Conceptual design and solution evaluation of a cooling and fuelling auxiliary unit for Wärtsilä 31DF

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BACHELOR'S THESIS

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Abstract

Auxiliary systems for marine vessel applications are often delivered and used as individual and separate components. The purpose of this thesis was to initiate development of a modular auxiliary unit, whose main functionality was to feed and regulate cooling water and fuel oil for Wärtsilä 31DF engines. The goal was to design a 3D-model concept of the auxiliary unit regarding requirements and functionalities from the Offshore market segment.

The thesis presents different types of functional schemes, auxiliary system components and technical specifications, and theory about product development and marine market segments. The theory chapter supports development of the conceptual design.

Different functional solutions were presented during the design phase, and system components were selected based on the determined functionalities. Siemens NX was used to design different 3D-models and the auxiliary unit assembly, based on the selected system components.

The thesis resulted in a modular cooling and fuelling unit variant for Wärtsilä 31DF, which covered the 12V, 14V and 16V cylinder configurations. The modular thinking and functional maps were key solutions to develop a flexible auxiliary unit that could be offered to the broad market. The work enables further development and evaluation of different layout solutions, to determine a final solution used for detail design.

Language: English Key words: auxiliary unit, conceptual design, market segment

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EXAMENSARBETE

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Abstrakt

Hjälpsystem för marina fartygsapplikationer levereras och används ofta som enskilda och separata komponenter. Syftet med detta examensarbete var att initiera utveckling av en moduluppbyggd hjälpenhet, vars huvudsakliga funktionalitet var att mata och reglera kylvatten och dieselbränsle för Wärtsilä 31DF-motorer. Målet var att utforma ett 3D-modellkoncept av hjälpenheten med avseende på krav och funktionaliteter från Offshore-marknadssegmentet.

I arbetet presenteras olika typer av funktionsdiagram, systemkomponenter och tekniska specifikationer samt teori om produktutveckling och marinmarknadssegment. Teoridelen fungerar som beslutsgrund för konceptlösningen.

Under designfasen presenterades olika funktionslösningar. Utgående från de bestämda funktionslösningarna valdes specifika systemkomponenter. Siemens NX användes för att designa 3D-modeller, utgående från de valda systemkomponenterna.

Arbetet resulterade i en 3D-modell för en moduluppbyggd kylnings- och bränslehjälpenhet för Wärtsilä 31DF, som täckte de olika cylinderkonfigurationerna 12V, 14V och 16V. Modultänkandet och funktionsdiagrammen var viktiga lösningar för att förstärka utvecklingen av en flexibel hjälpenhet som kunde erbjudas till en bred andel av den marina marknaden. Arbetet möjliggör vidareutveckling och utvärdering av olika layoutlösningar, för att bestämma en slutlig lösning för detaljdesign.

Språk: engelska Nyckelord: hjälpenhet, konceptdesign, marknadssegment

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Nimike: Konseptuaalinen suunnittelu ja ratkaisuarviointi jäähdytys- ja polttoaineavustusyksikölle Wärtsilä 31DF-moottoreille

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Tiivistelmä

Merialusten sovellukset kuten tukijärjestelmät toimitetaan ja käytetään usein erillisinä osina. Tämän opinnäytetyön tarkoitus oli alkaa kehittää modulaarista avustusyksikköä, jonka päätoiminto on jäähdytysveden ja dieselpolttoaineen syöttäminen ja säätäminen Wärtsilä 31DF -moottoreille. Tavoitteena oli suunnitella 3D-konseptimalli avustusyksiköstä Offshore-markkinasegmentin vaatimusten ja toimintojen perusteella.

Työssä esitellään erilaisia toimintakaavioita, järjestelmäkomponentteja ja teknisiä eritelmiä, sekä tuotekehityksen ja merimarkkinasegmenttien teoriaa. Teoreettinen osa toimii konseptiratkaisun päätöksenteon perustana.

Suunnitteluvaiheen aikana esitettiin erilaisia toiminnallisia ratkaisuja. Määritettyjen toiminnallisten ratkaisujen perusteella valittiin tiettyjä järjestelmäkomponentteja. Siemens NX-ohjelmistoa käytettiin 3D-mallien suunnitteluun, valittujen järjestelmäkomponenttien perusteella.

Lopputulos on 3D-konseptimalli modulaariselle jäähdytys- ja polttoaineavustusyksikölle Wärtsilä 31DF-moottoreille, joka kattaa sylinterikokoonpanot 12V, 14V ja 16V. Modulaarinen ajattelutapa ja toimintakaaviot ovat tärkeitä ratkaisuja joustavan avustusyksikön kehittämisessä. Avustusyksikköä voidaan tarjota laajalle osalle merimarkkinoita. Työn avulla voidaan edelleen kehittää ja arvioida eri ratkaisuja, jotta voidaan määrittää lopullinen ratkaisu yksityiskohtaiseen suunnitteluun.

Kieli: englanti Avainsanat: avustusyksikkö, konseptointi, markkinasegmentti

Abbreviations

3D	Three-dimensional
AE	Auxiliary Engine
CAD	Computer-Aided Design
CBF	Common Base Frame
DE	Diesel Electrical
DF	Dual-Fuel
DP	Dynamic Positioning
HFO	Heavy Fuel Oil
HT	High Temperature
LNG	Liquefied Natural Gas
LT	Low Temperature
MDF	Marine Diesel Fuel
ME	Main Engine
PDM	Product Data Management

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1 Introduction

This bachelor's thesis "Auxiliary Unit for Power Supply" is written for Wärtsilä Marine Business, Marine Power Solutions, Project Management, Project Engineering.

In 2015, the thesis "Modularisation of a Marine Vessel's Auxiliary System" (Krook, 2015) was written for Wärtsilä Marine Solutions. The thesis included a functional breakdown of an Offshore vessel's auxiliary systems. By using modularisation methods, new modular auxiliary products were determined. The modular auxiliary products would enhance systems by reducing complexity, and in return give smoother system installation processes for shipowners and shipyards. A result of the thesis was a modular auxiliary unit which main functionality was feeding and regulating cooling water and fuel oil. The auxiliary unit concept has previously been developed for the Wärtsilä 20 diesel engine (W20) and dual-fuel engine (W20DF) models.

The purpose of this bachelor's thesis is to initiate development of a similar auxiliary unit for the Wärtsilä 31DF (W31DF) engine model, based on the previously developed auxiliary unit concept. The scope of the thesis includes product development processes and methods, marine market segment analysis, functional mapping, conceptual design and cost estimations.

Product development processes and methods are clarified and evaluated in terms of end-to-end. The most suitable process and methods are applied on the auxiliary unit development. Marine market segments will be analysed and evaluated, with purpose to find out if the same Offshore segment demands and functionalities can be applied for other marine market segments – potentially creating opportunities for possibly profitable customer relationships.

Functional mapping includes development of cooling and fuelling auxiliary flow schemes, which is based on a thorough functional comparison of the previously developed auxiliary unit and W31 technical specifications. Based on the functional mapping, auxiliary unit variates are determined, and system components are selected. By using Siemens NX and utilising product data management (PDM) system Siemens Teamcenter, a conceptual 3D CAD assembly is designed of a W12-16V31DF cooling and fuelling unit variant.

1.1 Wärtsilä

Wärtsilä is a global leader in smart technologies and complete life cycle solutions for the marine and energy markets. In 2018 net sales totalled EUR 5.2 billion, with approximately 19 000 employees at the end of December 2017. The company has operations in over 200 locations in more than 80 countries around the world. Wärtsilä is listed on Nasdaq Helsinki.

Wärtsilä’s purpose is to enable sustainable societies with smart technology. As a smart technology company, enables Smart Marine and Smart Energy ecosystems throughout the entire lifecycles. The aim is to increase efficiency and to enable a zero-emission society. Zero emission society in other words means a clean environment, where the future is seen without emissions or pollution. (Wärtsilä 2018a)

The Smart Marine vision is to lead the industry’s transformation towards a Smart Marine Ecosystem by taking an approach of collaboration and smart technology. Additionally, minimise climate impact and a higher safety to the shipping industry by applying smart technology and performance optimisation services. (Wärtsilä 2018a)

The Smart Energy vision is to transition the energy landscape towards more flexible and sustainable energy systems, an energy future envisions of 100 % renewable energy. By providing essential technologies, lifecycle services and optimised solutions for future energy systems, Wärtsilä design, build and service optimal power systems for future generations. (Wärtsilä 2018a)

1.1.1 Marine Business and Energy Business

Marine Business and Energy Business are the two business lines which Wärtsilä consists of 2019. Wärtsilä serve market segments within energy, oil & gas offshore and onshore segments, marine market segments as merchant, cruise and ferry, special vessels and navy, and additionally the hydro & industrial segment. The current installed customer base approximates 182 GW and over 800 installations covered by Wärtsilä lifecycle solution agreements. (Wärtsilä 2018a)

Wärtsilä Energy Business delivers integration of technologies, services and solutions for sustainable and reliable energy systems, which enables a transition to more sustainable and modern energy systems for future generations. Installed power plant capacity approximates a total 67 GW in 177 countries, with over 70 installed global energy storage systems. (Wärtsilä 2018a)

The customer segments consist of three segments – Utilities, Independent Power Producers (IPPS), and Industrial Customers. Utilities are organisations providing electricity and or heat to power markets or end users. IPPS are financial organisations investing in power plants, to sell power to Utilities. Industrial Customers are businesses with captive power plants. Wärtsilä Energy Business products offered are i.e. engine power plants, energy storage and integration, solar power plants, solar-engine, renewable energy storage and hybrid solutions, and liquefied natural gas (LNG) infrastructure. (Wärtsilä 2018a)

Wärtsilä Marine Business is the provider of products and integrated solutions in the marine and oil & gas industries, such as gas and dual-fuel solutions as well as environmental solutions. Additionally, lifecycle solutions for shipowners and operators, as well as integrated solutions for shipbuilders, shipowners and operators. The market segments consist of Oil & Gas, Merchant, Cruise & Ferry, Navy and Special Vessels. (Wärtsilä 2018a)

1.2 Problem definition

As marine business projects are becoming more complex and the projects scope of supply increases, managing different products and systems require more effort when considering the customers' needs according to Krook (2015). The shipbuilding industry is a conservative business, where many power supply and propulsion systems are delivered as loose components. System based modular products are a clear benefit and need to be enhanced by changing focus among sales and project departments. The single supplier philosophy has gained attention in the shipbuilding industry. While shipbuilders emphasise a single supplier thinking, the responsibility has moved to the total solutions provider. Extensive resources are required of the total solutions provider, to keep track of the sub-supplier network. (Krook 2015, 60)

A recurring issue regarding ship design is space utilisation. The engine room space is often a compromise of what is remaining after achieved functionality and capacity of a vessel's main functions, thus auxiliary modules need to be minimised. The concentrated area and volume consumption followed with auxiliary modules is a main challenge towards inevitable use of loose auxiliary components. An auxiliary unit compiled of several components means several technical solutions grouped together in a concentrated area, thus resulting in a more compact unit which decreases the total space consumption. (Krook 2015, 57–58)

A recurring problem in product development is short descriptive product development processes, where the process steps are plain and brief. Where does initial product ideas start? How to turn invention ideas into products? How to introduce products to the market, and how to phase out products? Currently the product development processes can be difficult to follow due to processes’ simplicity, and process overviews lack further explanation in terms of end-to-end. Appropriate product development processes should ensure that improvements are introduced with a consistent and structured set of activities.

1.3 Thesis objectives

The purpose of this thesis is to initiate the development of a modular Wärtsilä 31DF cooling and fuelling unit. The auxiliary unit will be based on the framework for development of system based auxiliary products, included in the thesis by Krook (2015). A result of the thesis was an auxiliary unit which main functionality was feeding and regulating cooling water and fuel oil. The auxiliary unit concept has previously been developed for the Wärtsilä 20 engine model.

A goal of this thesis is to have a clear overview of which product development processes and methods are required when developing a new auxiliary product to the marine market in terms of end-to-end. The product development processes and methods will be evaluated to determine which process and methods are most suitable for the Wärtsilä 31DF cooling and fuelling unit.

Product development processes commonly include a market research, which consists of a market segment analysis. Another goal of this thesis is to apply a market segment analysis based on Wärtsilä specified marine market segments. As the previously developed auxiliary unit concept is built on demands and functionalities for the Offshore segment – other marine market segments will be further analysed and evaluated, with purpose to find out if the same Offshore segment demands and functionalities can be applied for other marine market segments.

The initial design of the concept includes functional mapping. Reviewing functionalities of the previously developed auxiliary unit in comparison with W31 technical specifications and flow schemes. Based on the functional mapping, accordingly design cooling and fuelling auxiliary unit flow schemes. System components are selected and listed based on the auxiliary unit flow schemes and the W31 technical specifications, and a cost estimation is applied on the auxiliary unit and possible unit variants.

Conceptual design of the auxiliary unit assembly and possible variants are designed as 3D CAD assemblies based on the selected system components, by using Siemens NX. The conceptual 3D assemblies along with descriptive technical specifications of the auxiliary unit and possible variants are stored in the PDM system Siemens Teamcenter.

1.4 Thesis delimitations

To delimit the scope of the thesis, it is decided to focus on product development of the cooling and fuelling unit until conceptual design. The detail design is being left out due to extensive work load and time limit. However, comprehensive product development processes and methods are described and clarified.

The market research is not redone, since a market research has been conducted in the thesis “Advanced Self-Aligning Mounting System” by Törnqvist (2018) which was written for Wärtsilä Marine Solutions. The thesis focused on the same objective – market shares and possible installations of W31 engines for the marine market segments. However, functions and demands within the market segments are researched and analysed.

The functional mapping will lead to two separate cooling and fuelling auxiliary unit flow schemes. One for W31 diesel engine models, and the second for W31DF engine models. Both cases will cover the whole cylinder configuration ranging from 8V-16V. Focus is held mainly on the W31DF engine and the upper cylinder configurations 12V-16V. Focus for the fuel oil system components is held on MDF (marine diesel fuel) instead of HFO (heavy fuel oil), due to trends forecasts more marine vessels using more MDF and less HFO.

To delimit the number of 3D assembly concepts in the conceptual design phase, one 3D assembly concept is created for the W12-16V31DF cooling and fuelling unit variant. The auxiliary unit assembly consists of several system component models and different material models. Standardised models will be gathered by utilising Siemens Teamcenter (PDM system), and unavailable models will be gathered from various suppliers. If models are unavailable in the PDM system and from suppliers, the models will be designed.

Due to sensitive information, the intended cost estimation is classified and has been excluded from the public thesis version. Fictional data for the purpose, would in the public thesis version be too abstract.

1.5 Secrecy

The parts in the thesis which contain classified and internal information are prohibited from being distributed outside Wärtsilä. The information is either removed or replaced by fictional data. Sensitive information, internal functional schemes, internal flow schemes and internal drawings are not included in the official and public thesis version.

2 Theory

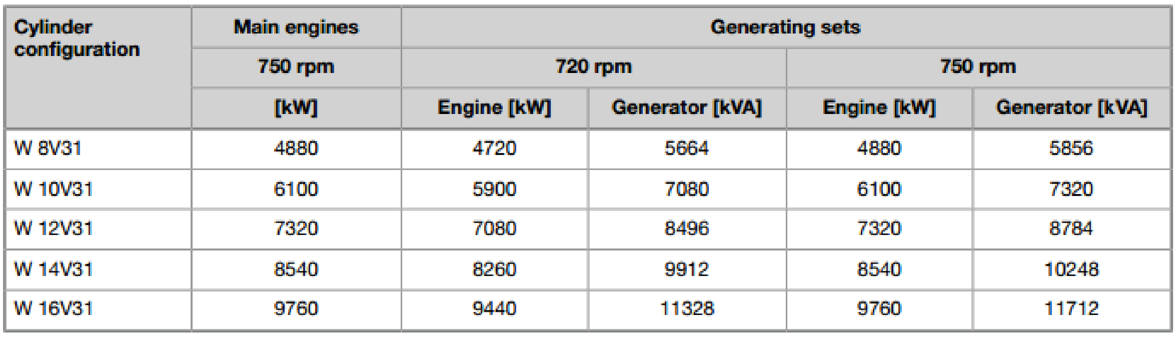
This chapter is the theory foundation of the thesis. The compiled theory work as an abstract and is the decision procedure for the different thesis objectives and goals. The chapter introduce different theories covering areas such as the basics and specifications of the Wärtsilä 31, background of modular auxiliary products, market segment fundamentals, product development and the phases of the product development process. The background and previous research are the core theory, since the thesis builds on the framework of development of system based auxiliary products.

2.1 Wärtsilä 31 engine

The W31 is a non-reversible, turbocharged and intercooled fluid speed diesel engine with direct fuel injection. The W31 is available in V8, V10, V12, V14 and V16 cylinder configurations and has a power output ranging from 4.2 to 9.8 MW, at 720 and 750 rpm. The W31 engine is available in three set of versions, Diesel, Dual Fuel (DF) and Spark Gas (SG). The engine is suitable for a wide range of ship types and applications. Either as a main propulsion engine (ME) arrangement – engine driving propeller at variable speed, diesel electric (DE) arrangement – engine driving generator, or as an auxiliary engine (AE) – engine driving generator. An auxiliary engine is commonly called a generating set or a genset, which consists of an engine and a generator, both mounted on a common base frame (CBF). (Wärtsilä 2018b)

Rating ranges of the W31 and W31DF can be seen in table 1 and 2. Typically, the W31SG is not used in marine applications, thus specifications of the engine type are not included. W31 and W31DF dimensional drawings for W10V31 & W12V31 can be seen in figure 1, and dimensions and weights in table 3 and 4. Respectively for W12V31, W14V31 & W16V31 in figure 2, as well as dimensions and weights in table 5 and 6.

