NOR Factory Acceptance Test Instructions

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BACHELOR'S THESIS

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Abstract

This thesis was commissioned by Wärtsilä Catalyst Systems in Vaasa. The purpose of the thesis was to create instructions for the factory acceptance test of the NOR, which is Wärtsilä's own NO_X reducer. The system works according to the SCR-process which is a chemical process that reduces the amount of nitrogen oxides in exhaust gases by adding a reagent and a chemical catalyst that is used to speed up the chemical reaction. The factory acceptance test is a set of tests carried out at the factory, before the products are sent to the customers to ensure that everything is working as intended.

The key method used to achieve the goal was to take part in the testing. First to observe and learn what was being tested and when a high enough understanding of the process had been achieved some testing would be carried out individually to be able to get as much experience of the testing process as possible. The result is a test instruction that is easy to understand and navigate but at the same time very informative if needed. It suits both more experienced users and novices alike as there is both simpler and more detailed instructions included.

Language: English Key words: SCR, NO_X, Instructions

EXAMENSARBETE

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Abstrakt

Detta lärdomsprov gjordes på uppdrag av Wärtsilä Catalyst Systems i Vasa. Målet med arbetet var att skapa en instruktion för kvalitetsgranskningen av NOR systemet som är Wärtsiläs egen NO_X reducerare. Systemet fungerar enligt SCR-processen vilket är en kemisk process som minskar på antalet kväveoxider i avgaser med hjälp av ett reducerande medel och en kemisk katalysator som påskyndar den kemiska reaktionen. Kvalitetsgranskningen består av ett flertal olika tester som utförs före den färdiga produkten skickas iväg till kunden. Detta för att försäkra sig om att den håller tillräckligt hög kvalitet och allt fungerar som det skall.

Nyckelmetoden för att uppnå målet var att medverka i dessa tester. Först i inlärningssyfte och senare när de nödvändiga kunskaperna var inlärda utfördes tester även individuellt för att få så mycket erfarenhet som möjligt av proceduren. Detta resulterade i en testinstruktion som är både lätt att förstå och använda, men samtidigt väldigt detaljerad och informativ om det behövs. Den lämpar sig både för mer erfarna användare och nybörjare tillika eftersom den innehåller både simpla och mera djupgående instruktioner.

Språk: engelska Nyckelord: SCR, NOR, Instruktion

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Tiivistelmä

Tämä opinnäytetyö tehtiin Wärtsilä Catalyst Systemsille Vaasassa. Työn tavoite oli luoda ohje NOR-järjestelmän tehdastestaukselle, joka on Wärtsilän oma NO_X vähennyslaite. Järjestelmä toimii SCR-prosessin mukaisesti, joka on kemikaalinen prosessi, joka vähentää NOx:in määrää pakokaasuissa, lisäämällä pelkistysainetta ja kemiallista katalyyttiä. Laadunvalvonta on sarja erilaisia testejä, jotka suoritetaan ennen lopputuotteen lähettämistä asiakkaalle, varmistaakseen että kaikki toimii niin kuin pitäisi.

Tärkein menetelmä tavoitteen saavuttamiseksi on ollut osallistuminen näihin testeihin. Ensin tarkkailemalla ja oppimalla ja myöhemmin, kun saavutettiin riittävä määrä osaamista tekemällä sen itse. Tämän tarkoituksena oli saada mahdollisimman paljon kokemusta menettelystä. Tämän tuloksena on testiohje, jota on helppo käyttää ja ymmärtää mutta samalla yksityiskohtainen ja tarvittaessa informatiivinen. Se soveltuu sekä kokeneemmille käyttäjille että aloittelijoille, koska se sisältää sekä yksinkertaisia että syvällisiä ohjeita.

Kieli: englanti Avainsanat: SCR, NO_X, Ohje

Innehållsförteckning

TERMS AND ABBRIVATIONS

SCR	Selective Catalytic Reduction
NOR	NO_X Reducer
NORC	The third generation of Wärtsilä's NO_X reducer
NO_X	Nitrogen Oxide
IMO	International Maritime Organisation
CSO	Combined SCR and OXI
OXI	Oxidation Catalyst
PDU	Power Distribution unit

1 Introduction

This thesis work covers the process of making test instructions for the factory acceptance test of the NORC which is the latest generation of Wärtsilä's NO_X reducers. The assignment was provided on the behalf of Wärtsilä Catalyst Systems and the supervisor from Wärtsilä is Tero Ketola who is the general manager of the delivery team.

The purpose of the factory acceptance test is to make sure that everything is working as intended when the products are shipped to site for commissioning. This is ensured by conducting a number of tests.

The first part of this thesis is a theoretical part that explains selective catalytic reduction and other necessary theoretical knowledge. After there is a brief introduction to the auxiliary units in the NORC scope. Afterwards follows a description of the work itself and how it was performed. Lastly, there is a summary and discussion of the results of the work.

1.1 Employer - Wärtsilä

Wärtsilä was first founded as a sawmill in 1834 and has since gone on to become a global leader in smart technologies in both the marine and energy sector. During this time span the company has taken many different forms from being a steel mill to an engineering workshop. The most noticeable change was when they entered the diesel engine market in 1938, leading to the first engine seeing the light of day in November 1942. They also experienced a number of name changes and mergers through the years but on the 22th of September 2000 the name Wärtsilä is recorded in the Finnish Trade Register. [1].

