN40	10	9	120	111	51	YES	147	320
27	Laundry, linen machine	Bimetallic	DN25	7,5	6	150	105	21	NO	-	-
28	Laundry dryer	Inverted bucket	DN15	3	6	127	100	27	NO	-	-
29	Forenta shirt steamer, trap one	Thermostatic	DN15	3	6	150	115	46	NO	-	-
30	Forenta shirt steamer, trap two	Thermostatic	DN15	3	6	150	125	52	YES	8	20
31	Forenta shirt steamer, trap three	Thermostatic	DN15	3	6	150	125	42	YES	8	20
32	Starboard evaporator	Ball float	DN50	12,5	9	90	80	27	NO	-	-
33	Steam to condensate line, starboard evap	Thermodynamic	DN15	3	9	170	150	41	YES	12	30
34	HFO settling tank 4P, coil one	Thermodynamic	DN15	3	9	127	120	52	YES	12	30
35	HFO settling tank 4P, coil two	Thermodynamic	DN15	3	9	-	-	-	OFF	-	-
36	Aft swimming pool heater	Ball float	DN50	12,5	9	80	120	24	Unsure	228 (if leaking)	475 (if leaking)
37	Lido midship pool heater	Ball float	DN50	12,5	9	30	110	7	Unsure	228 (if leaking)	475 (if leaking)
38	Hydro pool heater	Ball float	DN25	7,5	9	70	70	10	NO	-	-
39	Laundry, veit steamer	Inverted bucket	DN20	5	6	140	105	33	YES	24	50
40	Laundry, veit steamer two	Inverted bucket	DN20	5	6	140	115	37	YES	24	50
41	Laundry, trap next to steam inlet veit steamer	Thermostatic	DN15	3	6	150	-	18	NO	-	-
42	Forenta clothes stamp two, top trap.	Thermostatic	DN15	3	6	120	110	19	YES	8	20

43	Forenta clothes stamp two, bottem trap	Thermostatic	DN15	3	6	130	115	44	YES	8	20
44	Lido warm buffet, english breakfast, top trap	Thermostatic	DN15	3	3	126	120	43	YES	4	12
45	Lido warm buffet, english breakfast, bottem trap	Thermostatic	DN15	3	3	-	-	24	YES	4	12
46	Galley deck three, unit five	Thermostatic	DN15	3	3	120	110	49	YES	4	12
47	Galley deck three, unit six	Thermostatic	DN15	3	3	140	110	40	YES	4	12
48	Galley deck three, unit four	Thermostatic	Dn15	3	3	100	95	25	NO	-	-
49	Galley deck three, unit three	Thermostatic	DN15	3	3	90	80	35	NO	-	-
50	Galley deck three, unit two	Thermostatic	DN15	3	3	130	110	39	YES	4	12
51	Galley deck three, unit one	Thermostatic	DN15	3	3	120	110	52	YES	4	12
52	Galley deck two, unit one	Thermostatic	DN15	3	3	120	110	51	YES	4	12
53	Galley deck two, unit two	Thermostatic	DN15	3	3	105	100	34	YES	4	12
54	Galley deck two, unit three	Thermostatic	DN15	3	3	115	100	35	NO	-	-
55	Galley deck two, unit six	Thermostatic	DN15	3	3	120	105	33	YES	4	12
56	Galley deck two, unit eight	Thermostatic	DN15	3	3	130	100	26	NO	-	-
57	Galley deck two, unit seven	Thermostatic	DN15	3	3	129	115	54	YES	4	12
58	Galley deck two, unit five	Thermostatic	DN15	3	3	130	110	59	YES	4	12
59	Galley deck two, unit four	Thermostatic	DN15	3	3	120	110	51	YES	4	12
60	PO buffet warmer, lower trap	Thermostatic	DN15	3	3	120	115	49	YES	4	12
61	PO buffet warmer, top trap	Thermostatic	DN15	3	3	110	110	51	YES	4	12
62 &63	Crew galley buffet warmers	Thermostatic	DN15	3	3	140	110	40	YES	4	12
64	Crew galley dish washer, trap one	Thermostatic	DN20	5	3	80	120	35	NO	-	-
65	Crew galley dish washer, trap two	Thermostatic	DN20	5	3	140	120	48	YES	12	30
66	Crew galley dish washer, trap three	Thermostatic	DN20	5	3	145	120	53	YES	12	30
67	Galley dish washer deck two, against wall, trap one	Thermostatic	DN20	5	3	110	110	50	YES	12	30
68	Galley dish washer deck two, against wall, trap two	Thermostatic	DN20	5	3	-	-	35	YES	12	30
69	Galley dish washer deck two, against wall, trap three	Thermostatic	DN20	5	3	140	100	29	NO	-	-
70	Galley dish washer deck two, against wall, trap four	Thermostatic	DN20	5	3	140	100	29	NO	-	-
71 + 72	Condensate retour line from dishwasher deck two, smaller one	Thermostatic	DN20	5	3	-	70		NO	-	-
73	Deck three dishwasher, has one trap. Trap blocked, condensate line measu	Thermostatic	DN20	5	3	-	110	40	YES	12	30
74 + 75	Lido main dish washer, coil one	Thermostatic	DN20	5	3	120	100	32	NO	-	-
76	Lido main dish washer, coil two	Thermostatic	DN20	5	3	70	70	30	NO	-	-
									Total	557,5	1305