Table 1. Rating table for Wärtsilä 31 main engines and gensets. (Wärtsilä 2018c)



Cylinder configuration	Main engines	Generating sets			
	750 rpm	720 rpm		750 rpm	
	[kW]	Engine [kW]	Generator [kVA]	Engine [kW]	Generator [kVA]
W 8V31	4880	4720	5664	4880	5856
W 10V31	6100	5900	7080	6100	7320
W 12V31	7320	7080	8496	7320	8784
W 14V31	8540	8260	9912	8540	10248
W 16V31	9760	9440	11328	9760	11712

Table 2. Rating table for Wärtsilä 31DF main engines and gensets. (Wärtsilä 2018c)

Cylinder configuration	Main engines	Generating sets			
	750 rpm	720 rpm		750 rpm	
	[kW]	Engine [kW]	Generator [kVA]	Engine [kW]	Generator [kVA]
W 8V31DF	4400	4240	5090	4400	5280
W 10V31DF	5500	5300	6360	5500	6600
W 12V31DF	6600	6360	7630	6600	7920
W 14V31DF	7700	7420	8900	7700	9240
W 16V31DF	8800	8480	10180	8800	10560

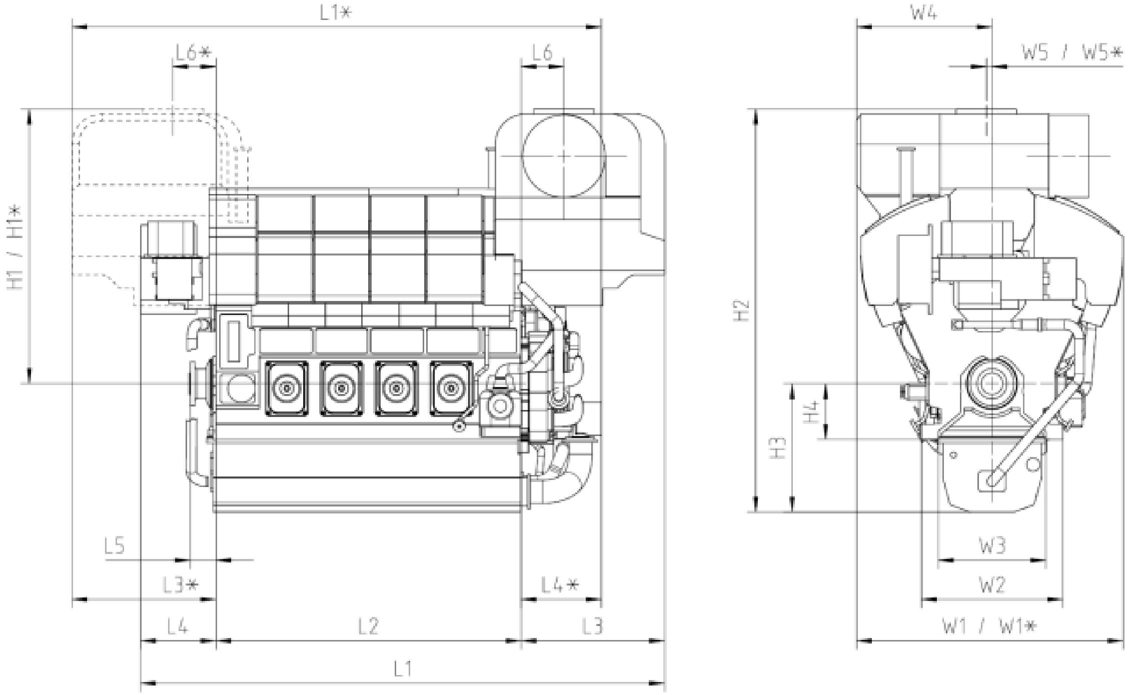


Figure 1. Drawing of W8V31 & W10V31 main engines. (Wärtsilä 2018c)

Table 3. W8V31 & W10V31 main engine dimensions. (Wärtsilä 2018c)

Engine	L1	L1*	L2	L3	L3*	L4	L4*	L5	L6	L6*
W8V31	6087	6196	3560	1650	1650	877	986	300	500	500
W10V31	6727	6836	4200	1650	1650	877	986	300	500	500

Table 4. W8V31 & W10V31 main engine dimensions and weights. (Wärtsilä 2018c)

Engine	H1	H1*	H2	H3	H4	W1	W1*	W2	W3	W4	W5	W5*	Weight tonne**
W8V31	3205	3205	4701	1496	650	3115	3115	1600	1153	1585	67	-67	56.7
W10V31	3205	3205	4701	1496	650	3115	3115	1600	1153	1585	67	-67	62

All dimensions in millimetre mm, weights in tonne.

* Turbocharger at flywheel end.

** Weight includes liquids (with normal wet sump), and without flywheel. Weight varies from diesel engine to dual-fuel engine (additional gas components weight 60 kg per cylinder for 8V or 10V engines, and 50 kg per cylinder for 12V, 14V and 16V engines).

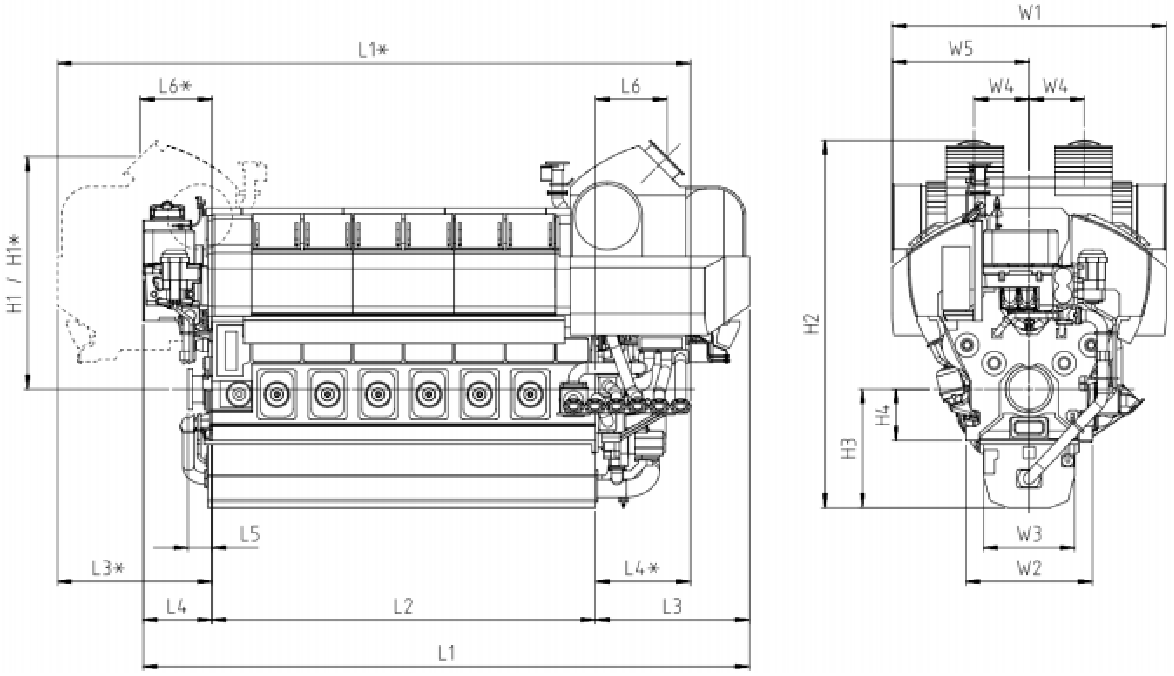


Figure 2. Drawing of W12V31, W14V31 & W16V31 main engines. (Wärtsilä 2018c)

Table 5. W12V31, W14V31 & W16V31 main engine dimensions. (Wärtsilä 2018c)

Engine	L1	L1*	L2	L3	L3*	L4	L4*	L5	L6	L6*
W12V31	7840	8090	4840	2000	2000	1000	1250	300	908	908
W14V31	8480	8730	5480	2000	2000	1000	1250	300	908	908
W16V31	9120	9370	6120	2000	2000	1000	1250	300	908	908

Table 6. W12V31, W14V31 & W16V31 main engine dimensions and weights. (Wärtsilä 2018c)

Engine	H1	H1*	H2	H3	H4	W1	W2	W3	W4	W5	Weight tonne**
W12V31	2926	2926	4633	1496	650	3500	1600	1153	698	1750	72
W14V31	2926	2926	4633	1496	650	3500	1600	1153	698	1750	78.1
W16V31	2926	2926	4633	1496	650	3500	1600	1153	698	1750	86.2

All dimensions in millimetre mm, weights in tonne.

* Turbocharger at flywheel end.

** Weight includes liquids (with normal wet sump), and without flywheel. Weight varies from diesel engine to dual-fuel engine (additional gas components weight 60 kg per cylinder for 8V or 10V engines, and 50 kg per cylinder for 12V, 14V and 16V engines).

2.2 Background and previous research

This chapter covers appropriate theory related to development of an auxiliary unit. Auxiliary module conditions (Chapter 2.2.1) describe factors and favours of modularisation, and what causes variance in auxiliary systems. Chapter 2.2.1.1 covers heat recovery theory required when calculating and dimensioning a heat exchanger. Shipbuilders and the supplier benefits and drawbacks of modular auxiliary products are described in Chapter 2.2.2. Conceptual design of an auxiliary unit (described in Chapter 2.2.3) is the results of the previous research, where the results include functional mapping of different engine arrangements and auxiliary systems.

2.2.1 Auxiliary module conditions

Marine auxiliary systems are often delivered as individual and separate components, where system integration and interface management are an important factor for success. Pre-built modular auxiliary units reduce the number of separate components, thus reduce the number of different suppliers for the shipbuilding industry. Pre-engineered modular auxiliary units reduce design mistake risks and should target the best and most efficient solution for shipowners, shipbuilders and suppliers. (Krook, 2015, III)

It is desirable to reduce the number of sub-suppliers involved, since involving many suppliers makes system integration difficult for shipbuilders. The more the design is customised, it is difficult to keep track of component compatibility. Ensuring component compatibility by standardised interfaces can be achieved by modular products, since functions of a system can be changed by interchangeable modules. (Krook, 2015, 49-50)

It is important to identify variances in auxiliary system arrangements. Factors causing variance, such as fuel type, engine type and cylinder configuration, determine which auxiliary product variants are needed. Cylinder configuration means the number of cylinders in a certain engine type. The size of components is determined by cylinder configuration. Fuel and engine type may require additional functions, i.e. charge air temperature control is required for dual fuel engines. (Krook, 2015, 49-50)

Engines and generating sets produce forms of heat which needs to be removed. Using cooling removes the heat, such as water, air circulation, oil or seawater. Freshwater cooling is split into low temperature (LT) circuit and high temperature (HT) circuit. The heat from the freshwater circuits are commonly transferred to seawater. Seawater reduces heat transfer capacity due to it creates corrosion in the seawater circulating systems. The corrosion can be reduced by using box cooling or central cooling systems. In central cooling systems the freshwater circulates in closed loops, and the seawater circulates in an isolated circuit through pumps, filters and valves. For cooling water systems, fuel oil systems and lubrication oil systems commonly use either tube or plate heat exchangers to transfer the excessive heat. Box cooling is used for smaller engines, while central cooling is used for larger engines. Box coolers are lowered into a sea-chest and the freshwater passes through a u-tube bundle. Central coolers are on the other hand plate heat exchangers. (McGeorge, 1997, 507) Box cooling is commonly used in Scandinavia and Europe, and central cooling is used in Asia. Due to European shipowners in Asia, box cooling is nowadays common. (Krook, 2015, 49-50)

International Maritime Organization (IMO) has developed guidelines for vessels operating in dynamic positioning (DP), to firm shipping industry with international standards. IMO standards increase the safety for operators, while reducing the risks of environmental hazards. A vessel built in compliance with the DP requirements, will receive a verification and acceptance document (FSVAD). DP guidelines give recommendations on the design and operation. (IMO, 2019)

DP-class limits possibilities to combine and separate. When a vessel is operated in DP mode, reliability and safety is combined. Each generating set has isolated and individual supply of fuel and cooling. DP will not cause variance if only considering DP operated vessels, however variance is caused looking at all vessel types. Between generating sets and propulsion arrangements, auxiliary functions can be shared, but for DP operated vessels this is not possible. Because vessels auxiliary functions are separated from main operations as fuel supply, cooling and lubrication, but not starting air systems. Additionally, heat recovery type causes variance in auxiliary systems. (Krook, 2015, 51-50)

Geographical operation areas are essential for a vessel’s heating a chilling arrangement, causing variance since e.g. cold ambient temperature requires additional heat supply. A vessel’s power supply system can be supplied with heat recovery. High consumption of freshwater on large cruise vessels is common, when freshwater generation is required, redundant heat is motivated. Another alternative is to not have any heat recovery. If there is no need for any heat supply, the heat can be transferred to the sea from the power systems. (Krook, 2015, 41-44)

2.2.1.1 Heat recovery with heat exchanger

In a heat exchanger heat is transferred from a hot fluid to a cold fluid. The hot fluid emits rate of heat exchange [W] is defined by equation (1). (Y.A. Çengel, J.M. Cimbala, R.H. Turner, M. Kanoglu, 2012, 927-938)

$$\Phi_h = m'_h(h_{h,in} - h_{h,out}) = m'_h c_h(t_{h,in} - t_{h,out}) \qquad (1)$$

Where m'_h is the hot fluid mass flow rate [kg/s], $h_{h,in}$ is the enthalpy [J/kg] of the inlet of the hot fluid and $h_{h,out}$ is the enthalpy [J/kg] of the outlet of the hot fluid. In the second part of equation (1), c_h is the specific heat capacity [J/kg · K], $t_{h,in}$ is the inlet temperature [℃] and $t_{h,out}$ is the outlet temperature [℃]. (Çengel, et al. 2012, 937-938)

The cold fluid received rate of heat exchange is defined by equation (2).

$$\Phi_c = m'_c(h_{c,out} - h_{c,in}) = m'_c c_c(t_{c,out} - t_{c,in}) \qquad (2)$$

Where m'_c is the cold fluid mass flow rate [W], $h_{c,in}$ is the enthalpy [kg/s] of the cold fluid inlet and $h_{c,out}$ is the enthalpy [kg/s] of the cold fluid outlet. In the second part of equation (2), c_c is the specific heat capacity [J/kg · K], $t_{c,in}$ is the inlet temperature [℃] and $t_{c,out}$ is the outlet temperature [℃]. (Çengel, et al. 2012, 937-938)

The mass flow rate can be calculated from a fluids density ρ [kg/m^3] and volume flow rate V' [m^3/s], according to the relationship $m' = V' \cdot \rho$. For the hot fluid mass flow rate relationship $m'_h = V' \cdot \rho_h$ follows, and the cold fluid mass flow rate $m'_c = V' \cdot \rho_c$ follows. (Çengel, et al. 2012, 937-938)

The similarity in equation (1) and (2) applies only when the fluid does not undergo phase transition. In an adiabatic heat exchanger (when there is no heat exchange with the surrounding) $\Phi_h = \Phi_c$. The purpose of a heat exchanger is to change the temperature for the fluid. The cool fluid wants to cool the hot fluid to a temperature that is most near the cool fluid's inlet temperature, or it is desired to heat the cold fluid to a temperature which is as close to the hot fluid's inlet temperature as possible. How well this succeeds is stated with the heat exchangers temperature efficiency. The temperature efficiency indicates how large the temperature change is in relation to the temperature difference between the incoming flows. (Çengel, et al. 2012, 937-941)

Temperature efficiency for cooling of the hot flow is defined by equation (3).

$$\eta_h = \frac{\Delta t_h}{\theta} \tag{3}$$

Temperature efficiency for heating of the cold flow is defined by equation (4).

$$\eta_c = \frac{\Delta t_c}{\theta} \tag{4}$$

Where θ is the temperature difference [K] between the incoming hot flow rate and the cold flow rate. For both co-current and countercurrent heat exchanger Δt_h [K] is the temperature difference between the hot inlet temperature and hot outlet temperature, and Δt_c [K] is the temperature difference between the cold inlet temperature and the cold outlet temperature. (Çengel, et al. 2012, 931-941)