The organization earlier consisted of three main branches; Marine Solutions, Energy Solutions and Services. Marine Solutions provides innovative products and integrated solutions for all kinds of marine vessels. Energy Solutions provides engine based power plants, solar power plants, energy storage and integration solutions. Services provides lifecycle services to both the marine and energy side. These services range from basic support that ensures the maximum lifetime of the products to spare parts. In 2019 there was an organizational change that saw Services removed and their tasks integrated in the two new branches that are Marine Business and Energy Business. As of 2019 Wärtsilä has about 19 000 employees located in more than 80 countries around the globe and has operations in over 200 locations worldwide. [1] [2]

1.1.1 Marine Business

As of 2019 Marine Business is one of the two main branches in Wärtsilä. The scope that it provides is very large and includes almost everything needed for a marine vessel to function. These systems are used on large variety of vessels including everything from large cruise ships to small fishing vessels. [2]

1.1.2 Exhaust Treatment

Exhaust treatment includes two different departments, one being Catalyst Systems which is described more detailed in the next subchapter. The other department is Scrubber which as the name explains makes scrubbers. A scrubber is an exhaust gas cleaning system that is used to remove the SO_X (Sulphur Oxide) in the exhaust. It uses seawater that reacts with the sulphur oxides to form sulphuric acid. No further chemicals are needed as the alkalinity of the seawater are used to neutralize the acid. While Catalyst systems are located in Vasa, Finland, the Scrubber team is located in Moss, Norway.

1.1.3 Catalyst Systems

Catalyst systems is part of the environmental solutions organization which in turn is part of the Marine Business organization. Catalyst systems is responsible for Wärtsilä’s own SCR system meaning they handle everything from design, development, sales and managing the products until services takes over the responsibilities. The products can both be sold as new installations and retrofits on existing marine vessels and power plants. As there are some variations between marine and power plant applications Catalyst Systems offers two different SCR products. The one used in marine vessels is called the NOR (NOx-reducer) and the one used in powerplants is called CSO (Combined SCR and OXI).

Overall the NOR and the CSO are the same product, however there are two things that sets them apart from each other. The first one being the automation control system, which in the NOR is Wärtsilä’s own platform UNIC while PLC is used in the CSO. The second difference is in the reactor, where the CSO has an extra OXI (oxidation catalyst) layer.

1.2 Purpose

The purpose of this thesis is to make an instruction for the testing of the auxiliary units of the NOR. The requirements are that it should be informative and easy to understand, use and update. The instructions should go through step by step what should be tested and give clear instructions on how to do this. The instruction is primarily focused on the Marine version (NOR), because the Power plant version (CSO) is very project specific and therefore it was concluded that a standardized instruction would not work very well for it.

There was a strong need for an instruction of this kind because it did not exist any earlier and that proved to be a problem. The only thing that existed earlier was a kind of check list for some general things, but it did not give a clear picture of what to do. This could lead to the know-how of the testing only existing in the minds of the engineers that carries out the testing. This could lead to complications if someone possessing this know-how were to change jobs or something similar.

The instructions are also made to help speed up the learning curve for new employees as well as giving a better understanding for how the system works and to give a clearer picture to everyone of what is really being tested as most of the department has no clue about that.

1.3 Delimitations

This thesis focuses mainly on the NOR which is used for marine projects. It will not include the CSO because the variations from project to project are quite large. Based on that it was concluded that it would not be possible to make a standardized instruction that would also be detailed enough for it to be of any use even though some of it will be usable. The work will also only include the auxiliary units that are standard for the NOR scope because it was concluded that it would become too large of a scope to include everything.

2 Theory

Selective Catalytic Reduction is a chemical process that reduces the nitrogen oxides in exhaust gases by inducting a reagent that will mix with the exhaust gases. Nitrogen oxides are gases that are harm-full both to the environment and the human health. This has lead to the implementation of NO_X emission limitations.

2.1 Nitrogen Oxide (NO_X)

Nitrogen oxides is a name used for a group of gases that are composed of nitrogen and oxygen. The ones that is most known and most hazardous are nitric oxide (NO) and nitrogen dioxde (NO_2). They are both formed in high-temperature combustion processes in the atmosphere. Nitric oxide is formed when nitrogen combines with oxygen according to the reaction formula (1).

$$N_2 + O_2 \rightarrow 2NO \quad (1)$$

Nitrogen dioxide is formed when the nitric oxide reacts with the surrounding oxygen according to reaction formula (2).

$$2NO + O_2 \rightarrow 2NO_2 \quad (2)$$

These are both produced by natural and human activities. The yearly production is estimated to be between 20 and 90 million tons from natural sources and 24 million tons that is produced by humans. The natural sources include lightning strikes, biological decay and volcanoes. The human activities that cause this are mainly exhaust gases from cars and emissions from power plants. Most of the NO_X produced in these processes are nitric oxide but it quickly reacts with oxygen when released into the atmosphere to form nitrogen dioxide. In Figure 1 it is shown more in depth what the human factors that produce NO_X are. [3] [4]