Appendix eight: Expenses caused by leaking steam traps

	According to Spirax Sarco				According to UE Systems			
Leaking traps	**Kg/hour**	**after port hours (kg)**	**Daily costs on MDO (euro)**	**Daily costs on HFO (euro)**	**Kg/hour**	**after port hours (kg)**	**Daily costs on MDO (euro)**	**Daily costs on HFO (euro)**
Condensate return HFO 3C, coil one	12	120	1,69	1,11	30	300	4,23	2,77
Aft fuel module	82,5	825	11,64	7,63	165	1650	23,28	15,25
Sludge tank 19P coil	12	120	1,69	1,11	30	300	4,23	2,77
Fuel oil purifier two	20	200	2,82	1,85	70	700	9,87	6,47
Fuel tank 3Sb, coil two	12	120	1,69	1,11	30	300	4,23	2,77
Laundry, forenta clothes press one	8	80	1,13	0,74	20	200	2,82	1,85
Laundry, forenta clothes press two, trap two	8	80	1,13	0,74	20	200	2,82	1,85
Laundry, forenta pants press, trap one	8	80	1,13	0,74	20	200	2,82	1,85
Laundry, forenta steamer, trap two	8	80	1,13	0,74	20	200	2,82	1,85
Forenta pants press two, trap one	8	80	1,13	0,74	20	200	2,82	1,85
Forenta pants press two, trap two	8	80	1,13	0,74	20	200	2,82	1,85
Crew & passengers hot water locomotive trap, aft one	147	1470	20,74	13,59	320	3200	45,14	29,58
Forenta shirt steamer, trap two	8	80	1,13	0,74	20	200	2,82	1,85
Forenta shirt steamer, trap three	8	80	1,13	0,74	20	200	2,82	1,85
Steam to condensate line, starboard evap	12	120	1,69	1,11	30	300	4,23	2,77
HFO settling tank 4P, coil one	12	120	1,69	1,11	30	300	4,23	2,77
Laundry, veit steamer	24	240	3,39	2,22	50	500	7,05	4,62
Laundry, veit steamer two	24	240	3,39	2,22	50	500	7,05	4,62
Forenta clothes stamp two, top trap.	8	80	1,13	0,74	20	200	2,82	1,85
Forenta clothes stamp two, bottem trap	8	80	1,13	0,74	20	200	2,82	1,85
Lido warm buffet, english breakfast, top trap	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck three, unit six	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck three, unit two	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck three, unit one	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck two, unit one	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck two, unit two	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck two, unit six	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck two, unit seven	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck two, unit five	4	40	0,56	0,37	12	120	1,69	1,11
Galley deck two, unit four	4	40	0,56	0,37	12	120	1,69	1,11
PO buffet warmer, lower trap	4	40	0,56	0,37	12	120	1,69	1,11
PO buffet warmer, top trap	4	40	0,56	0,37	12	120	1,69	1,11
Crew galley buffet warmers	4	40	0,56	0,37	12	120	1,69	1,11
Crew galley dish washer, trap two	12	120	1,69	1,11	30	300	4,23	2,77
Crew galley dish washer, trap three	12	120	1,69	1,11	30	300	4,23	2,77
Galley dish washer deck two, against wall, trap one	12	120	1,69	1,11	30	300	4,23	2,77
Galley dish washer deck two, against wall, trap two	12	120	1,69	1,11	30	300	4,23	2,77
Deck three dishwasher, condensate line measured.	12	120	1,69	1,11	30	300	4,23	2,77
Total	**557,50**	**5575,00**	**78,65**	**51,53**	**1335,00**	**13350,00**	**188,33**	**123,39**