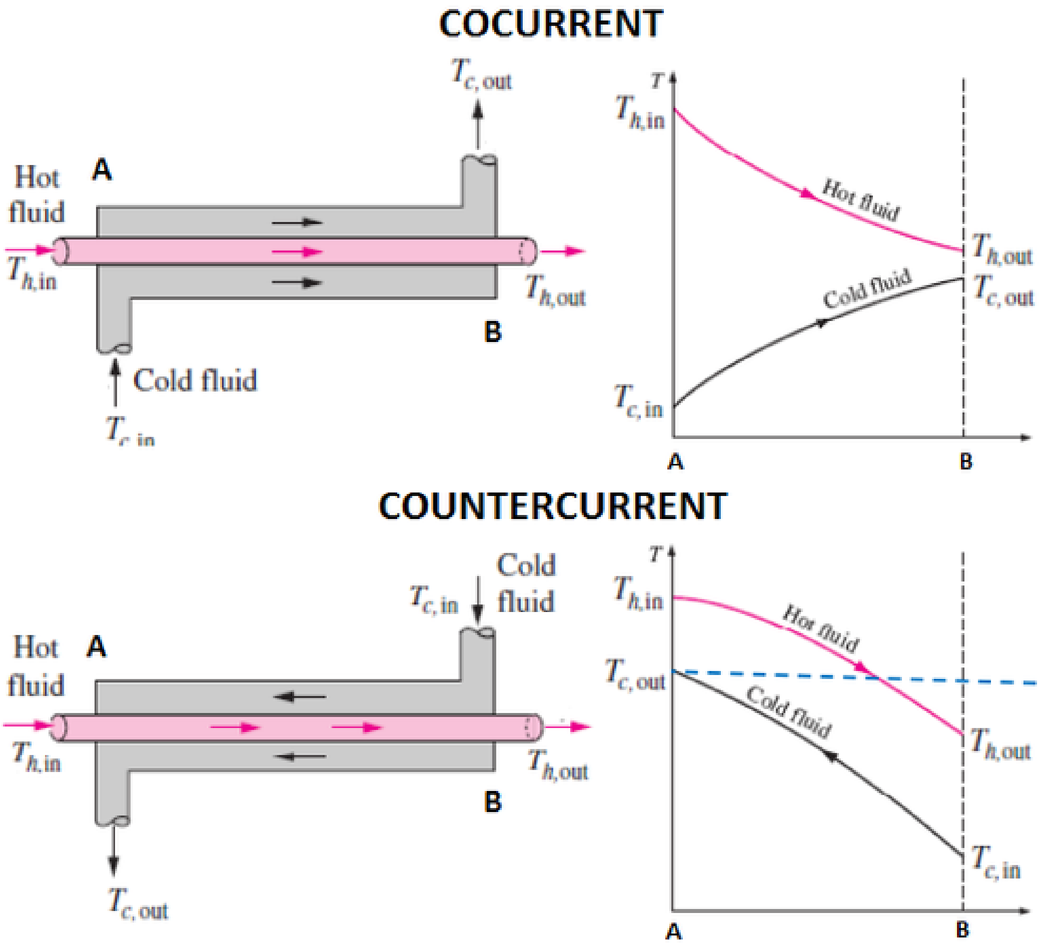


Figure 3. Temperature curves in a co-current respectively a countercurrent heat exchanger. The hot fluid flows through the inner tube. (Quora, 2019)

The heat flow [W] transmitted from hot to cold fluid via a wall is defined by equation (5)

$$\Phi = UA(t_h - t_c) = UA\vartheta \qquad (5)$$

Where U is the overall heat exchange coefficient $[\mathrm{W/m^2 \cdot K}]$, and A is the wall surface area $[\mathrm{m^2}]$ where the heat is transferred. (Çengel, et al. 2012, 931-941)

In a heat exchanger the temperature difference ϑ [K] is generally different in difference places. In co-current heat exchanger, the temperature difference is greater at the inlet than the outlet. In countercurrent heat exchanger, this depends on which fluid has a greater temperature change. In other words, which fluid has the greater heat capacity flow $(m'c_p)$. Temperature differences at different points of a heat exchanger, causes curvature in the temperature curves seen in figure 3. The temperature changes faster where the temperature difference is large. Instead of constant temperature difference in equation (5), for a heat exchanger one must use an average temperature ϑ_m [K]. For co-current and countercurrent heat exchangers, the average temperature is called logarithmic mean temperature difference (LMTD or ϑ_{lm}) [K] is defined by equation (6). (Çengel, et al. 2012, 931-941)

$$\vartheta_{lm} = \frac{\vartheta_1 - \vartheta_2}{\ln\frac{\vartheta_1}{\vartheta_2}} \qquad (6)$$

Where ϑ_1 [K] and ϑ_2 [K] are defined by equation 7.1-7.4.

$\vartheta_1 = t_{h,in} - t_{c,out}$ (for countercurrent and crosscurrent) (7.1)

$\vartheta_1 = t_{h,in} - t_{c,in}$ (for co-current) (7.2)

$\vartheta_2 = t_{h,out} - t_{c,in}$ (for countercurrent and crosscurrent) (7.3)

$\vartheta_2 = t_{h,out} - t_{c,out}$ (for co-current) (7.4)

The heat flow [W] transmitted from hot fluid to cold fluid via a wall for both co-current and countercurrent heat exchanger is defined by equation (8). (Çengel, et al. 2012, 931-941)

$$\Phi = UA\vartheta_m = UA\vartheta_{lm} \qquad (8)$$

2.2.2 Benefits and drawbacks of modular auxiliary products

Intention of the study Krook (2015) is to bring benefits for the shipowner. Reduced complexity of installing modular products should reduce the investment cost for shipowners. A summary of benefits and drawbacks can be seen in table 7.

Table 7. Benefits and drawbacks of modular auxiliary products. (Krook, 2015, 51)

Benefits for shipbuilder
+ Standardised units with predefined interfaces + Faster and smoother installation + Interchangeable modules + Reduction of loose components + Simplified routing of pipes and cables + Risk mitigation, e.g. reducing communication mistakes + Less engineering hours + Preassembled units + Pre-tuned functions
Drawback for shipbuilder
- Larger investment cost - Concentrated volume consumption - Reduced freedom to optimise piping - Additional weight compared to loose components - More concentrated piping connections
Benefits for supplier of auxiliary modules
+ Growth by new system-based products + Simplified interface management + Reduction of loose components + Control of product variety + Improved control of commissioning + Internal processing assisted + Testing and verification
Drawbacks for supplier of auxiliary modules
- Requires a notable amount of internal resources - Cost increase, due to costs of updating modular products - Cost increase, due to preassembly

Shipbuilder and shipowner are given more freedom to make design changes when standardised units are used. The preassembled auxiliary systems with standardised units enable faster installation and reducing costs for the shipbuilder. Less engineering hours and shorter installation time are achieved by a preassembled unit with pre-tuned functions, such as testing and tuning of control functions which are integrated to the auxiliary units, i.e. adjustable control valves. Predefined products improve the control of product variety, while simplifying the internal processing and commissioning. (Krook, 2015, 52)

2.2.3 Conceptual design of an auxiliary unit

The core result of the study by Krook (2015) is the conceptual design of auxiliary modules, intended for a diesel electrically (DE) powered vessels equipped with dynamic positioning. The conceptual design consists of a power supply (generating set), module A and module B. Module A and B form the fuel and cooling supply for a generating set. The modules have various variants, that are needed to fulfil stakeholder requirements. Auxiliary variants are needed due to variety of cylinder configurations, causing different sizes of functions. The auxiliary modules should be independent and interchangeable units, enabling design changes with reduced overall impact on the system. (Krook, 2015, 54)

Module A and B combined complete an auxiliary product, covering fuel and cooling supply for a generating set. Module A consists of approximately 50 components, such as fuel feed stand-by pump, electrical heater for preheating, electrical HT-water preheating, electrical LT-water pump for generator and fuel oil cooler, heat recovery, valves, adjustable orifices, fuel flow meters and various instruments for measurements. Module B consists of the segregated central cooler or box cooler. (Krook, 2015, 53-54)

Additionally, the study covers main engine propulsion arrangement and the auxiliary functions. The same concept follows the propulsion arrangement as for the genset arrangement, considering the cooling of electrical and propulsion equipment. Variants are affected by the type of seawater cooling, and the amount of required cooling affects the size of the functions. It is common for a generating set to use engine driven pumps for cooling water circulation, while a separate feeding water unit is needed for propulsion arrangements. In this case module C and D are implemented. Module C enables flow of seawater coolant, while module D consists of circulation pumps for freshwater. (Krook, 2015, 55-56)

The main engine propulsion arrangement requires cooling of electric motors, drives and hydraulic equipment. Combining cooling of drives and electric motors might be challenging due to the long distance between the units, otherwise the number of auxiliary components can be reduced. (Krook, 2015, 56)

2.3 Market segmenting

This chapter covers appropriate market segmenting theory. Market segmentation, targeting and positioning (Chapter 2.3.1) are three major steps which describe how a broad market could generally be approached in a market analysis point of view. Chapter 2.3.2 describe Wärtsilä Marine Business' different customer segments within the marine market. Previous marine market research (Chapter 2.3.3) will later be used for market segment analysis.

The marketing process in a customer-oriented organisation begins with knowing the organisations customers and prospective customers. To know and understand the customers, there are several elements to consider. The most important of these elements are the customers' technologies and processes, and the customers' products. Firstly, it is essential to get to know the customers' technologies and processes, and how the customers apply them. The customers' willingness to apply technology will impact the supplier's products. The second element, the customers' products, tells what the customer will use the product or service for, and what they will expect of it. It is easier to anticipate the customers' needs, by understanding the customers' products and their fit in the market. (R. P. Vitale, J. Giglierano, W. Pfoertsch, 2011, 124-127)

2.3.1 Segmentation, targeting and positioning

Three important concepts in marketing is segmenting, targeting and positioning. Segmentation process is to divide the market into segments. It is beneficial to tailor an offer according to the specific segment needs, rather than offering attributes which are compromised to the broad market. The targeting process means choosing segments based on the organisations strengths and target the segments that will provide the most value. The positioning process is the creation of greater value for targeted customers, than what is offered by competitors. These three process concepts are defined as segmentation framework. (Vitale, et al. 2011 148-150)

Basic framework of segmentation is finding groups with similarities in what is bought and how they act. To partition large and complex markets into subgroups gives better understanding and management. The goal of the segmentation process is to create opportunities for more profitable relationships and improve understanding of the segment subgroups. Broad segments require products that appeal for the entire segment. By selecting smaller segments, the number of potential customers that one offering can reach is reduced. The offering could be defined with specific attributes that have value to the smaller group of customers, rather than a compromised offering which almost may meet the demands of a larger market. Markets can become over-segmented; fragmentation and diversity may occur which makes it difficult to gain profitability from the smaller markets. (Vitale, et al. 2011, 148-152)

2.3.2 Marine market segments and sub-groups

Wärtsilä Marine Business main customers are divided into five major segments: Merchant, Offshore, Cruise & Ferry, Navy and Special vessels. The segments are further divided into sub-groups for different type of vessels. (Wärtsilä 2018e)

Merchant includes all vessels for seaborne transportation such as: General cargo vessels, Bulk carriers, Crude oil tankers, Container vessels, Product tankers, Chemical and product tankers, Reefer vessels, LPG/LNG carriers, Car carriers, Nuclear fuel carrier, Asphalt carriers, Heavy lift tankers, Multi-purpose vessels, and Shuttle tankers. Figure 4 shows examples of Merchant vessels. (Wärtsilä 2018f)

Figure 4. Figure shows a Crude Oil Tanker (top left), Container Vessel (top right), General Cargo Vessel (bottom left), and a Bulk Carrier (bottom right). (Wärtsilä 2018f)

Offshore includes vessels and platforms used in oil and gas exploration as well as their supporting activities: Offshore supply vessels, Anchor handling tug supply vessels (AHTS), Jack-up rigs, Drillships, Floating production storage & offloading (FPSO), Semi-submersible rigs, Offshore construction vessels, Pipe carriers, Offshore diving support, Barges & platforms, Offshore research vessels, Fixed production platforms, and Seismic survey vessels. Figure 5 shows examples of Offshore vessels. (Wärtsilä 2018f)

Figure 5. Figure shows an Anchor Handling Towing Supply Tug AHTS (top left), Offshore Supply Vessel (top right), Fixed Production Platform (bottom left), and a Drillship (bottom right). (Wärtsilä 2018f)

Cruise & Ferry includes: Passenger & cargo vessels, Ferries, Yachts, Cruise vessels, Crew and launch boats, Sailing ships, Passenger landing vessels, High speed passenger vessels, and Air cushion vessels. Figure 6 shows examples of Cruise & Ferry vessels. (Wärtsilä 2018f)

Figure 6. Figure shows a Yacht (top left), Cruise ship (top right), Passenger ferry (bottom left), and a Passenger & cargo vessel (bottom right). (Wärtsilä 2018f)

Special vessels include a wide range of various vessels such as: Fishing vessels, Powered Barges, Escort tugs, Dredgers, Inland tankers, Pilot vessels, Inland pushboats, Firefighting vessels, Icebreakers, Semi-submersible heavy lift vessels, and Lightships. Figure 8 shows examples of Special vessels. (Wärtsilä 2018f)

Figure 7. Figure shows a Dredger (top left), Semi-submersible heavy lift vessel (top right), Icebreaker (bottom left), and an Escort tug (bottom right). (Wärtsilä 2018f)

Navy includes various types of naval vessels and submarines such as: Patrol boats, Submarines, Landing crafts, Fast attack crafts, Frigate, Survey and research ships, Anti-ship attack vessels, Corvettes, Training ships, Minesweepers, Destroyers, Surface-to-air missiles, Torpedo and missile recovery ships, and Aircraft carriers. Figure 7 shows examples of Navy vessels. (Wärtsilä 2018f)

Figure 8. Figure shows a Patrol boat (top left), Frigate (top right), Destroyer (bottom left), and an Aircraft carrier (bottom right). (Wärtsilä 2018f)

2.3.3 Previous marine market research

The marine market and its segments are investigated and researched in the thesis "Advanced Self-Aligning Mounting System" by Törnqvist (2018). Findings in the thesis show the potential for a W31 in context of an advanced self-aligning mounting system product in the marine market segments. The market research approach used a quantitative method with secondary data. The data sample included information of approximately 7000 vessels collected from Clarksons World Fleet Register. According to Clarksons (2018) the Clarksons Company provides several shipping related services, as research of the shipping, trade, offshore and energy markets. The research is ISO9000 classified and offers over 50 years of collected data. (Törnqvist, 2018, 23)

The data sample collected was delimited to commissioned vessels or vessels in service built from 2014 to 2018. The data sample included the following information: vessel name, status, type, length, gross tonnage, year built, engine type and designer, power output, and to what group the vessel belongs to. (Törnqvist, 2018, 12)

The thesis investigates the percentage each segment holds in the marine market. According to Törnqvist (2018, 12) this was achieved by specifying the segments for each vessel type, by Wärtsilä's specifications. The marine market segment shares can be seen in figure 9.

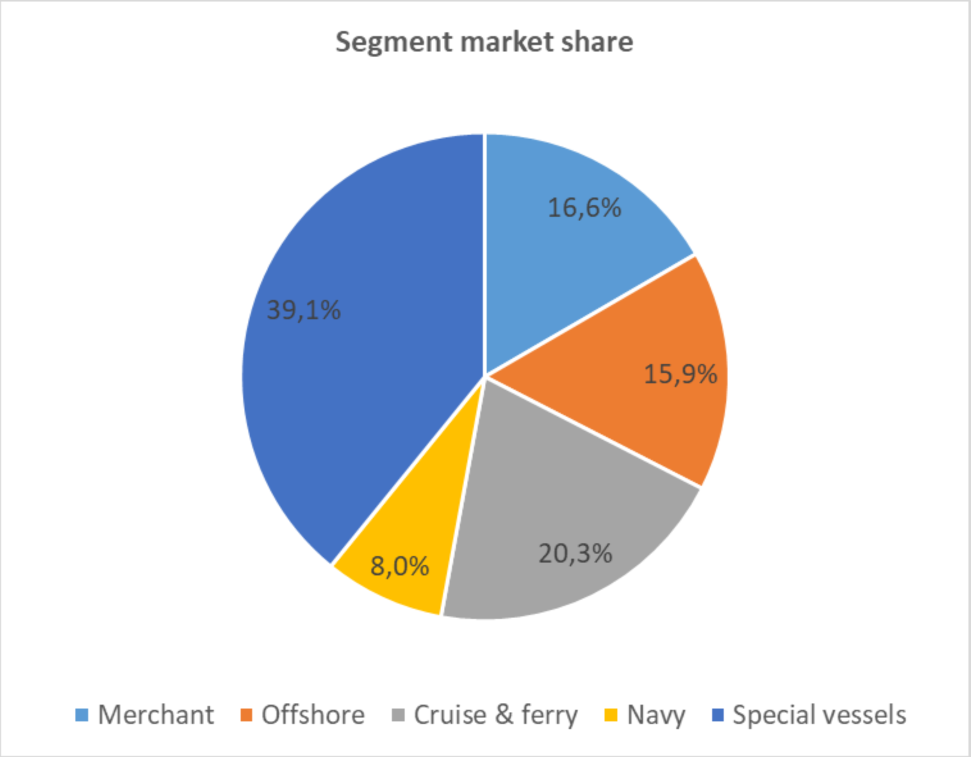


Figure 9. Pie chart showing shares of the marine market each segment holds. (Törnqvist, 2018)

2.4 Product development

This chapter covers industrial product development theory which can be applied to different products and services. Systematic product development motives (Chapter 2.4.1) describe efficiency as an essential motive for systematic product development. Altered product development conditions (Chapter 2.4.2) describe different issues as well as development of necessities within product development. Product development in an industrial company is a complex problem-solving process driven by different factors such as society and environment, further described in Chapter 2.4.3.

2.4.1 Systematic product development motives

Industrial development of products to be produced and sold to a market to customers which conceive the products as useful, easy to use and have such a value that the customers are ready to buy and use the products. Product typically is perceived as a physical product, but may also be a service, i.e. a technical system.