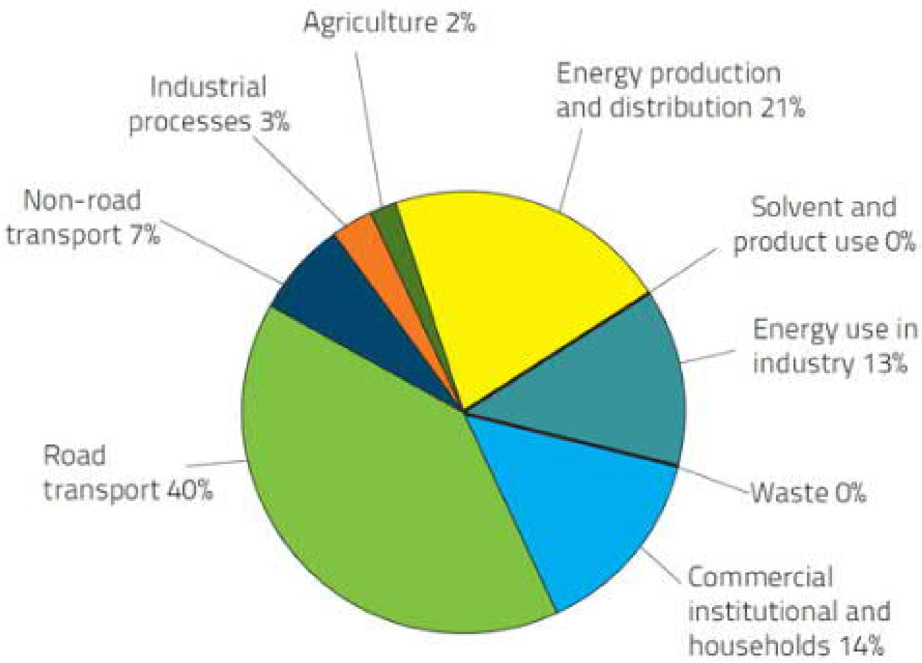

Figure 1. NO_X emissions in the EU 2011. [16]

2.1.1 Environmental effects

Of the two nitrogen oxides, nitrogen dioxide is the one that is considered as dangerous. In high concentrations it can cause the death of plants and roots but also cause severe damage to the leaves of many crops.

Furthermore, nitrogen dioxide is one of the reasons behind smog which is a severe air pollution that is common in highly industrialized or populated places that have high emissions. It is categorized into two different kinds, summer smog and winter smog. Summer smog which is also referred to as photochemical smog is primarily caused when nitrogen dioxide and hydrocarbons react with sunlight and produces ozone. Ozone is generally considered as a good thing as it protects us from ultraviolet radiation, but when it is this low in the atmosphere is considered as a pollutant. The other kind is winter smog which is mainly caused by the increase in for example coal combustion during the winter months when the need for heat production is higher.

Another environmental hazard that NO_X are a cause to is acid rain. Acid rain is caused by nitrogen oxides and sulfiric dioxide that when emitted into the atmosphere reacts with different chemicals to form nitric and sulfiric acids. These later fall to the ground with the help of rain and snow. Acid rain has a negative effect on many different aspects of the environment, but it mainly harms the soil and water by lowering the pH value. This leads to difficulties for plants and trees to grow and in lakes it can lead to fish dying as they can’t survive if the pH gets too low. [5] [6]

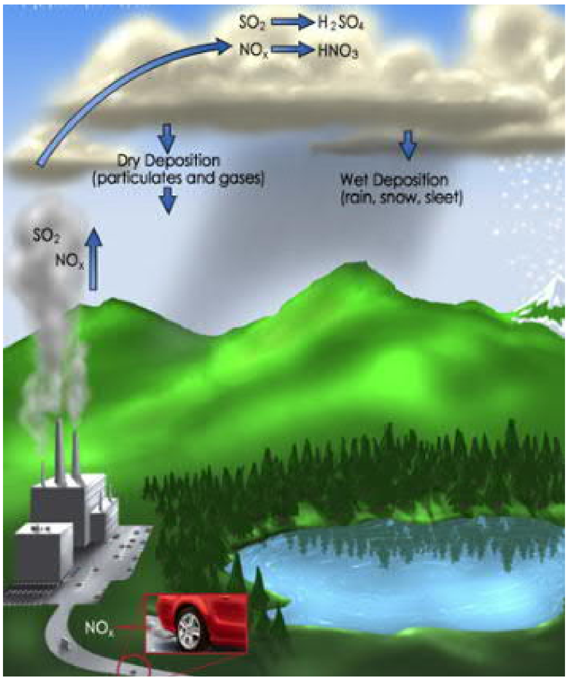

Figure 2. Formation off Acid rain. [19]

2.1.2 Health effects

As nitrogen oxides are a gaseous substance, the most common way to be exposed to it is via inhalation when breathing in emissions from vehicles and powerplants. Even though inhalation is the most common way exposure may also occur by skin contact if the concentration is high enough.

If exposed to them they can have a negative health effects with both mild and more severe consequences. The short-term symptoms of inhaling nitrogen oxide are irritation of the airways, headaches, dizziness, breathing difficulties and coughing. The long-term effects can be asthma or other infections in the respiratory systems. The effects when exposed to high concentration to the skin or eyes is irritation and burns. Furthermore, if very high levels of nitrogen oxides is inhaled it may lead to more severe effects like swelling of the throat, fertility problems mainly for females and even in worst case scenarios death. [6]

2.2 Reducing agent

To be able to reduce the NO_X emissions in the exhaust gas, a reducing agent has to be added which will work as the reductant in the chemical reaction. There are generally two different reductants that is being used in SCR systems, these are ammonia (NH_3) and urea $CO(NH_2)_2$. The ammonia used can either be in the form of pure anhydrous ammonia, which does not contain any water or aqueous ammonia which is a water based ammonia solution. Aqueous ammonia is somewhat toxic but can be handled relatively safely. Pure anhydrous ammonia on the other hand is of a toxic and hazardous nature because of its high vapor pressure.