Engineering and design in industrial product development is the context where efficiency is desired. The efficiency should result in development of a product which fulfil customer or user demands and expectations on functionality and quality. Simultaneously as the product company’s demands and expectations on least possible lead time (the time it takes from development start to market introduction). Additionally, least possible consumption of research- and development (R&D) resources. The society’s demands of sustainability should also be fulfilled. (H. Johannesson, J-G. Persson, D. Pettersson, 2013, 19)

2.4.2 Altered product development conditions

The past decades have a distinctive sign of market segmenting, customer adaptation, and new demands i.e. sustainability, environment adaption, security and design. The strong international dependency is distinct, since the global competition is severe and new product generations succeed each other in a high tempo. Products become more complex and often contain several different technical solutions within mutual systems. Design aspects become increasingly important when technical performance is taken for granted. Product development, engineering and design become a critical function to keep companies’ competitiveness. (H. Johannesson, et al. 2013, 43)

To accomplish the different demands, product developing and producing companies' re-uses components and subsystems within product generations and product variants. The mutual parts and subsystems build together a product platform, which lays as basis for different product generations and product variants. (H. Johannesson, et al. 2013, 43)

Systematic engineering with efficient project management becomes more necessary. A simple product which is based on conventional technology without high-tech contents, demand systematic and thorough engineering and higher technical competence to accomplish cost-effectivity and quality. Developing a simple and slim product often demand considerably bigger development contribution than a more complicated product. (H. Johannesson, et al. 2013, 43)

2.4.3 Development process - a problem solving process

Developing products in an industrial company is a complex problem-solving process with many different concurrent participants, such as other processes within a company as well as other companies and surrounding societies. It is crucial for a successful product development, to understand the fundamentals for the complex process, the context, characteristics, participants and necessity of way of working, methods and tools. (H. Johannesson, et al. 2013, 60-61)

The product development process for a developing and producing company, is one of several processes co-operating in a company. The process should be put within a company context, which in turn is part of an even bigger context where the company interact with its surrounding society. This can be seen in figure 10. (H. Johannesson, et al. 2013, 60-61)

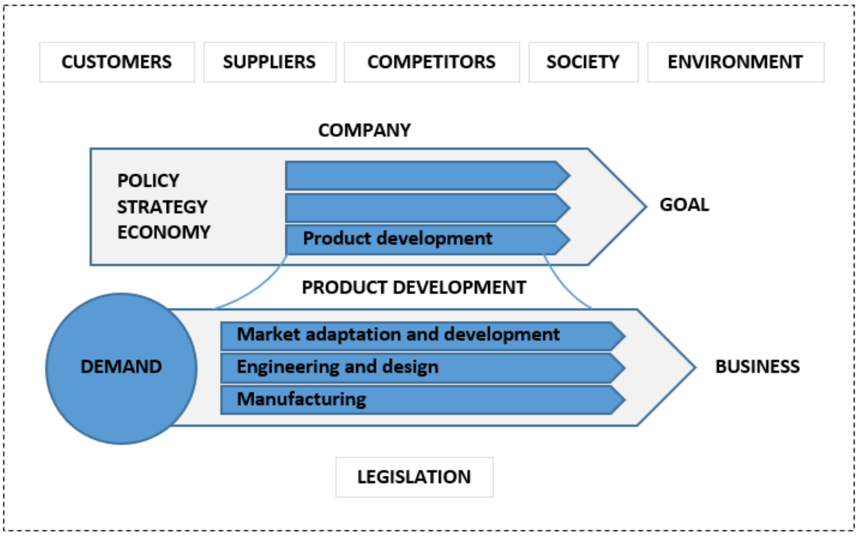


Figure 10. Product development in a company. (H. Johannesson, et al. 2013, 61)

The bigger context visually described in figure 10, consists of customers, suppliers, competitors, society, environment, and legislation that determine the bigger context where the company interact. To reach its goals, the company is steered by its policies, strategies and economy, whereas the product development within a company is part of that goal. While the market demands are met with market adaptation, engineering, design, and manufacturing of a product – the product development create business in return. (H. Johannesson, et al. 2013, 60-61)

2.5 Product development process phases

An objective of this thesis is to further clarify the phases included in the product development process. Each phase of the process is described in this chapter. Strategy (company strategy described in Chapter 1.1) and market analysis (described in Chapter 2.3) theory is not further described in this chapter.

Systematic product development process is beneficial, since it is structured and will naturally be well documented and thus provide traceability. Typically, all process phases are gone through during development of new products. The process phases can be used several times, and they cover both synthesis and analysis. The product development process phases can be seen in figure 11. (H. Johannesson, et al. 2013, 115)

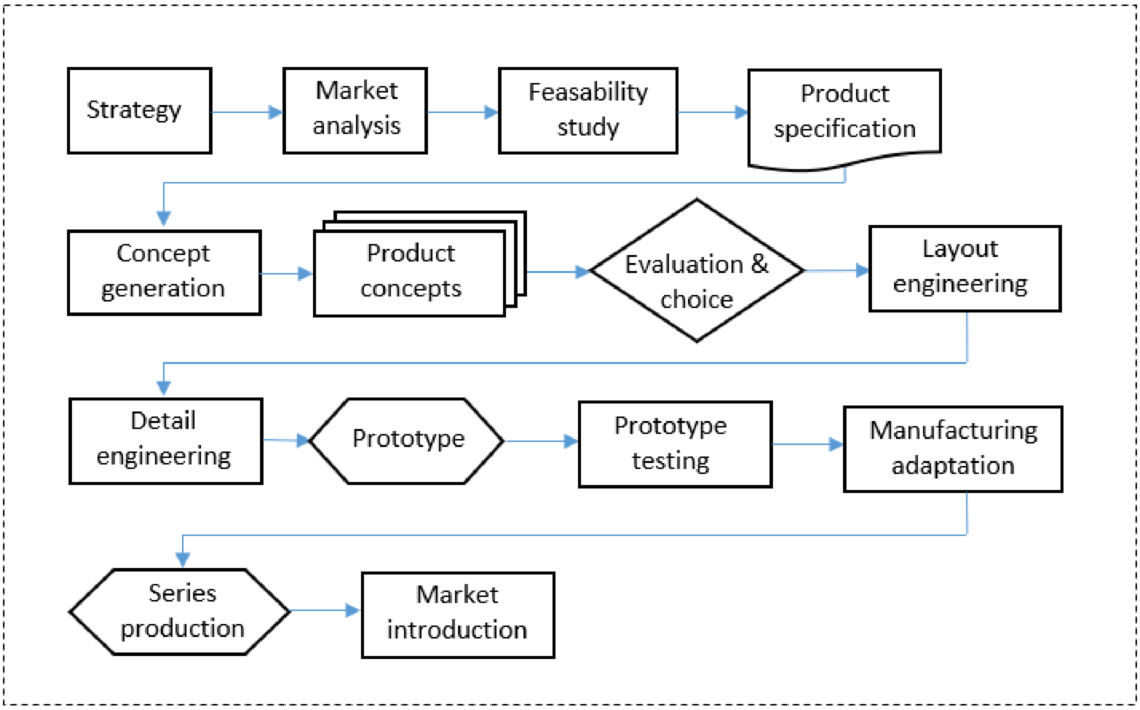


Figure 11. Product development process phases. (H. Johannesson, et al. 2013, 115)

The design phase of the product development process mainly includes concept generation, product concepts, evaluation and choice and detail engineering. The design phase and the including steps are described and seen in figure 12.

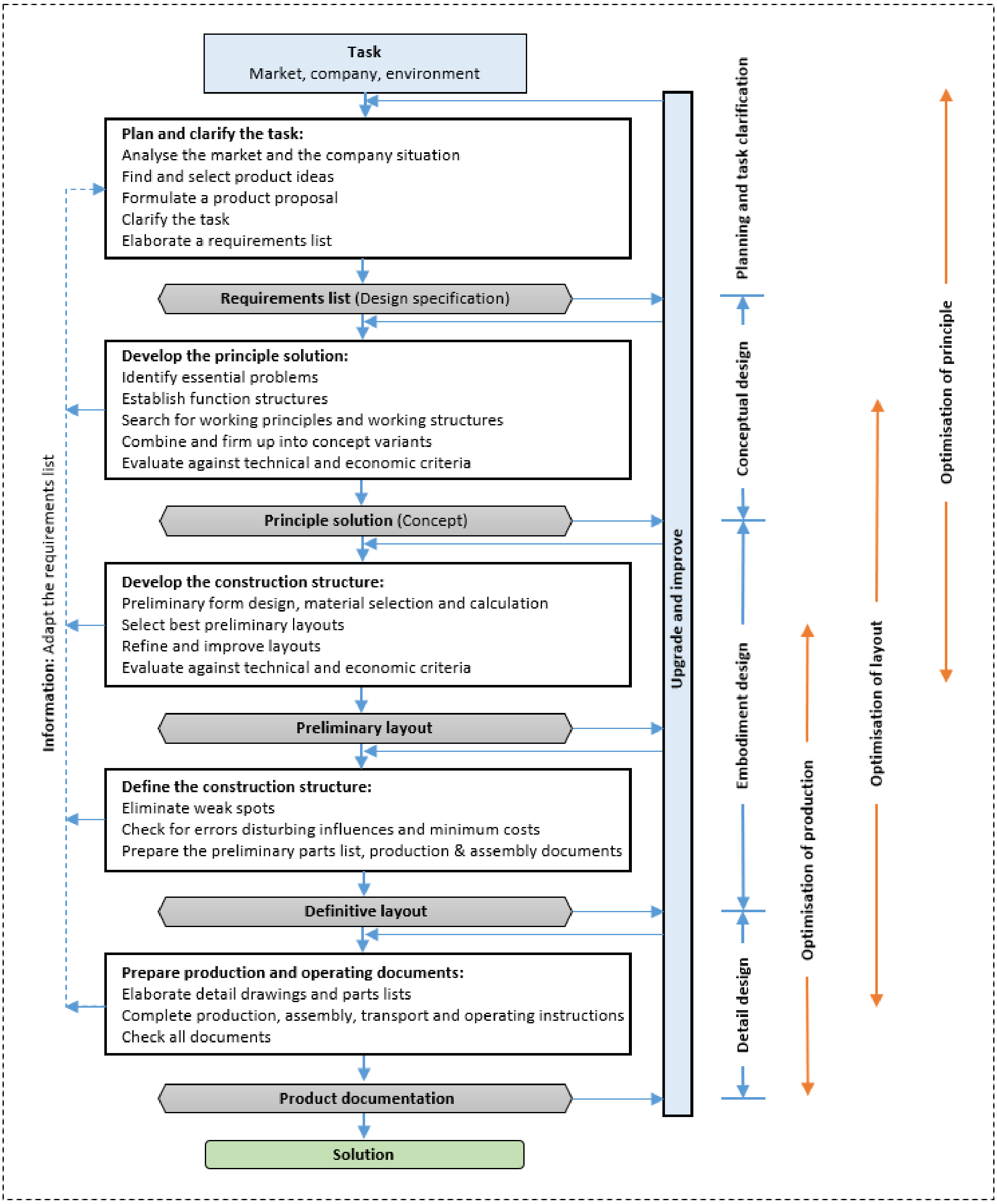


Figure 12. Product development design phase with including steps. (G. Pahl, 2007, 130)

2.5.1 Feasibility study

In a feasibility study an unprejudiced problem analysis should be considered before new product development. Background materials such as market, design and technical information is gathered. Different technical solutions and other presumptions should be uncritically examined, so that the development is not initiated on incorrect premises. A product's future expenses are determined by the feasibility study and the concept design phases, thus limited amount of resourced should be used. (H. Johannesson, et al. 2013, 115)

A feasibility study should lead to a requirement specification draft, where functional requirements are determined. Functional requirements describe what the product should execute. Development of new technical solutions and product concepts means that the specification details are further developed successively throughout the product development project as well. (H. Johannesson, et al. 2013, 115-116)

2.5.2 Product specification

The task in the product specification phase is to establish a specification of the product. This should be done by using input information that can be used as a starting point when later searching for engineering solutions. The product specification should also be used as a reference when evaluating the engineering solutions and the final product solution. (H. Johannesson, et al. 2013, 116)

The product specification should be developed and updated during the engineering process. During the engineering process the product specification should lead to a goal specification, which should lead to a final product specification when the engineering process ends. The final specification should describe the final product. (H. Johannesson, et al. 2013, 116)

In the goal specification, the task is to gather and describe all relevant criteria for the product under development such as: criteria that are given in the task conditions, criteria that are revealed through analysis and clarification of the task, and criteria that follows the result of design and engineering decisions during the engineering process. (H. Johannesson, et al. 2013, 116)

A purposeful, clear and accurate product specification reflects the needs that the product is to meet, and what is demanded by the market. In other terms, the product specification should be as accurate as possible, from the very beginning until the end of the project. (H. Johannesson, et al. 2013, 116)

2.5.3 Conceptual design and generation

After product task clarifications are completed, the conceptual design phase determines product principle solutions (G. Pahl, et al. 2007, 131). Conceptual design is a step of the design phase. According to (H. Johannesson, et al. 2013, 119) in engineering contexts, the term concept means product concept – a first-hand attempt on a solution to an engineering problem. Such solution includes:

- A preliminary rough product layout which includes estimated additional margin
- A preliminary cost estimation
- Descriptions of technical solution principals written in text
- Descriptions of solution properties in relation to product specification (preferably with an evaluation matrix)
- Motives for the choice of sub-solutions
- Compilation of rough estimations, analyses and experiments with obtained results

According to G. Pahl, et al. (2007, 131) the solution could additionally include:

- Connection schematics
- Block diagrams or function structures
- Circuit diagrams or flow schemes
- In some cases, line sketches or rough scale drawings are enough

Similar concept descriptions do not give enough basis for prototype manufacturing, namely the initially manufactured product according to the product specification. For this to happen, the concept solution needs further development in order to concretise to a complete basis for prototype manufacturing. In the complete basis, all parts are described in detail for manufacturing of a physical product. (H. Johannesson, et al. 2013, 119)

According to G. Pahl, et al. (2007, 130) there are several steps included in the conceptual design phase. While the concept design phase is seen in the design phase flow diagram in figure 12, the conceptual design phase is further described in the conceptual design flow diagram seen in figure 13.

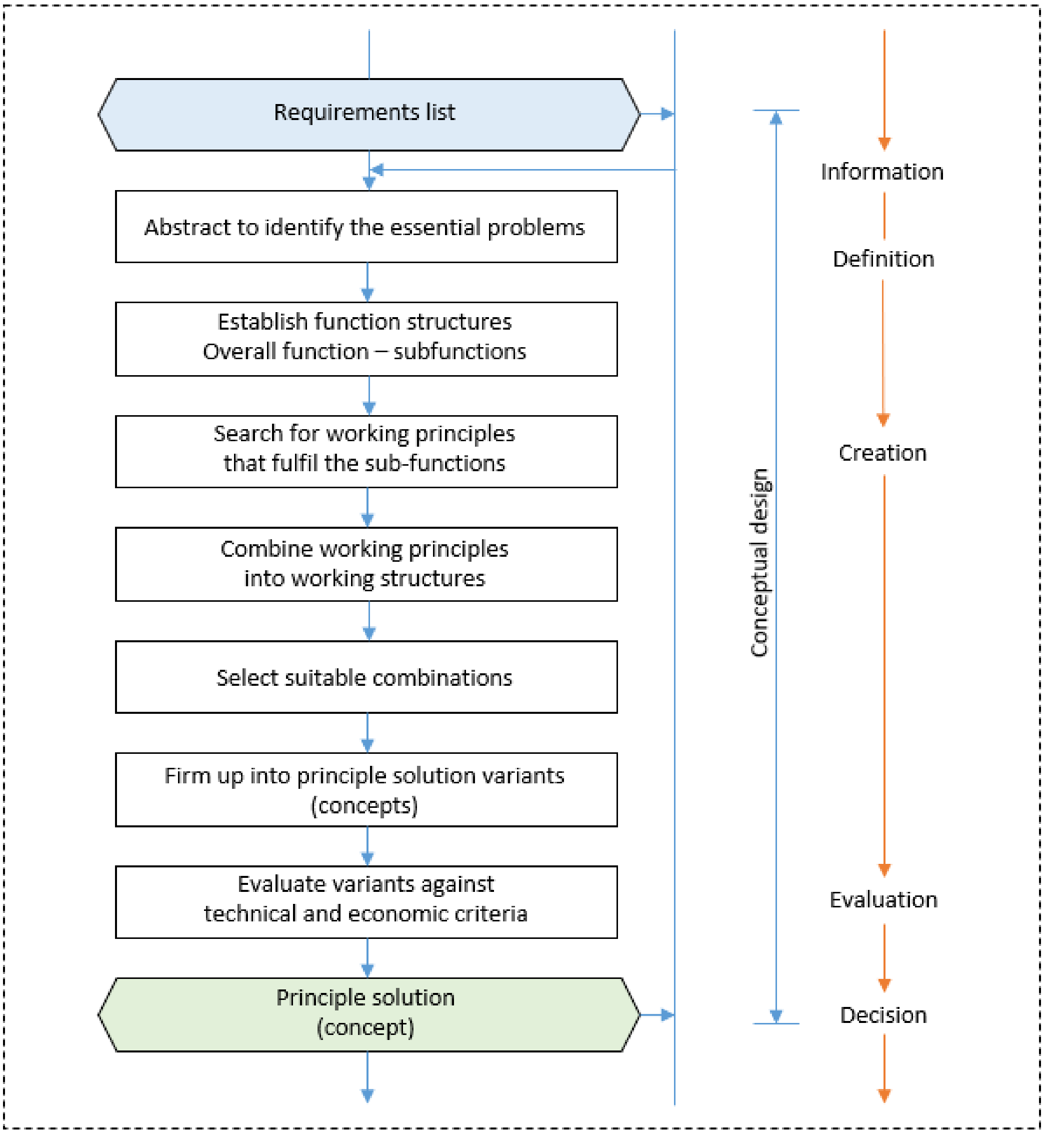


Figure 13. Steps of conceptual design. (G. Pahl, et al. 2007, 160)

According to G. Pahl, et al. (2007, 159) the steps involved correlate and satisfy the principles of the problem-solving process (described in Chapter 2.4.3). None of the steps included in the conceptual design phase should be skipped if the right choice of concept solution (described in Chapter 2.5.6) is to be selected.