The usage of ammonia as a reducing agent is not that common any more due to its hazardous and toxic nature. Instead the most common choice today is urea as it holds many advantages compared to ammonia. It is non-toxic and easy and safe to handle. It also has a very high availability all over the world as it is commonly used in the food processing industry and as fertilizers as well. Under normal circumstances urea is a solid substance but when used as a reductant in SCR systems it has to be in liquid form. This is a aqueous urea solution which consists of approximately 32.5 % urea and 67.5 % deionized water. This solution can also be called diesel exhaust fluid (DEF) or perhaps the most common name ad-blue which is most known for being used in diesel trucks.

No matter which reducing agent is used, the end products off the reaction will be the same. The urea will begin to thermally decompose and undergo hydrolysis as soon as it makes contact with the exhaust gas. If the urea at this point is heated up to temperatures higher than 160 ºC it will primarily turn into ammonia and carbon dioxide according to reaction formula (3). [3]

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2 \qquad (3)$$

2.3 Selective Catalytic Reduction

SCR stands for Selective Catalytic Reduction which is a term used to describe the chemical process that take place when harmful nitrogen oxides in exhaust gas are reduced to nitrogen (N_2) and water (H_2O), by letting the exhaust gas flow through a special catalytic element. This is achieved by adding a reducing agent to the exhaust stream before letting it pass through the catalytic chamber where most of the chemical reactions take place. If combined with a SCR system the process can be used on a wide variety of fuels that include natural gas, industrial gas, light, heavy and crude fuel oil. The primary usage area for SCR systems are applications that use heavy duty engines for example power plants, marine and truck engines.

The main advantage of using a SCR system compared to other exhaust treatment technologies is that they have the highest NO_X reduction ratio which means that with a SCR system the NO_X emissions can be reduced by as much as up to 90 %. Despite this the SCR system also has some disadvantages compared to the competition. It requires pretty much space to house the urea tank and the advanced to control system. The operational costs are also relatively high as it requires a constant supply of urea to function. There is also a risk for ammonia slip that could lead to ammonia emissions if the dosing is excessive or the mixing process is not completed.

The main component where most of the chemical reactions in the SCR process takes place is the reactor, which is a steel casing with an inlet and an outlet, that the exhaust gas coming from the engine flows through. The main functions of the reactor is to house the catalytic elements and to provide a suitable environments for the chemical reactions to take place. Meaning that the temperature must be held at the right level so that the chemical reactions are optimal. The catalytic elements are often the shape of a rectangular cuboid with a varying amount of square cells, which gives it a look that resembles that of the inside of a beehive. As cells in the catalyst goes the length of it, the exhaust gas is allowed to flow right through it which allows for the chemical reactions of the NO_X reduction to take place on the inner walls of the catalyst cells. The number of elements and layers of elements installed in the reactor can vary. Figure 3 shows what a catalyst element can look like.

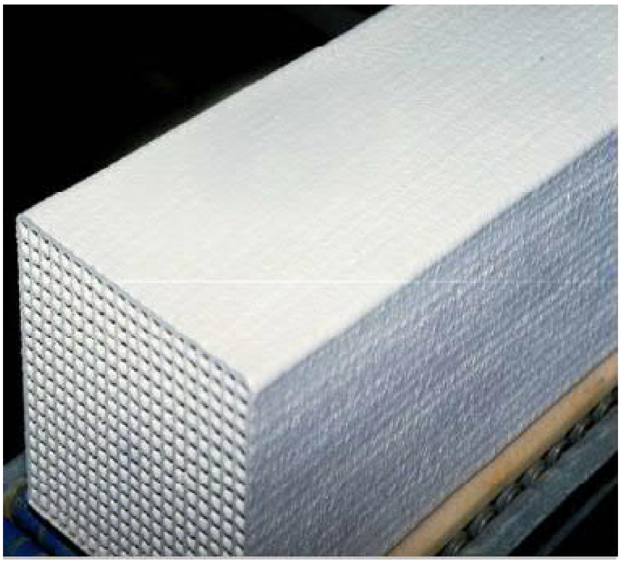

Figure 3. SCR Catalyst.

As earlier stated, most of the chemical reactions that are part of the SCR process takes place in the SCR reactor and to be more exact on the inner walls of the catalytic elements. After the exhaust gas have been mixed with the reducing agent and reach the elements in the reactor, the selective catalytic reduction will start and the reducing agent will start to be absorbed by the catalytic elements. The reaction formulas for the selective catalytic reduction (4), (5) and (6).

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O \tag{4}$$

$$2NH_3 + NO + NO_2 \rightarrow 2N_2 + 3H_2O \tag{5}$$

$$8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O \tag{6}$$

These three formulas show the main reactions that take place during the selective catalytic reduction. As seen in the formulas, the ammonia reacts with the nitrogen oxides and nitrogen dioxides. As the products of the reaction only are various amounts of nitrogen and water, they are much less harmful compared to the reactants. The first formula is generally referred to as the standard reaction for selective catalytic reduction. The second one is the fastest of the three as it reduces both nitrogen oxide and nitrogen dioxide at the same time and is therefore called fast-SCR. This is the optimal way of reducing NO_X, but the problem is that it requires an equal amount of nitrogen oxide and nitrogen dioxide. To solve this problem a diesel oxidation catalyst (DOC) can be used. Its function is to oxidise the nitrogen oxide to form more nitrogen dioxide in the exhaust gas so that the second reaction will be more prone to happen.

The amount of reducing agent injected into the exhaust stream has to be controlled because if it is to low the NO_x reduction will also be too low. On the other, hand if the injected amount of reducing agent is to high there will be a risk for some ammonia slip, which means some ammonia will be emitted. This can other than excessive injection also be caused by bad mixing or ammonia being stored on the catalyst elements. It is much more unlikely that the ammonia will react with oxygen instead of NO_X, but as shown in the reactions (7),(8) and (9) it is a possibility.

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 3H_2O \tag{7}$$

$$4NH_3 + 5O_2 \rightarrow 4NO + H_2O \tag{8}$$

$$4NH_3 + 4O_2 \rightarrow 2N_2O + 6H_2O \tag{9}$$

This is an issue because the ammonia may form different toxic products such as various ammonium sulphates. This is especially problematic in diesel applications that use a SCR system as the suplhur (S) levels are higher which in turn leads to higher suplhur oxide (SO_X) levels in the exhaust stream. This will lead to problems as the sulphates start to load up on the walls in the catalyst which will lead to negative impacts on the chemical functionality and eventually clogging of the reactor. [3]

2.4 International Maritime Organization (IMO)

The International Maritime Organization is a specialized organization that is a part of the United Nations. It was formed in 1948 on an international UN conference in Geneva, but it took until 1958 before the IMO Convention entered into force. Originally it was known as Inter-Governmental Maritime Consultative Organization (IMCO) but in 1982 it was changed to the name it uses today. The objective of the organization is to create universal rules for the shipping industry that is supposed to ensure that the industry stays fair and effective. Shipping is responsible for more than 80 percent of all the global trade transports thanks to its low cost and high efficiency and dependability. The rules and guidelines concern almost every thinkable aspect of the shipping industry ranging from ship building to the emission regulations relevant in this thesis work. [7]

The limits for NOx emissions applies to all marine diesel engines installed on a ship with a power output greater than 130 kW. The NOx regulations are divided into three different levels, these are: Tier I, Tier II and Tier III.

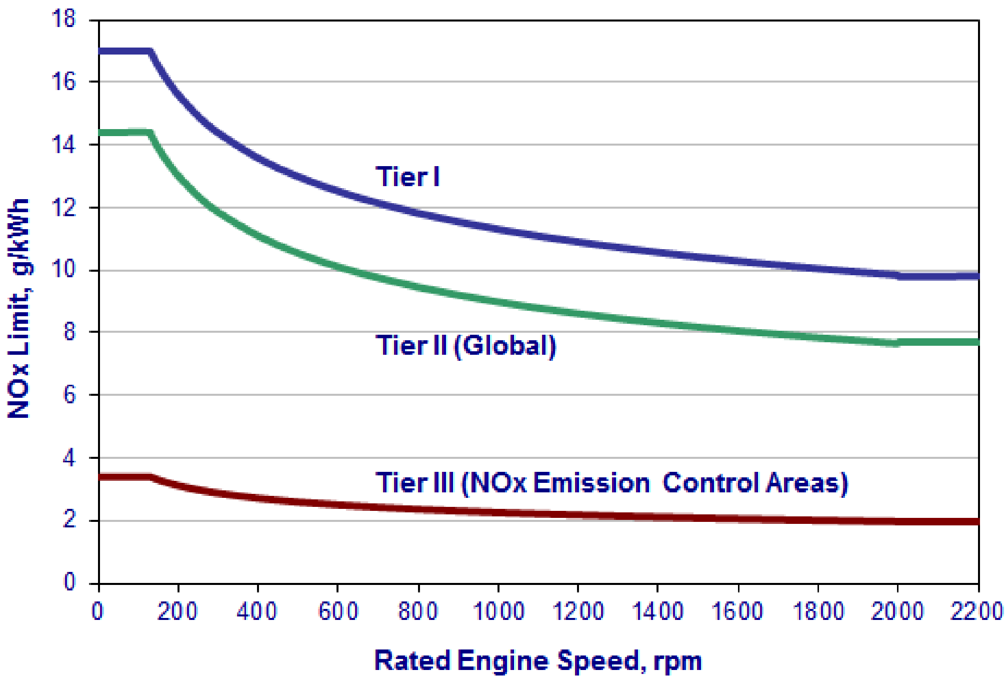

Figure 4.The different Exhaust limitation Tiers. [8]

The Tier I and II are limitations need to be followed globally while Tier III only is active in certain emission control areas. Today there are four existing emission control areas. These are the US Carribean ECA, North American ECA, North sea and the Baltic sea.

Nowadays the Tier II limitations are expected to be met by the engine itself through optimization of the combustion process, while the Tier III limitations requires a dedicated control system to reduce the NOx emissions. More detailed information on this can be found in the NOx technical code which specifies all the requirements for survey testing and Certification of marine diesel engines. [9]

2.5 Catalyst

In chemistry a catalyst is an element or substance that accelerates the reaction rate of a chemical process without itself directly being involved in the reaction between the other elements. This means that it normally should not be altered or changed by the reaction at all. For a chemical reaction to take place between two elements they first need to have enough activation energy. This means that they require a certain amount of potential energy for the chemical reaction to take place. A catalyst is used to lower the activation energy needed for the reaction to happen and therefore accelerating the process. This leads to the catalyst elements being one of the most important components used in the SCR system when it comes to chemical functionalities. [10]

3 NORC Scope

Wärtsilä's own marine SCR product called the Wärtsilä NOx reducer (NOR) was first introduced in 2010. The first generation of the product was called NORA followed by NORB and the current generation is NORC on which this thesis is focused on.