2.5.4 Concept evaluation and concept choice

According to H. Johannesson, et al. (2013, 120-121) the intention with evaluation of the generated solution alternatives in the concept phase, means that each alternative should be analysed and determined of its value and quality in proportion to the demands and desires described in the product specification. This means that the solution alternative analysis results are compared to each other – a decision should be made in accordance to the choice with most value and quality. In other terms, the alternative which most fulfil the criteria in the product specification should be chosen for further development of details. The following difficulties may occur:

- Value of a solution are affected by many different properties
- Different properties have relative different significance
- Different interested parties value properties differently
- Properties can either be measured as quantitative, or judged qualitatively
- Lack of information of a solution alternative when decisions are to be made

The analysis of the different solution properties, and at the same time the evaluation of, and comparison between, each alternative's value and quality needs to be done before decisions can be made. Property analyses are made for each individual property, by using technology-based modelling and analysis simulation methods. Both theoretical and experimental methods can be used to analyse solution alternatives properties. Quantitative results are preferred, however in some product property cases this is not possible. In these cases, relying on qualitative judgements is the second option. (H. Johannesson, et al. 2013, 121)

Systematic evaluation with a decision matrix aid comparison and decision of the solution alternatives individual total value and quality. First step is to eliminate bad solutions, and the second step of the evaluation can be done by using relative decision matrixes. This way the solution alternatives are further reduced. At the same time, new alternatives can be found by combining old alternatives. (H. Johannesson, et al. 2013, 121)

After a systematic evaluation, a quantitative comparison should be made, i.e. criteria weight method could be used when comparing alternatives with a weighted sum of ratings. Each solution should gain rating for each fulfilled criterion. If a quantitative comparison is not possible, a qualitative comparison should be made by using a relative decision matrix. (H. Johannesson, et al. 2013, 121-122)

2.5.5 Embodiment design

According to G. Pahl, et al. (2007, 130-132) the step Embodiment Design in the design phase of the product development process, is a step in-between conceptual design (described in Chapter 2.5.3 and 2.5.4) and detail design (described in Chapter 2.5.6). The term Embodiment Design according to H. Johannesson, et al. (2013, 115) is called Layout Engineering, and is partly concept design and partly detail design.

During embodiment design, starting from a concept solution (principle solution, working structure) which should determine a construction structure (overall layout) of a technical product. The embodiment design step should result in a product layout (further described in Chapter 2.5.6). (G. Pahl, et al. 2007, 130-132)

To produce several preliminary layouts is often necessary. The preliminary layouts should be scaled simultaneously or successively, to determine advantages and disadvantages of the different layout variants. Enough elaboration of the layouts should result in an evaluation, where the layouts are evaluated against economic criteria and technical criteria. Evaluation of individual variants may lead to a layout that looks most promising, which may benefit from incorporating ideas from other less promising layouts. Combination and elimination of less promising layouts should lead to the best layout (definitive layout). At this stage of the design phase, financial viability needs to be checked and if met, only then the detail design phase should be started. (G. Pahl, et al. 2007, 130-132)

2.5.6 Detail design

According to H. Johannesson, et al. (2013, 122) the starting point in the detail design phase, is the chosen concept solution which will be further developed to a functional product that fulfils the product specification criteria. The intention with the detail design phase is that the product is functional and usable, a viable basis for manufacturing of a prototype. The prototype functionality and usability should be tested, analysed and verified. The detail design phase includes:

- Choosing dimensions and standard components
- Engineering further details and choose material
- Defining the product architecture
- Describing the product layout

According to G. Pahl, et al. (2007, 132) the detail design phase could additionally include:

- Specifying surface properties and materials
- Estimating production possibilities
- Producing all drawings and other production documents

Product architecture means how a product is structured – how a structure’s functional elements are arranged into solution chunks and interact and co-operate with other chunks and interfaces they relate to. When planning what type of product architecture a product should have, careful consideration should be taken when choosing components, so they fit in with the overall product structure and component interfaces. (H. Johannesson, et al. 2013, 122)

Product layout means how the product's components are arranged in relation to each other. Both architecture and layout relate to the product's configuration. A product's architecture has different ways to group a product's functional solutions, while a product's layout is about grouping and placing physical components and the geometrical details. Additionally, both architecture and layout are shaped when a concept solution is developed to a product assembly with standardised components and the engineered details. (H. Johannesson, et al. 2013, 122)

2.5.7 Prototypes

Nowadays virtual prototyping is used in the prototype phase, where prototypes are modelled, simulated or even animated using CAD-systems or other related computer software. That way the geometrical model can be inspected and analysed e.g. predict a products performance, or operation simulation before manufacturing a physical prototype. Generally physical products are required to be tested in laboratories to verify technical solutions. (H. Johannesson, et al. 2013, 124-125)

2.5.8 Manufacturing adaption

Prototypes are not often engineered to be viable for direct manufacturing. The basis that has been developed for the concept solution and the prototype needs further engineering development and adaptation before it may lay as basis for regular manufacturing. This is done in the manufacturing and end-engineering phase when the final product is worked out in detail for process, interaction or economical direction. (H. Johannesson, et al. 2013, 125)

Process direction means when the product is worked out in detail and can be manufactured and assembled with intended tools and intended methods. These aspects, like interaction direction and economical direction should be worked out during the beginning and throughout the product development – so decision made, are based on these aspects as well as in accordance with the product specification. Engineering and manufacturing of different tools should be integrated in the product development as well as distribution and service related questions such as packaging and maintainability. (H. Johannesson, et al. 2013, 125)

2.5.9 Market introduction

Product design has underlaying importance when it comes to increasing sales of products. Nowadays designed models and figures are not only used for decision basis but create dialog and create better market studies. Typically, in market introduction today, products introduced to markets have a type of virtual basis even though manufacturing of the products have not yet begun. In some cases, this can be a risk if design changes are to be made late in the product development process. Careful consideration needs to be taken before introducing a product to the market in such cases, else it might lead to disappointed customers and difficulties in sales. (H. Johannesson, et al. 2013, 128)

When a new product is developed, it is not enough with a product ready for manufacturing. Market introduction require extensive planning and training for the sales organisation. Extensive technical documentation is required for sales, spare part co-ordination, services and customers. Throughout the products lifecycle, according to H. Johannesson, et al. (2013, 128-129) different product information is needed for market and service functions:

- Product information on web pages, data sheets and sales brochures
- User manual and operation & product care manuals
- Technical basis for press releases and exhibitions
- Spare part catalogues
- Service manuals for the product and/or the product’s service personnel
- Training material for the sales, after-sales and customers
- Environmental Product Declaration (EDP)
- Dismantling and recycling instructions

2.5.10 Phase-out of products

This chapter is not a phase of the product development process shown in figure 12, however important theory related to product development.

Product developers need to consider opportunities to phase-out a product, when a product of technical and economic reasons has served its purpose. The product solution should ease dismantling, fragmenting or separating materials. A priority order often used today is reduce, reuse and recycle – avoid or reduce the amount of undesirable material, reuse components if possible, and recycle materials. Information regarding dismantling or scrapping should be available for future recycling. Recycling can be driven by recycling companies or product suppliers, if a product manufacturer and supplier own and sell a product’s function and usability. (H. Johannesson, et al. 2013, 130-131)

Dematerialisation describe lean products and processes for long term environmental sustainability. Dematerialisation in short is a reasoning where environmental impact is directly proportional to the amount of materials in use and under the influence of mankind and our society. This means the environmental impact is strongly dependent of the amount of materials in circulation. Reducing the amount of materials is required to produce useful functions and reduce materials circulation velocity. According to H. Johannesson, et al. (2013, 130-131) this can be done by:

- Reducing the amount of materials in a product
- Increasing a products lifecycle, i.e. by upgrading critical components
- Increasing the products efficiency

Engineering in modules, is an alternative when engineering for long life cycles. Engineering in modules gives opportunities to replace modules which from an environmental point of view are worst, to more environmental adapted and developed modules. (H. Johannesson, et al. 2013, 130-131)

3 Design procedures

What is foremost important in this chapter, is that the information from the previous chapters is used and followed. This chapter covers the procedures for the initial design and the conceptual design for the W31DF cooling and fuelling unit. Functionalities of the previously developed cooling and fuelling unit are compared, adapted and applied to the W31DF cooling and fuelling unit. System components, general components and pipe connections are selected. This results in conceptual design for the W12-16V31DF cooling and fuelling unit variant which is compiled into a 3D assembly along with a general arrangement assembly.

3.1 Initial design

This chapter covers the essential parts before the intended conceptual design can take place. Cooling and fuelling functionalities for the previously developed auxiliary unit are compared to functionalities and requirements for the W31 and W31DF engine models. Existing, missing and new functionalities are adapted, followed by a first-hand cooling and fuelling flow scheme sketch for both diesel and dual-fuel types. System components are selected for the cooling and fuelling unit variants, on basis of the engine technical requirements.

3.1.1 Functional mapping

By comparing the previously developed auxiliary unit function scheme and cooling and fuelling flow schemes with the W31/W31DF cooling water system flow schemes and fuel oil system flow schemes found in the product guides, the connection and component function codes could be differentiated and checked if the function codes match each other – if there are existing, new or obsolete connections and components.

It was decided to start with the W31DF auxiliary unit over the W31 auxiliary unit since the W31DF engine model had additional components related to fuelling compared to the diesel engine model, meanwhile the diesel engine model had most of the connections and components in common. In other terms, less connections and components had to be added to the W31 fuelling and cooling auxiliary unit flow scheme. It was also decided to focus only on MDF (marine diesel fuel) components instead of HFO (heavy fuel oil) components.

The initial connection and component function codes for the previously developed auxiliary unit were compiled into an excel sheet, to ease overviewing and comparing functionalities. See table 8.

Table 8. Initial system connection & component descriptions and function codes for the previously developed auxiliary unit.

	DESCRIPTION	CODE	CONN./COMP.
FUEL CONN.	To Engine fuel inlet	E101	Connection
	From Engine fuel outlet	E102	Connection
	To Engine fuel stand-by connection	E105	Connection
	To Engine pilot fuel inlet	E112	Connection
	From Engine pilot fuel outlet	E117	Connection
COOLING CONN.	To Engine HT-water inlet	E401	Connection
	From Engine HT-water outlet	E402	Connection
	Water from preheater to engine HT-circuit	E406	Connection
	To Engine LT-water inlet	E451	Connection
	To Engine LT-water outlet	E452	Connection
	LT-water to generator/gearbox	G460	Connection
	LT-water from generator/gearbox	G461	Connection
FUEL COMP.	Pressure reduction valve	01	Component
	Cooler (MDF)	1E04	Component
	Suction strainer (MDF)	1F07	Component
	Pilot fuel fine filter (MDF)	1F10	Component
	Flow meter (MDF)	1I03	Component
	Stand-by pump (MDF)	1P08	Component
COOLING COMP.	Heat recover / (Evaporator)	4E03	Component
	Heater (preheater)	4E05	Component
	Circulating pump (preheater)	4P04	Component
	Circulating pump (LT)	4P15	Component
	Temperature control valve (heat recovery)	4V02	Component
	Temperature control valve (LT)	4V03	Component
	Temperature control valve (charge air)	4V09	Component
VESSEL CONNECTIONS	To ship central cooler/box cooler	E1	Connection
	From ship central cooler/box cooler	E2	Connection
	From ship fuel supply to Engine	E3	Connection
	From Engine to ship fuel supply	E4	Connection
	From Engine control system	-	Connection
	From LNG Pac	-	Connection
	To LNG Pac	-	Connection
	From Vessel heating system	-	Connection
	To Vessel heating system	-	Connection

Fuelling related connections and component function codes and symbols for the previously developed auxiliary unit flow schemes were compared and adapted in accordance with the W31DF fuel oil system flow schemes seen in figure 14 and 15.

Cooling related connections and component function codes and symbols for the previously developed auxiliary unit flow schemes were compared and adapted in accordance with the W31DF cooling water system flow schemes seen in figure 16 and 17. An adapted W31DF cooling and fuelling flow scheme drawing was designed, based on figures 14, 15, 16 and 17. For function symbol interpretation, see Appendix C.

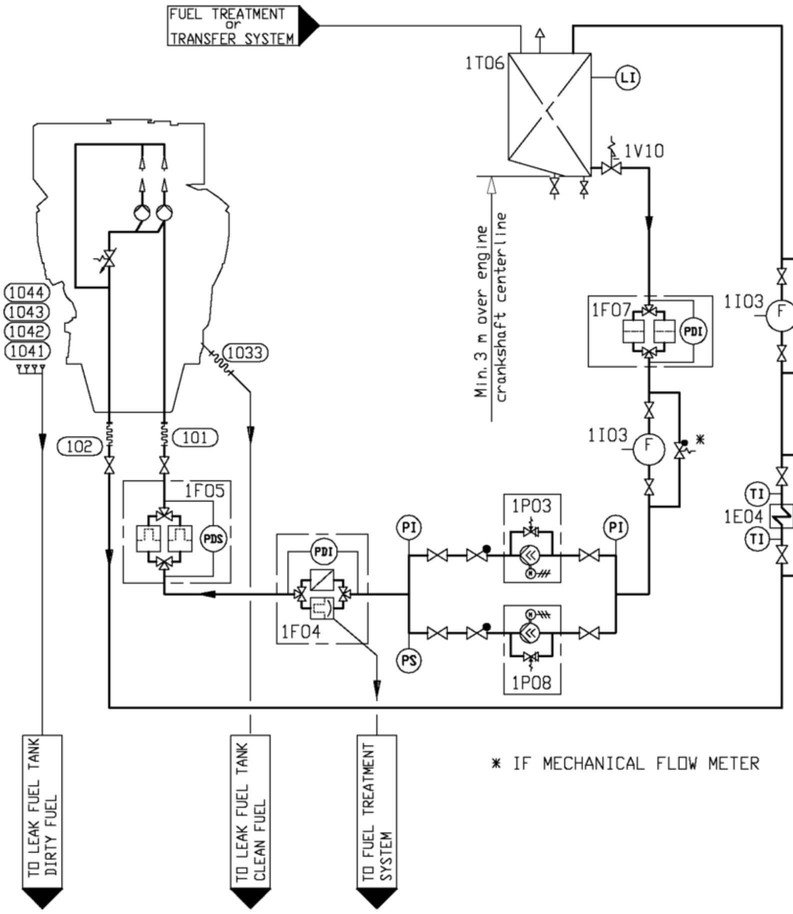


Figure 14. Example fuelling flow scheme for W31DF single main engine, with auxiliary component 1P03 Circulation Pump (MDF). (Wärtsilä 2019a)

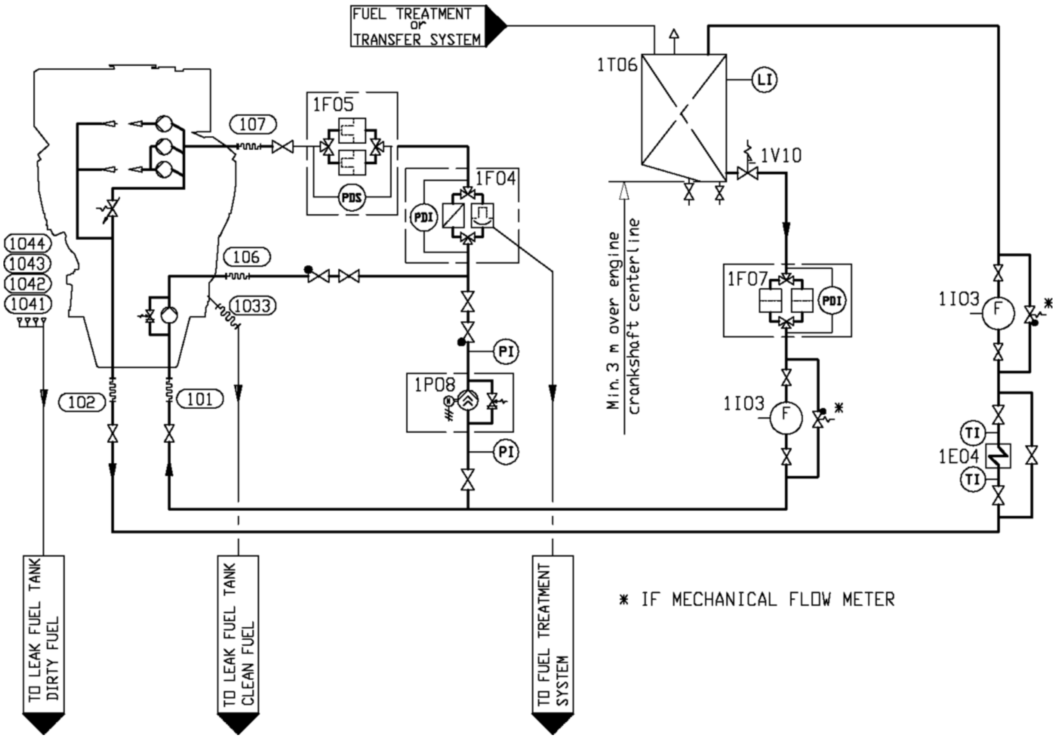


Figure 15. Example fuelling flow scheme for W31DF single main engine, with component 1P03 Circulation Pump (MDF) integrated in the engine. (Wärtsilä 2019a)