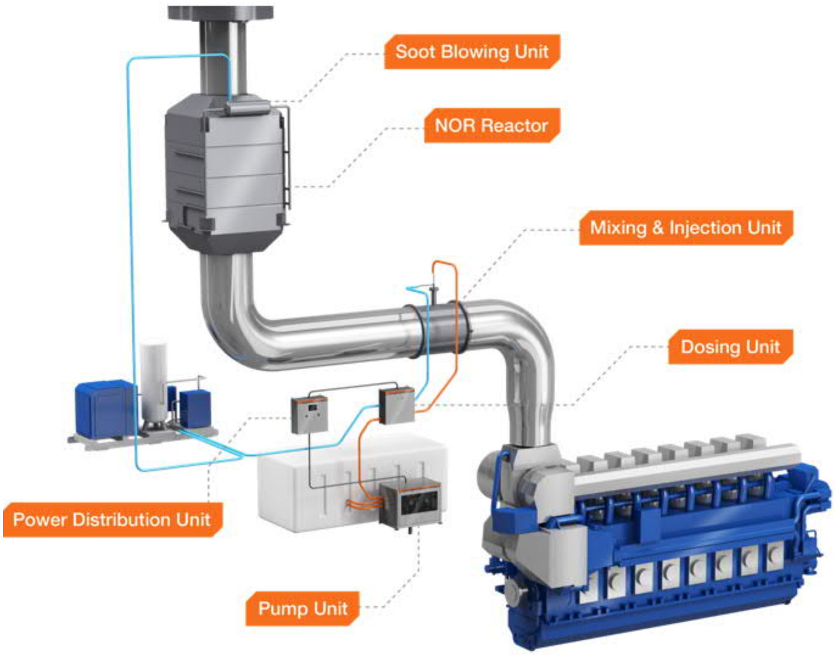

Figure 5. The standard NORC scope [11]

As seen in Figure 5, the system requires a lot of different parts for it to function. Some units are mandatory for the system to work and others are extra things that can be added to improve performance an add some extra features. The units that are mandatory for the process are listed below.

- Power Distribution unit.
- Pump unit.
- Dosing unit.
- Mixing & Injection unit.
- NOR reactor.

The power distribution unit as the name suggests is used to provide electricity to the rest of the system. The pump unit's function is to pump the urea from the tank on to the dosing unit. In the dosing unit the amount of urea that is to be injected in to the exhaust gas is determined based on the amount of NO_X in the exhaust. The function of the Mixing & Injection unit is to first inject the urea in to the exhaust stream so that it can mix with it and undergo hydrolysis into ammonia. When the exhaust gas reaches the NOR reactor, the SCR-process starts to take place on the inside walls of the catalytic elements. The reactor comes in different sizes depending on the amount of layers with catalytic elements that is needed. Mounted on the reactor is also a soot blowing unit, which has the purpose of blowing out any leftover soot stuck in the catalytic elements.

The additional units that are not required for the system to function, but improves its functionality are the following:

- NO_X sensor or Humidity transmitter.
- By-Pass unit.

The by-pass unit is used to redirect the exhaust flow so that it does not flow through the reactor when the system is not in use. The function of the NO_X sensor and the humidity transmitter is to provide the dosing unit with more detailed information of the exhaust gases so the dosing can be changed accordingly. [11] [12]

3.1 Power Distribution Unit

The function of the power distribution unit is to provide voltage to the systems auxiliary units. There are two different options available, a 380-480 VAC supply or a 690 VAC supply. In the later there is a 690/400 VAC transformer used to lower the voltage. As some auxiliary units require a 24 VDC supply it also has some AC/DC converters to achieve this. From the Beijer panel on the cabinet door, different information and values connected to the SCR process can be found. A single power distribution unit is able support up to eight engine/reactor installations. [12]

3.2 Dosing Unit

The dosing unit is what decides how much of the reagent should be injected into the exhaust stream. It consists of an airline and a reagent line. The components located on the air line consists of air filters and a regulator which can be used to regulate the air pressure, and also an air flow switch that redirects the air if the pressure gets too high. The reagent line mainly consists of a flow meter and a proportional valve that is used to keep an eye on the reagent flow and dosing amount respectively.

The dosing unit can be ordered in three different sizes 1-3. The only notable changes are the diameters of the air and reagent lines which in turn leads to the dosing capacity being higher. It runs on a 24 VDC supply, coming from the power distribution unit and is able to communicate with the engine via Modbus TCP or a remote terminal unit. Each dosing unit can only support one engine installation. Located inside the dosing unit is also the COM10, which holds the automation software for the system. [12]

3.3 Pump Unit

The pump unit is used to pump the reagent from the tank to the dosing unit and then onwards to the injector. It can either be a single pump unit or it can be a redundant pump unit. Single pump units only have one pump and redundant pump units have two pumps. One is the primary pump and one works as a backup pump, which is only used if the first one stops running. These can also be ordered in three different sizes (0.5, 1 and 2) the larger the size the higher the pump capacity. Located on the pump unit there are also one or two Vacon frequency converters. The number depends on the number of pumps used as the function of these are to control the pumps. The pump unit consists of three lines one inlet line and two outlet lines, one which goes to the dosing unit and one that brings the abundant urea back to the tank. [12]

3.4 NOx sensor and Humidity transmitter

Projects never use both a NO_X sensor and a humidity transmitter as they both fill similar tasks. This means projects are either equipped with NO_X sensors or humidity transmitters not both at the same time.

NOx sensors can be installed either before or after the NOR reactor and in some case both before and after the NOR reactor. The NO_X sensor is used to determine the amount of nitrogen oxides in the exhaust gas and give input to the dosing unit on the amount of reagent needed. The humidity transmitter also provides input to the dosing unit so that the amount of reagent needed can be decided. Instead of measuring the NO_X values in the exhaust it measures the humidity. [12]

3.5 By-Pass Unit

The function of the by-pass unit is to divert the exhaust flow to an alternative route that does not go through the SCR chamber. This is used on ships that mostly operates outside of the IMO's emission control areas so that the system can be turned off without risking to shorten the life time of the catalytic elements. If the exhaust flow was to pass through the catalytic elements while the system is turned off it would suffer unnecessary wear. It can also be used as a safety measure if the SCR where to clog for example. It would automatically open up an alternative route for the exhaust flow.

The by-pass is controlled by the dosing unit. It also includes a frequency converter that controls the sealing air blower. This frequency converter can be of three different sizes; 5.5 kW, 15 kW or 30 kW. Other parts included in the by-pass system are a 3-way damper, on-off damper, connection panels and transmitters for pressure and temperature differences. [12]

4 Execution

The Factory acceptance test is carried out at a special premise that consists of three different test cells, which means that three different projects can be tested at the same time. Each test cell is also equipped with its own electrical connections so that testing can be carried out even if some problems would arise in the other test cells. The same goes for the air supply as well, and to substitute the reagent all test cells are equipped with a water tank.

The units are lifted in to place with a crane and fastened to racks to make them more accessible when worked upon. This also eases the process of connecting all the cables and hoses. Most of the units are manufactured by a number of different subcontractors, for this reason the material and serial numbers that are located on the cabinets and some individual components have to be documented. The reason for this is that it makes it easy to keep track on the different parts if faults were to appear. To be able to conduct the testing, the required connections have to be made. In practice this means the electrical supply cables, the hoses transporting the water and finally the air supply.

4.1 Power Distribution Unit

The power distribution unit mainly consists of circuit breakers that control the power supply to the other units, so if something goes wrong, the PDU will be able to shut everything down. The Beijer panel located on the front door has to be configured with the right software so that the desired values can be displayed on the panel, these include different temperatures and pressures. Inside the PDU there is also a network switch, which makes communication between the different units possible. Connected to the network switch is also the humidity transmitter, which has to be configured with the right IP address and subnet mask for it to work. This is done by connecting an Ethernet cable to it and then using PUTTy or a similar software to conduct the configuration.

4.2 Dosing Unit

The dosing unit is equipped with instruments that can control and monitor the flow value. The flow meter has to be configured to operate within the right flow interval. This is done by connecting an ethernet cable to the flow meter and then connecting to it via it's IP address and then uploading a parameter package to it. The proportional valve has to be configured to the right mode, so it supplies the right amount of reagent. This does not require any special equipment as it is done via the controller that is provided with the proportional valve. The air flow switch is also calibrated by setting a high and low set point. The high setpoint is set when the air is flowing through the system, and the low set point when no air is flowing through. Through the regulators on the airline the right air pressure can be set, if the air pressure is wrong the flow will not be stable.

For the system to be runnable a software package has to be uploaded to the COM10. These software packages are always project specific as the automation that it controls often vary from project to project. To be able to do this a connection has to be established between the COM10 and a computer with the program UNITool installed. Via UNITool the project specific software can be uploaded and other modifications made if necessary.

Furthermore, the connections for the reagent and air lines has to be connected. The required connections are an inlet and outlet for both the reagent line and the air line.

4.3 Pump Unit

The pumps are controlled by frequency converters, so a boot loader is required for them to work. This boot loader is a general file and not project specific one. To get the communication working a project specific parameter list is uploaded that contains the necessary IP addresses. As the frequency converter used is from Vacon a special cable is needed and their programs to be able to perform this task. The multi monitor on the frequency converter should also be configured to show the desired information.

Always when testing, the filter has to be replaced with a test filter so the real one that is going to the customer stays brand new. To prevent any unnecessary dry run, some water is to be added to the inlet line during startup. There is also a dry run protection system installed on the pumps, which requires a little cup to be filled with water which will work as lubricant in this case.

To ensure that the pump is working as it should and no leakages are present, a manual pressurarization run is conducted. This is done by locally controlling the pump via the frequency converters and then the pressure is driven up to 6 bars. The pressure is controlled by tightening or loosening the pressure control valve.

4.4 By-pass Unit

The By-pass Unit only requires some minor configurations and testing. The Wago control unit is to be configured. This is done by flicking the seven DIP buttons on it in different order to get the desired configuration. To save the configuration, after each step the power has to be turned off using the fuse before doing the next configuration, otherwise it will overwrite the previous one.

Then the same basic software that is also uploaded to the frequency converters on the pump unit is to be uploaded here as well. The parameter list containing the IP address configuration on the other hand is not the same, but all of this is done following the same procedures as the frequency converters are of the same model.

4.5 Test Run and after treatment

When all off the above things has been tested and eventual problems taken care of, then a test run is conducted to ensure that the whole system works as intended.

The requirements for the test run to take place are all the different auxiliary units, air, water and a computer with UNITool installed. Before commencing the test, a last check is to be made that there are no loose connections for neither the electrical cables nor the air or reagent pipes. When everything is in order, the fuses can be turned on starting with the main power switch. To start the test run itself a connection with the COM10 is to be established using UNITool. Then the parameters that are shown is to be configured so it shows all the necessary values. Now the flow can be controlled via the program, starting of small the flow is to be brought up the max flow value that is found in the project plan. A trend window is opened to be able to follow the development of the flow. When the flow has been kept stable for approximately two minutes it can be raised to the next interval. When at the max flow value, it should be kept there until it is stable enough for the high set point of the airflow switch to be set again.