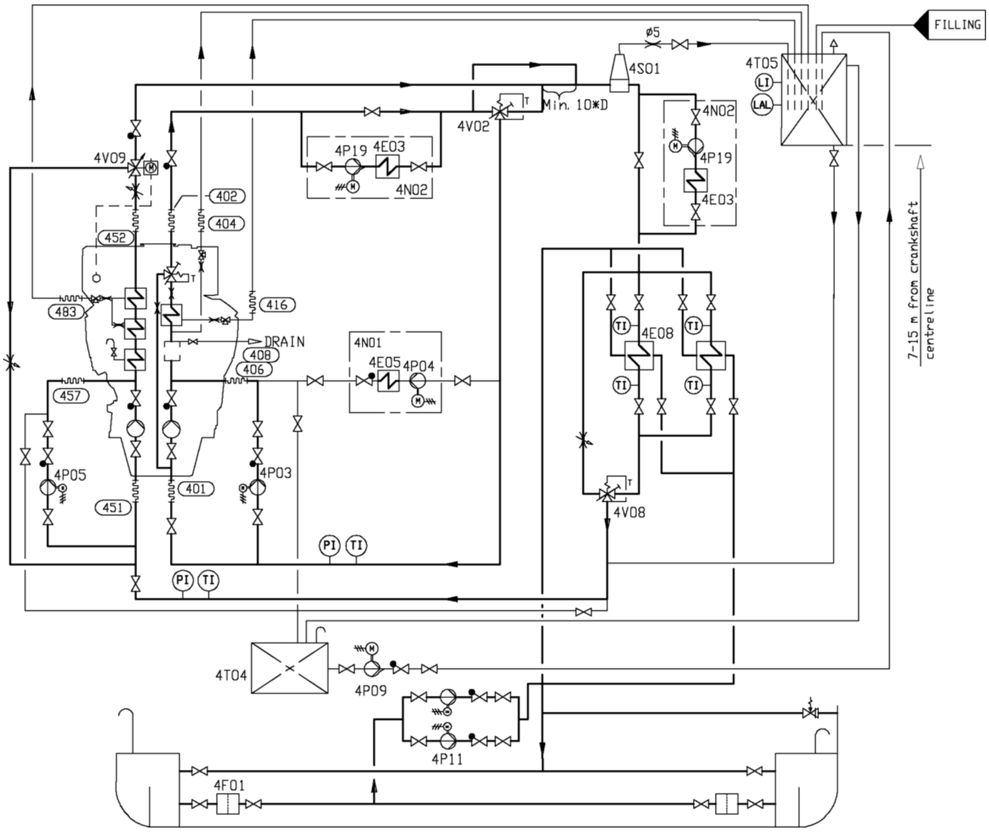


Figure 16. Example of external cooling water system flow scheme for W31DF single main engine. (Wärtsilä 2019a)

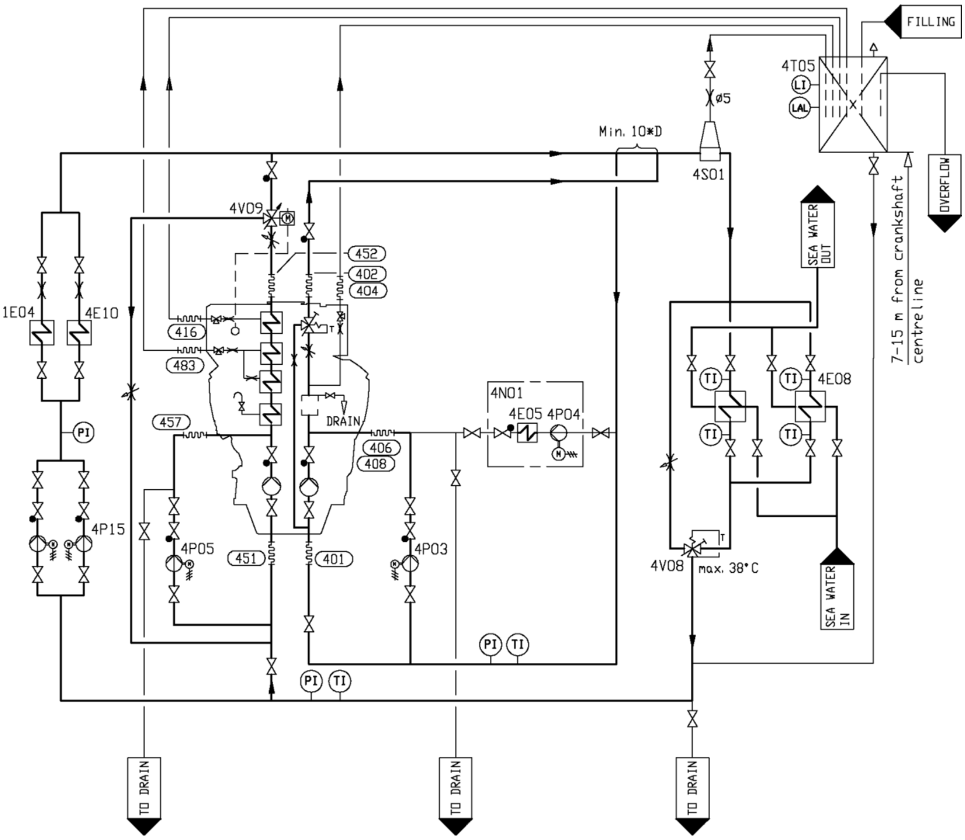


Figure 17. Example of arctic solution, external cooling water system flow scheme for W31DF single main engine. (Wärtsilä 2019a)

3.1.2 System component selections

All the existing and new system component function codes (seen in table 9, Chapter 4.2.1) were checked in TERPS (Total Engine Room Package for auxiliary Systems), based on the W31DF technical requirements (seen in Wärtsilä 2019a). TERPS is an internal auxiliary system product portfolio with standardised system components. TERPS was used to interpret the function codes which had been used to define the various system components.

The engine technical specifications were considered as requirements when the system components were selected. The technical specifications were engine arrangements, fuel mode, engine speed and load for different systems such as fuel oil system, HT cooling water system, LT cooling water system as well as heat balance. According to Wärtsilä (2019a) each W31DF engine arrangement (ME, AE and DE) had different specifications at different engine speeds 720 RPM and 750 RPM, and if either gas mode or diesel mode was used. The engine arrangement, engine speed and which fuel mode had the highest rate in the specifications determined the requirements that had to be fulfilled. Thus, the requirements determined the capacity of the system components which were to be selected.

A specification for the arrangements was heat balance, which specified the jacket water and charge air heat. Jacket water and charge air heat summed the total HT-circuit heat load at 100 % engine load. The purpose of the total HT heat balance was for this case required to calculate and determine an appropriate heat exchanger (4E03). In accordance with the information given in Chapter 2.2.1.1, a non-standardised plate heat exchanger used for a LT-circuit was adapted. The plate heat exchanger's specifications were used as boundary conditions, to calculate and validate the information in Chapter 2.2.1.1 (see Appendix A for calculations). The calculations were further adapted for the W31DF auxiliary unit, as the HT-circuit would work as hot fluid in the heat exchanger while a vessel's heating system would work as cold fluid (see Appendix B for calculations).

Other general components included in the auxiliary unit were represented by general function symbols in the functional mapping, unlike the function codes which represented the system components. The function symbols representing other components i.e. general valves such as butterfly valves, ball valves, non-return valves, reduction valves, temperature indicators and sensors, as well as pressure indicators and sensors. The valves were either manually actuated or electrically pneumatically actuated. System component and connection inlet and outlet sizes were considered when selecting the general components, as the inlet and outlet sizes naturally determined the dimensions of the general components.

3.2 Conceptual design

The next step of the design phase is mainly embodiment design, which commonly is interpreted and defined as conceptual design. This chapter covers the conceptual design and concept generation for the W12-16V31DF cooling and fuelling unit variant. The conceptual design is designed in CAD application Siemens NX11 using PDM application Siemens Teamcenter to gather and store information, 3D-models and drawings. Gathered and stored models are mainly the selected system components, general components, and various assemblies and standardised material profiles.

3.2.1 Conceptual 3D assemblies

The vision of the concept was that the assembly would consist of a supporting frame structure made of rectangular hollow tubes and various supports. The frame would be holding all the system components, general components, connection flanges and all the piping. To be viable to create an initial 3D assembly, different CAD models were gathered internally and from various suppliers. Models gathered were the selected system components, valves, non-return valves and various frame materials. The system components and connections flange sizes information were gathered in accordance with the engine technical specifications and the various component technical specifications. The vessel connection sizes were empirically dimensioned in accordance with which circuit interfaces within the auxiliary system they interacted with as well as which external equipment they interacted with.

All applicable fuelling and cooling inlet and outlet connection placements for the auxiliary unit as well as the counterpart connection placements on the engine side (for all cylinder configurations) were further analysed. This covers cooling water connections E101, E102, E106, E107 and fuel connections E401, E402, E406, E408, E451, E452 and E457. Additionally, generator and gearbox specific connection G460 and G461 placements were analysed. By conforming the placements of the counterpart connections on the engine side, it was logically determined where all the inlet and outlet connections for the auxiliary unit had to be placed.

All the pipelines and pipe flanges linking all the system components, inlet and outlet connections seen in table 11 (Chapter 4.2.2) as well as the general components were considered when all the flanges were designed for the auxiliary unit. The flanges were designed as welding flange type 01 according to standard EN 1092-1 (ISO 7005-1) and material standard according to ISO 630-2. Internal steel pipe guidelines and technical data from pipe suppliers were gathered when the straight and bent steel pipes were designed. Steel pipes commonly require interfaces to its surroundings such as pipe fittings, clamps and slide in connections which were all considered and used while attempting a first-hand conceptual design.

Manually actuated shut-off valves of butterfly type were added for certain connections. The shut-off valves were added for E106, E107, both G460, both G461, as well as in and outlet LNGPac connections. The shut-off valves were assembled in between two pipe flanges, placed at the end of the connections.

The system components, automated valves, indicators, sensors and instrumentation often require different types of electrical and automation (E&A) equipment to function, i.e. circuit boards, power supplies, relays, pump motor starters, main switches, power buttons, reset buttons and electrical cables. The E&A equipment were considered and visually represented by a cabinet. The intention of the cabinet was to store the necessary and vital E&A equipment related to all the components. In cooperation with the E&A Engineering department, the cabinet dimensions were estimated to preliminary 1600 x 1200 x 300 mm. Focus was mainly held on mechanical engineering and less focus on cabling.

A general arrangement was also designed to further clarify the scale perspective of the W12-16V31DF cooling and fuelling unit. The general arrangement consisted of a W16V31DF genset assembly, the auxiliary unit, and a 180 cm human representation. In the general arrangement the auxiliary unit was placed at the free end of the engine, with a reasonable distance in between and on the same floor level. The free end of an engine is the opposite side to the driving end which is commonly occupied by a generator in a genset arrangement or a gearbox in a main engine arrangement.

The genset assembly used a simplified engine model, simplified common base frame and a simplified generator. Simplified model means a model with lower amount of details and interior, compared to a model used for i.e. manufacturing, machining and welding drawings. Commonly, simplified models are used for engine representations suitable for sharing externally in public.

The general arrangement representation was complemented with piping and hoses. External vessel equipment related to cooling water were connected with pipelines to the auxiliary unit, likewise between the auxiliary unit and the Genset. External vessel equipment related to MDF were connected with hoses to the auxiliary unit, likewise between the auxiliary and the Genset. Piping for non-auxiliary unit related connections such as lube oil, compressed air as well as natural gas were also designed for the general arrangement. To differentiate what pipelines and hoses contain, colour markings are used in accordance with international standards. Pipe and hose colour markings used were based on the ISO 14726 standard.

- ISO 5031 Green colour marking represents sea water (cooling water)
- ISO 5008 Blue colour marking represents fresh water (cooling water for heat recovery)
- ISO 5018 Brown colour marking represents fuel (MDF)
- ISO 5091 Yellow colour marking represents flammable gases (natural gas)
- ISO 5063 Orange yellow colour marking represents oil other than fuel (lubricating oil)
- ISO 5043 Grey orange colour marking represents non-flammable gases (compressed air)

For the results and analysis of the first-hand concept of the W12-16V31DF cooling and fuelling unit assembly and the general arrangement, see Chapter 4.3.

4 Analysis and results

This chapter covers the analysis and results of the procedures, such as the marine market segment function analysis, the initial design of the auxiliary unit, as well as the conceptual design of the W12-16V31DF auxiliary unit variant. Additionally, this chapter covers descriptive functional and technical specifications for the auxiliary unit variants.

4.1 Market segment function analysis

As of the thesis delimitations, the market research was not redone since a market research in the thesis by Törnqvist (2018) focused on the same objective – market segment shares and possible installations of W31 engines for the marine market segments.

The collected data from the Clarksons World Fleet Register, were limited to vessels built from 2014 to 2018 which were either commissioned vessels or vessels in service. A quantitative method with secondary data was used, where the collected data gave information of approximately 7000 vessels. The segments were investigated and achieved by specifying the segments for each vessel type in accordance with Wärtsilä's specifications.

The marine market was segmented in accordance with segmentation (step 1) of Chapter 2.3.2, to better understand the marine market segments as well as the broad marine market. The previously developed auxiliary unit concept was based on the Offshore segment, which is the most demanding marine market segment (except the Navy segment). Since the Offshore segment is a demanding market segment, the same functional requirements should be applicable to the less demanding segments (Merchant, Cruise & Ferry, and special vessels) as well. Functionalities and demands could potentially vary depending on which market segment the auxiliary unit would be used in, thus could cause variants of the auxiliary unit. Regardless of the market segment, the different market segments are expected to have most of the functionalities and demands in common.

In accordance with targeting process (step 2) of Chapter 2.3.2, the segments Offshore, Merchant, Cruise & Ferry and Special Vessels are targeted segments. Thus, they were expected to provide most value based on Wärtsilä's strengths and the expected function commonalities of the auxiliary unit. The Navy segment was decided to be left out due to the segment being further demanding and potentially causing further auxiliary unit variants, e.g. due to shock absorption demands. Additionally, the Navy segment covers the least amount of marine market shares compared to the other marine segments according to the marine market share pie chart in figure 9 (Chapter 2.3.4). By positioning the targeted segments (step 3) according to Chapter 2.3.2, greater value for the targeted customers should be created, if the pre-engineered modular auxiliary unit is developed (according to Chapter 2.2.1).

It was decided to apply the functionalities from the Offshore segment to the other marine segments. Unexpected alterations of demands from a certain segment might cause product variance. Product variance will be compensated by utilising interchangeable auxiliary modules. Thus, the same auxiliary unit can be offered to the broad market, instead of an auxiliary unit with functionalities and attributes that are compromised.

4.2 Initial design

This chapter covers analysis and results of the functional mapping, system component selections and determination of auxiliary unit variants. The functional mapping results are compiled to a list of system components and connections. The system components and connections have different function codes which represent the functionality of the actual components. These actual components are selected from different system component suppliers and compiled into a list consisting of engine technical requirements and system component specifications.

4.2.1 Functional comparison and analysis

Commonly DF-engines are designed to use either liquid fuel or gas fuel. During diesel operation the engine operates on the Diesel cycle (compression ignition), and during gas operation the engine operates on the Otto cycle. Typically, for an Otto cycle spark plug ignition is used, however DF-engines instead uses injection of small amount of diesel fuel (pilot fuel) to ignite the compressed gas fuel & air mixture in a cylinder’s combustion chamber. DF-engines such as the W20DF and W34DF have separate pilot fuel connections, compared to the W31DF. For the W31DF, connections E112 (to engine pilot fuel inlet) and E117 (from engine pilot fuel outlet) were unavailable due to that the connections had been integrated with the fuel system connections E101 (to engine fuel inlet) and E102 (from engine fuel outlet). Due to the unavailable external connections, the components 01 (pressure reduction valve) and IF10 (pilot fuel fine filter MDF) which were dependent of E101 and E102 were not applicable for the W31DF.

Connection E105 (to engine fuel stand-by connection) was also unavailable for the W31DF. However, new connections E106 (from engine fuel to external filter) and E107 (fuel from external filter to engine) were available according to figure 15. There are two engine model scenarios, one where the component 1P03 (circulation pump, MDF) is integrated on the engine (seen in figure 14). In the second scenario (seen in figure 15), 1P03 is an external circulation pump which is parallel connected with 1P08 (stand-by pump, MDF). This also caused two similar scenarios for the cooling and fuelling unit.

Component 1P08 was available for the W31DF but connected with the unavailable connection E105. 1P08 in this case was either connected to E101 in the first scenario (seen in figure 14), or parallel connected with E106 in the second scenario (seen in figure 15). Both scenarios used new components 1F04 (automatic filter, MDF) and IF05 (fine filter, MDF). These filters were added and connected in a series to either connection E101 or E107. Other fuelling related components such as 1F07 (suction strainer, MDF), 1I03 (flow meter, MDF) and 1E04 (cooler, MDF) remained unchanged.

Fuel flow meter (1I03) remained unchanged. The flow meter was used for monitoring the fuel supply consumption for both inlet (connection E3) and outlet (connection E4). The suction strainer (1F07) must ensure a positive static pressure of about 30 kPa on the suction side of the MDF circulation pump (e.g. 1P03 and 1P08). In case of excessive pressure drop, a by-pass line around the flow meter automatically opens (Wartsila 2019a).