Following this the flow is set higher than the max value to test that the auxiliary units are capable of dealing with the flow that they are rated for. It also has to be tested that they are capable of withstanding some powerful deviations in the flow. To simulate this the flow is to be rapidly changed from a very high flow to a very low a couple of times to see how it reacts. It is normal that it will take a couple of seconds for it to reach the new set point. The test run itself is now completed. One important thing to remember is that the trend has to be saved in the project folder, so that if any problems should arise in the future it can be referred to the trend, and there by proving that there were no problems during testing.

When it has been concluded that everything is working as intended, the next phase is to disconnect everything and then clean the Auxiliary units. As safety is of paramount importance the main power switch is to be turned off first before starting to disconnect the wires. When that is done all the external electrical supplies going to the auxiliary units is to be disconnected. Furthermore, the water and air pipes are to be disconnected, as these connections is to be reused again for the next project the removal process has to be very cautiously conducted to not cause any unnecessary damage. The following step is the removal of any leftover water in both the dosing unit and the pump unit. This is achieved by blowing air through both of the systems separately until the outlet air feels completely dry.

To avoid the water from spraying all over the place the air valve has to be turned on cautiously.

In the final part of the testing process all extra parts and eventual garbage is to be removed from the auxiliary units to make them look as representable as possible. The reverse thing to what was done at the start of the testing will now be carried out again. Meaning that any missing cover plates and similar parts is to be put back in their original spots. Then the Auxiliary units are lifted back on to the pallets on which they arrived to be sent along to the customer. In some cases, if time is short the auxiliary can just be sent along in the racks they are hanging in and the warehouse personnel will handle the packaging phase.

5 Results

The goal of this thesis work was to create instructions for the testing conducted on the auxiliary units of the NORC during the factory acceptance test. The requirements as stated earlier was that it would have to be easy to use, understand and update but also be informative enough so testing could be conducted with its help. The aim was to give everyone a better understanding on what was being done during the testing and that the knowledge would not be locked only to a few individuals.

The instruction created as the result of this work fulfills just that. It consists of a frontpage where all the different steps are clearly visible so that it does not take forever to find a specific one if the reader does not require all of them. The frontpage only contains a brief description of the task that is to be carried out to keep it as simple and short as possible. Then under each of the steps there will be a link that leads to a more detailed instruction of how to do it step by step. This part is meant to give new employees, that are not very familiar with the system, a clearer picture of how it works. This kind of instruction will also enable less cunning personnel to conduct some of the testing. The more detailed ones have both pictures showing you what to do and text describing it. To make it even more obvious there are numbers and arrows for every step as well. Making it nearly impossible to not understand at least a little bit about the task that should be performed.

It was discussed quite a lot on how the instructions should be built up. It was first meant to be one single document but that was later ruled out as it would have become too long and confusing. The possibilities to create a wizard file that would move automatically to the next step when the earlier one was completed. This was ruled out because it was a bit too advanced and time consuming.

Ultimately it was decided to go with a document that contains all the steps that is to be carried out and a brief description for each step. Furthermore, there are links that leads to the more detailed instructions.

The frontpage also contains information about other needed documents, like for example models for the test reports that should be filled out after the FAT is conducted. Furthermore, where certain software packages, that are needed in the different auxiliary units are located. Displayed are also some different programs that have to be installed on the computer used to conduct the tests.

Another important part are the safety regulations, that shows what to keep in mind when conducting the tests and where to be extra careful. Additionally, what safety equipment that are required to use in certain situations. When a first version of the instructions had been made, a full test session was conducted following said instructions to see if they worked as intended. The result of this test was that most of them did, but some required a couple of minor changes and additions. Overall when these minor fixes had been made the result showed that they corresponded very well with what the goal set up at the beginning of the work.

6 Conclusion

To conclude the thesis work, almost all the goals that was set up during the kick-off meeting held at the beginning of the work have been fulfilled. Although some parts of the goal was not possible to achieve. This was mostly due to the simple fact that there was not enough time to include everything if it was to be done on time. The things that were left out were some additional tests for the By-Pass unit. This due to it being a quite new addition to the system and therefore not much is known about what to test, but more tests for it will be added to the instructions in the future when they have been conducted and created. It could also happen that the testing of the By-Pass automation unit will be outsourced to the subcontractor, as the tests performed right now are not that demanding. Another part of the system that did not make it into this first revision of the instructions was the NO_X sensor. This was due to the fact that there were no projects with the NO_X sensor equipped that was being tested during the time of this thesis work. This as well will be included in a future version of the instructions.

Other than these two things, all the other auxiliary units have instructions for the full process that is being conducted at the moment this work was made. If there in the future would arise a need for more or different kind of tests, the instructions have been made in a way that they are very easy to update. This goal has been achieved through the layout that was chosen for it. When a new instruction is created the only thing that has to be done is to add a new row, write a small description and add the link to the more detailed version. This way the document won’t become confusing even if new steps are added.

7 Discussion

When the work first started the plan was to start studying documents related to the NORC system, but truth be told not really that much could be learned from the documents that existed. You could say that the work itself really started when I began participating in the testing because that was the best way to get a clear picture for how the system worked. With the work now done I can say that my understanding for how all the systems in the NORC works have increased a lot if you compare it to before the start of the work when I only had experience of drawing wiring diagrams for them. In that regard it has been extra interesting to learn and see more about how they actually work.

I feel that I have gotten very good support from various people around the catalyst team whenever it’s been something that I have been wondering about. And I feel that this work has provided some valuable experience in many different areas that will help me in the future as well.

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