Cooling related connections (seen in figure 16 and 17) such as E401 (to engine HT-water inlet), E402 (from engine HT-water outlet), E406 (water from preheater to engine HT-circuit), E451 (to engine LT-water inlet), E452 (from engine LT-water outlet), G460 (LT-water to generator/gearbox) and G461 (LT-water from generator/gearbox) remained unchanged.

Additional new connections such as E408 (HT-water from stand-by pump) and E457 (LT-water from stand-by) were added. Connection E408 was connected to same outlet as E406, with a new component 4P03 (stand-by pump, HT) connecting them. Connection E457 was added along-side with connection E451, with a new component 4P05 (stand-by pump, LT) connecting them. According to Chapter 2.2.1 DP-class demands redundancy, thus E457 and 4P05 were required. Simultaneously, two 4P15 (circulating pump, LT) were necessary. One circulation pump worked as a primary, while the other as a stand-by pump.

When external equipment (generator or a gearbox) are installed in the same cooling water circuit, there must be a common LT temperature control valve and separate circulating pump (4P15) in the external system. In this case the common LT temperature control valve (4V03) is installed after the central cooler and controls the temperature of the water before the engine and the external equipment, by partly bypassing the central cooler. The valve in this case is electrically actuated. The recommended set-point of the temperature control valve 4V03 is 35 ºC, due to max LT cooling water temperature before engine is 38 ºC (Wartsila 2019a).

LT temperature control valve (4V03) was no longer applicable, but component 4V08 (temperature control valve, central cooler) was. The function code varied, but the temperature control valve was similar. Component 4V03 was unavailable due to the component is related to connection E1 (to vessel central cooler/box cooler) and E2 (from vessel central cooler/box cooler) which are connections not utilised in general engine installations seen in figure 16 and 17. It was decided that component 4V03 would remain unchanged.

Temperature control valve 4V02 after the heat recovery (4E03) controls the maximum temperature of the water that is mixed with HT water from the engine outlet (E401) before the HT pump. In this case the control valve is electrically actuated. Especially in installations with DP feature, installation of valve 4V02 is recommended to avoid HT temperature fluctuations during low load operation (Wartsila 2019a). The set-point is usually 75 ºC, and the max HT cooling water temperature before engine is 83 ºC (Wartsila 2019a).

Other cooling related components such as 4E03 (heat recovery/evaporator), 4E05 (heater, preheater), 4P04 (circulating pump, preheater), and 4V02 (temperature control valve, heat recovery) were applicable and remained unchanged. Preheater 4E05 is used to heat HT water temperature to minimum 70 ºC. This take approximately 10-15 hours when recommended heating power is 5 kW/cylinder (Wartsila 2019a).

Component 4V09 (temperature control valve, charge air) was only applicable for W31DF. The temperature of the charge air is maintained on desired level with an electrically actuated temperature control valve in the LT circuit. The control valve regulates the water flow through the LT-stage of the engine charge air cooler according to the measured temperature in the charge air receiver. Additionally, for W31DF the charge air temperature is controlled according to engine load.

Existing and new cooling and fuelling component & connection function codes and descriptions for the auxiliary unit were compiled into a list, which can be seen in table 9. Due to secrecy, the designed cooling and fuelling unit flow schemes have not been included in the thesis.

Table 9. Existing and new main connection & component descriptions and codes compilation for the W31DF cooling and fuelling unit.

DESCRIPTION		E/N	CODE	APPLY
FUEL CONN.	To Engine fuel inlet	E	E101	OK
	From Engine fuel outlet	E	E102	OK
	To Engine fuel stand-by connection		E105	N/A
	To Engine pilot fuel inlet		E112	N/A
	From Engine pilot fuel outlet		E117	N/A
	Fuel to external filter	N	E106	OK
	Fuel from external filter	N	E107	OK
COOLING CONNECTIONS	To Engine HT-water inlet	E	E401	OK
	From Engine HT-water outlet	E	E402	OK
	Preheated water to engine HT-circuit	E	E406	OK
	HT-water from stand-by pump	N	E408	OK
	To Engine LT-water inlet	E	E451	OK
	To Engine LT-water outlet	E	E452	OK
	LT-water to generator/gearbox	E	G460	OK
	LT-water from generator/gearbox	E	G461	OK
	LT-water from stand-by	N	E457	OK
FUEL COMPONENTS	Pressure reduction valve		01	N/A
	Cooler (MDF)	E	1E04	OK
	Automatic filter (MDF)	N	1F04	OK
	Fine filter (MDF)	N	1F05	OK
	Suction strainer (MDF)	E	1F07	OK
	Pilot fuel fine filter (MDF)		1F10	N/A
	Flow meter (MDF)	E	1I03	OK
	Circulation pump (MDF)	N	1P03	OK
	Stand-by pump (MDF)	E	1P08	OK
COOLING COMPONENTS	Heater (LT preheater)	N	02	OK
	Heat recover / (Evaporator)	E	4E03	OK
	Heater (preheater)	E	4E05	OK
	Stand-by pump (HT)	N	4P03	OK
	Circulating pump (HT preheater)	E	4P04	OK
	Stand-by pump (LT)	N	4P05	OK
	Circulating pump (LT)	E	4P15	OK
	Temperature control valve (heat recovery)	E	4V02	OK
	Temperature control valve (LT)	E	4V03	OK
	Temperature control valve (charge air)	E	4V09	OK
VESSEL CONNECTIONS	From LNGPac	E		OK
	To LNGPac	E		OK
	From Vessel heating system	E		OK
	To Vessel heating system	E		OK
	To Vessel central cooler/box cooler	E	E1	OK
	From Vessel central cooler/box cooler	E	E2	OK
	From Vessel fuel supply	E	E3	OK
	To Vessel fuel supply	E	E4	OK

4.2.2 System component selections and unit variants

Technical data requirements varied in between the W8V31DF to W16V31DF – according to Chapter 2.2.1, due to cylinder configuration determined the size of components. E.g. a W8V31DF require capacity of an engine driven pump 80 m^3/h (nominal) in a HT cooling water system, while a W10V31DF and W16V31DF require capacity of 90 m^3/h respectively 150 m^3/h. Thus, capacity of e.g. component 4P05 (stand-by pump, LT) had to deliver at least the minimum volume flow dependently on which cylinder configuration.

All the existing and new system components (seen in table 9) were available in TERPS except 4E03 (heat recovery/evaporator), 4E05 (heater, preheater) and 4P04 (circulating pump, preheater) due to the components were not standardised. Information was gathered internally and from suppliers.

The purpose of the heat exchanger (4E03) is to transfer heat from hot fluid to a cold fluid. In this case the HT cooling water works as a hot fluid and the vessels heating system (fresh water circulation from i.e. a boiler) as a cold fluid. A plate heat exchanger used for a LT temperature arrangement, had a 400 kW rate of heat exchange in a LT arrangement (see Appendix A), while theoretically having 1160 kW rate of heat exchange in the current arrangement (see Appendix B). The hot temperature inlet 93 °C and outlet 75 °C, as well as cold temperature inlet 60 °C and outlet 74 °C determined the maximum rate of heat exchange for a counter-current plate heat exchanger from the same supplier, while using same specified boundary conditions such as mass flow rates, design pressure and heat surface area.

A trend showed that the cylinder configurations W8V31DF and W10V31DF determined one auxiliary unit variant, and the cylinder configuration W12V31DF, W14V31DF and W16V31DF determined a second auxiliary unit variant. In most component selection cases, two component variants per system code were required to fulfil the requirements for the whole W31DF range. E.g. required fuel oil flow to engine was 3,6 m^3/h for W8V31DF and W10V31DF, while W12V31DF, W14V31DF and W16V31DF required 7,2 m^3/h. In other terms the components in the lower ranging cylinder configuration ends were oversized. As least possible number of variants was preferred, it was decided to maintain two variants of W31DF auxiliary units covering the whole W31DF engine range.

The W31DF technical requirements and corresponding system components were compiled into a technical specification and requirements list, which can be seen in table 10. Due to secrecy, the system component suppliers have not been included in the thesis.

Table 10. Auxiliary unit technical specification and requirement list specified in accordance with engine technical requirements.

W31DF	Engine requirements					System component spec.					
COOLING AND FUELLING AUXILIARY UNIT	**Required Vol. flow** [m3/h]					**Max Vol. flow** [m3/h]		**Connection Inlet size** [mm]		**Connection Outlet size** [mm]	
System Components	**V8**	**V10**	**V12**	**V14**	**V16**	**V8-V10**	**V12-V16**	**V8-V10**	**V12-V16**	**V8-V10**	**V12-V16**
Circulation pump (MDF) **1P03**	3,6		7,2			4,5	9	DN50	DN65	DN50	DN65
Stand-by pump (MDF) **1P08**						4,5	9	DN50	DN65	DN50	DN65
Flow meter (MDF) **1I03**						4	12	DN40	DN40	DN40	DN40
Cooler (MDF) **1E04**						5	8	KL7150	DN65	KL7150	DN65
						9	14	KL3057	DN50	KL3057	DN50
Suction strainer (MDF) **1F07**						7	12	DN50	DN65	DN50	DN65
Automatic filter (MDF) **1F04**						5	8	DN65	DN80	DN65	DN80
Fine filter (MDF) **1F05**						5,7	11,2	DN40	DN65	DN40	DN65
Stand-by pump (HT) **4P03**	80	90	110	130	150	100	150	DN100	DN150	DN100	DN150
Stand-by pump (LT) **4P05**						100	150	DN100	DN150	DN100	DN150
Circulating pump (LT) **4P15**						100	150	DN100	DN150	DN100	DN150
Temp. control valve, HR **4V02**						113	177	DN100	DN150	DN100	DN150
Temp. control valve (LT) **4V03 (4V08)**						113	177	DN100	DN150	DN100	DN150
Temp. control valve (LT) **4V09**						113	177	DN100	DN150	DN100	DN150
Circ. pump (preheater) **4P04**	8	10	12	14	16	10	16	DN50	DN50	DN50	DN50
	Heating capacity Power [kW]					**Max Heat cap.** [kW]		**Connection Inlet** [mm]		**Connection Outlet** [mm]	
Heater (HT preheater) **4E05**	40	50	60	70	80	54	81	DN40	DN40	DN40	DN40
Heater (LT preheater) **02**											
Heat recover **4E03 ***	1304	1630	1956	2282	2608	1160	1160	DN100	DN100	DN100	DN100
								DN100	DN100	DN100	DN100

Engine speeds 720 rpm, 750 rpm
Gas mode or diesel mode
* Max heating balance at 100 % load. Total HT-circuit (jacket-water and charge air)

4.2.3 Functional specification

The W31DF cooling and fuelling unit has adapted nearly all the functionalities from the boundary conditions of the previously developed auxiliary unit. Compared to the existing functionalities, the auxiliary unit has gained additional enhancing functionalities which ensure normal and safe operations. Such functionalities are redundancy, segregation, automatic stand-by fuel and cooling water feeding, blackout start fuel feeding as well as enabling heat recovery with set points to desired levels. The following summarised specification describe functionalities for both the W8-10V31DF and W12-16V31DF cooling and fuelling unit variants.

Fuel oil system

- Feeds and filters fuel oil
  - Automatic stand-by fuel feed if pump fails during normal operations
  - Automatic blackout start fuel feed with pneumatic pump
- Regulates fuel pressure and temperature
- Measures fuel consumption

LT cooling water system

- Preheating cooling water enables engine start in gas mode
- Regulates cooling water temperature based on temperature set-points
- Regulates cooling water temperature based on engine load
- Feeds cooling water for generator/gearbox
  - Automatic stand-by cooling water feed if pump fails during normal operations
- Enables LNG evaporation (DF models)
- Fuel oil cooling
- Automatic stand-by cooling water feed if pump fails during normal operations

HT cooling water system

- Preheating with preheater or with external heat source through reverse heat exchanger
- Regulates water temperature
- Enables heat recovery with set point for fresh water generation (different variants)
- Automatic stand-by cooling water feed if pump fails during normal operations

4.3 Conceptual design

First-hand planning and determining connection placements and connection flange sizes were critical. Ideally, the placement of the auxiliary unit should be at the free end of a W31DF engine since most counterpart cooling and fuelling connections were located at the free end.

Most of the connection flange sizes on the engine side determined the counterpart connection flange sizes for the auxiliary unit. The generator and gearbox specific G460 and G461 flange sizes were empirically dimensioned to DN80. The vessel connections E1 (to vessel central cooler/box cooler) and E2 (from vessel central cooler/box cooler) were dimensioned to flange sizes DN150, i.e. same as 4V03 (3-way temperature control valve, LT) since E2 was directly in circuit with the valve. Other vessel connections E3 (from vessel fuel supply) and E4 (to vessel fuel supply) followed the same reasoning, E3 and E4 were dimensioned to DN25 as the connections were determined by E101, E102, E106 and E107. The inlet and outlet vessel heating system connections were dimensions to DN100, which were determined by the plate heat exchangers (4E03) cold side inlet and outlet flange sizes.

Looking at the free end of the engine – fuel pipe connections E101, E102, E106 and E107 were located at end of the engine. Cooling water pipe connections E402, E401, E451, E406/E408 and E452 were located on the left side near the free end, while pipe connection E457 was located on the right side near the free end for V12, V14 and V16 cylinder configurations. However, pipe connection E457 was located on the left side for V8 and V10 cylinder configurations. Thus, all fuel connections were initially placed on the front right side of the auxiliary unit, while all the cooling water pipe connections were place on the front left side except E457 which was placed on the right side of the auxiliary unit.

The location of pipe connections G460 and G461 varies and depends of the generator or gearbox model. To solve either situation, it was determined to have double pipe connections on the auxiliary unit. A pair on the left side of the auxiliary unit and a second pair on the right side. Remaining connections were the vessel connections. Naturally, all the vessel connections indirectly connected to the engine were placed on the back side of the auxiliary unit.

Finally, all the standardised connections and components for the auxiliary unit were compiled into a pipe connection list based on table 9 and 10, which can be seen in table 11.

Table 11. W12-16V31DF auxiliary unit system components and connections with corresponding function codes and pipe connection flange sizes.

	DESCRIPTION	CODE	CONN.
FUEL C.	To Engine fuel inlet	E101	DN25
	From Engine fuel outlet	E102	DN25
	Fuel to external filter	E106	DN25
	Fuel from external filter	E107	DN25
COOLING CONNECTIONS	To Engine HT-water inlet	E401	DN150
	From Engine HT-water outlet	E402	DN150
	Preheated water to engine HT-circuit	E406	DN150
	HT-water from stand-by pump	E408	DN150
	To Engine LT-water inlet	E451	DN150
	To Engine LT-water outlet	E452	DN150
	LT-water to generator/gearbox	G460	DN80
	LT-water from generator/gearbox	G461	DN80
	LT-water from stand-by	E457	DN150
FUEL COMPONENTS	Cooler (MDF) - hot side	1E04	DN65
	Cooler (MDF) - cold side	1E04	DN50
	Automatic filter (MDF)	1F04	DN80
	Fine filter (MDF)	1F05	DN65
	Suction strainer (MDF)	1F07	DN65
	Flow meter (MDF)	1I03	DN40
	Circulation pump (MDF)	1P03	DN65
	Stand-by pump (MDF)	1P08	DN65
COOLING COMPONENTS	Heater LT (preheater)	02	DN40
	Heat recover / (Evaporator)	4E03	DN100
	Heater HT (preheater)	4E05	DN40
	Stand-by pump (HT)	4P03	DN150
	Circulating pump (preheater)	4P04	DN50
	Stand-by pump (LT)	4P05	DN150
	Circulating pump (LT)	4P15	DN150
	Temperature control valve (heat recovery)	4V02	DN150
	Temperature control valve (LT)	4V03	DN150
	Temperature control valve (charge air)	4V09	DN150
VESSEL CONNECTIONS	To Vessel central cooler/box cooler	E1	DN150
	From Vessel central cooler/box cooler	E2	DN150
	From Vessel fuel supply	E3	DN25
	To Vessel fuel supply	E4	DN25
	From LNG Pac	-	DN100
	To LNG Pac	-	DN100
	From Vessel heating system	-	DN100
	To Vessel heating system	-	DN100

4.3.1 Conceptual 3D assemblies

In accordance with Chapter 2.5.3-5, it is important to notice that there are a variety of ways designing a product, and it is especially difficult finding a final principle solution. To find an as near optimal solution as possible, often require several preliminary layouts which should be evaluated against economic and technical criteria. In this case, an attempt of a single preliminary layout was designed.

A first-hand attempt on a conceptual design for the auxiliary unit resulted in an assembly which dimensions were approximated preliminary 3000 mm (width) x 2000 mm (depth) x 3200 mm (height). Appropriate colours were selected based on the colour palette used for W31. Rendered trimetric views representing the auxiliary unit is seen in figure 18 and figure 19. In addition to the 3D assembly model, an outline drawing for the auxiliary unit was designed as well (see Appendix D). The outline drawing represents the auxiliary unit seen from different views that show preliminary dimensions, component and connection notes.

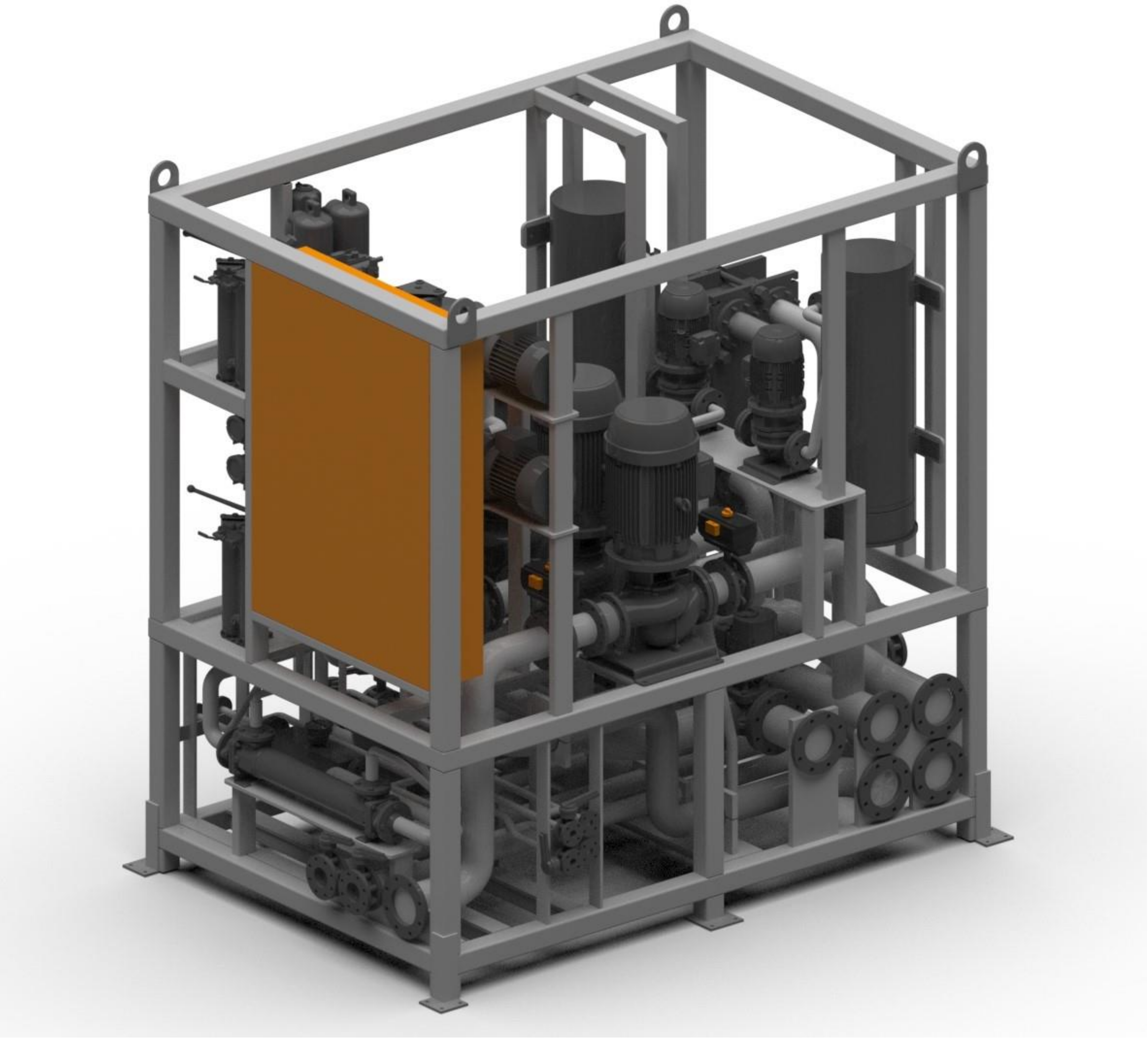


Figure 18. Trimetric view of the frontside of the assembled W12-16V31DF cooling and fuelling unit.

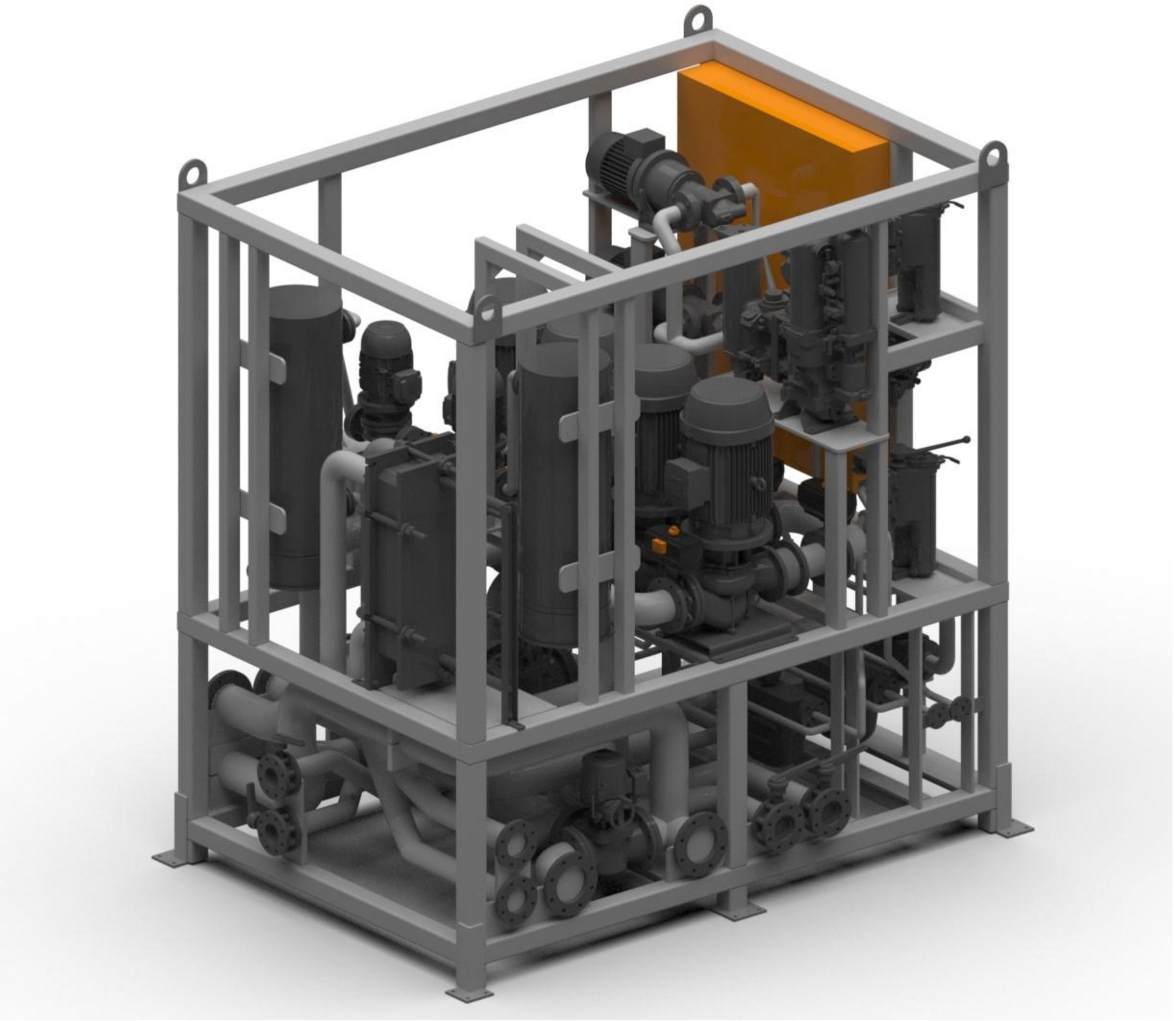


Figure 19. Trimetric view of the backside of the assembled W12-16V31DF cooling and fuelling unit.

According to Chapter 2.2 and problem definitions (Chapter 1.2) it is important to design a modular auxiliary product with a small footprint. A small footprint is required since engine room space is often a compromise of what space remains after vessel main functions are fulfilled. As it was desired to maintain a small footprint and a concentrated volume, naturally it was preferred to extend height of the auxiliary unit rather than extending width and depth.

There were many factors which contributed to decisions in the overall design for a compact modular auxiliary unit, e.g. space and margin utilisation. Intentionally excess space was implemented for different components and pipelines, while considering easy manufacturing, assembling and serviceability.

The auxiliary units frame structure consisted of various standardised profiles which initially should be welded. The frame consisted of hollowed square tubes, hollowed rectangular tubes, supports, brackets, pipe clamps, and various plates and bars. The frame consisted of two main sections. The idea of the two sections were to separate critical cooling and fuel components from the piping as well as cooling, fuel and vessel connections. The bottom section consisted of the piping and connections, three-way valves (4V02, 4V03 and 4V09), cooler (1E04) and the fuel flow meters (1I03). Remaining cooling and fuelling components as well as the E&A cabinet were placed in the top section. As utilisation of height was important, it was natural to place the preheating pressure containers in vertical installations.

While designing the layout of the auxiliary unit, considering service design was important. Necessary maintenance of the auxiliary unit should be as effortless and smooth as possible; thus the large system components were assembled in the top section. While considering service design, redundancy solutions were implemented. The redundancy solutions enables normal operations during failures. Redundancy were covered mainly by stand-by pumps such as centrifugal pump (1P08) and circulating pump (4P03 and 4P15). Utilising service design to further ease maintenance, excess space was saved above centrifugal pumps (1P03 and 1P08) and the circulating water pumps (4P03, 4P05 and 4P15). This means that lifting and replacing worn and broken critical feed pumps can take place during normal operations.

The plate heat exchanger (4E03) was placed in the top section of the auxiliary unit. As HT cooling water worked as hot fluid for heat recovery, the plate heat exchanger was placed next to the HT-water outlet (E402) piping. According to the plate heat exchanger technical specification, recommendations indicated that space should be kept free from fixed installations behind the back frame plate. As the current arrangement of installed plates summarised a heating surface of 8,1 m^2, there is excess space for additional plates. The surface area will increase if additional plates are installed. Thus, the rate of heat exchange will increase proportionally according to equation (8), Chapter 2.2.1.1.

The manually actuated shut-off valves for connections E106, E107, G460, and G461 as well as inlet and outlet LNGPac connections, were implemented to create further segregation functionality. Segregation in this context, means separating or isolating certain systems or components from the main functionality of the auxiliary unit. As these connections are dependable of which engine configuration and which type of generator is used, if the engine uses an integrated fuel feed pump, and which side the cooling water connections are located on a generator. The scenarios are described in Chapter 4.2.1.

The general arrangement was designed to further clarify the scale perspective for the auxiliary unit in comparison with a W16V31DF genset and a 180 cm human representation. As all engine cooling water and fuel inlet and outlets were located at the free end of the engine, the auxiliary unit was naturally placed at the free end of the engine. The location of the auxiliary unit at the free end of the engine would benefit the shipyard when considering minimising material usage. As all the counterpart connections on the auxiliary unit were logically placed near corresponding engine connections. Thus, required pipelines connecting the auxiliary unit and the engine means minimising pipeline lengths. Rendered trimetric view of the general arrangement is seen in figure 20.

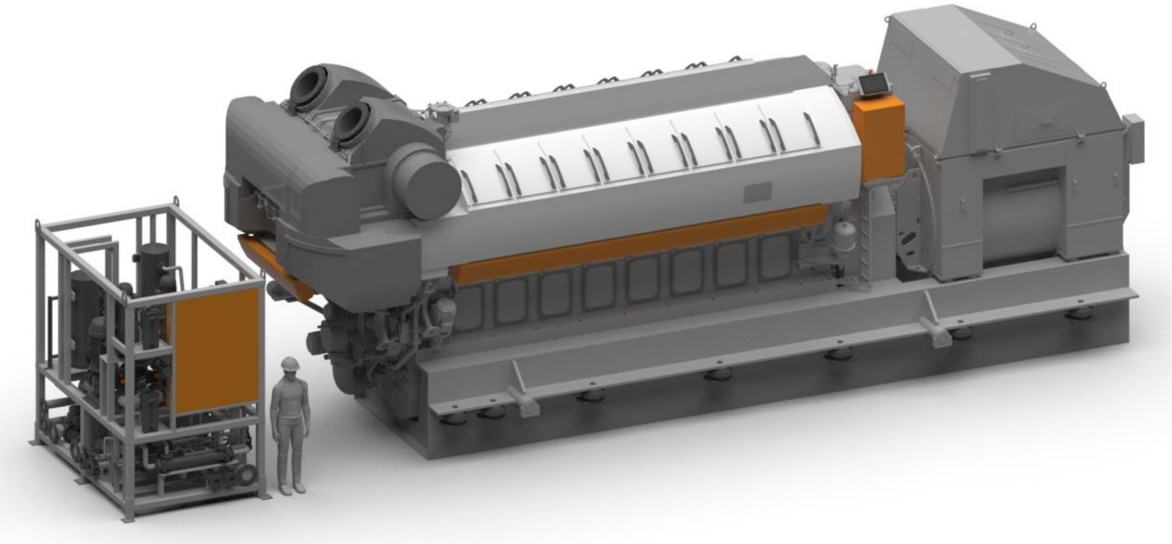


Figure 20. Trimetric side view of a general arrangement consisting of a W16V31DF genset (simplified model) and the auxiliary unit at the free end of the engine, next to a 180 cm human representation.

The general arrangement model was further enhanced by designing conceptual pipelines and hoses to visually clarify the coherence. Rendered trimetric views of the general arrangement are seen in figure 21 and 22.

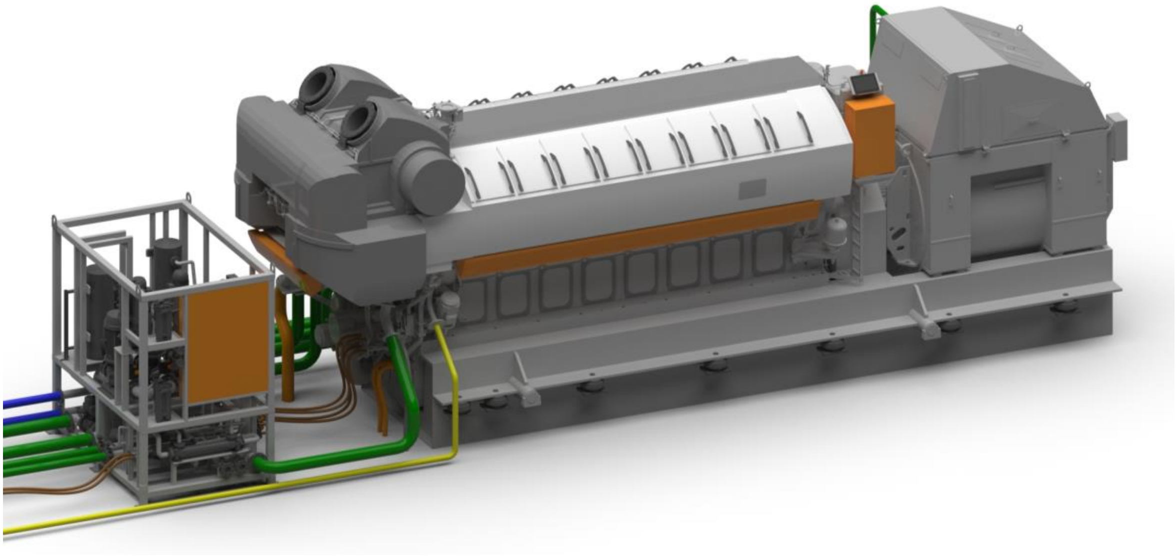


Figure 21. Trimetric side view (right side) of the general arrangement representation. External vessel related equipment connected with pipelines and hoses to the backside of the auxiliary unit. Auxiliary unit connected with pipelines and hoses to the W16V31DF Genset (simplified model).

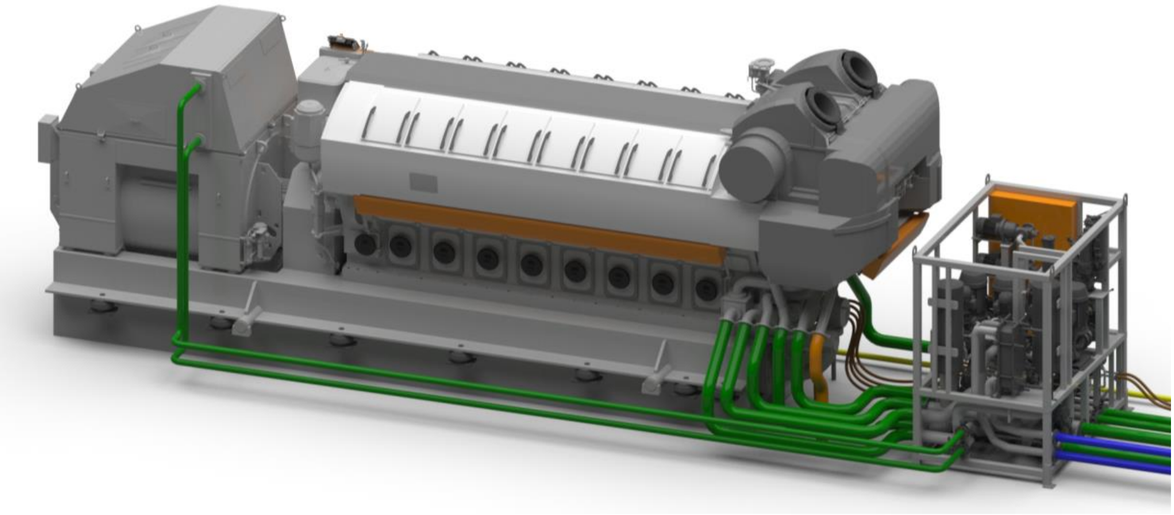


Figure 22. Trimetric side view (left side) of the general arrangement representation. External vessel related equipment connected with pipes and hoses to the backside of the auxiliary unit. Auxiliary unit connected with pipelines and hoses to the W16V31DF Genset (simplified model).

Prior to designing the bottom section and top section of the auxiliary unit required careful planning and decision making, as minimal footprint was important. Looking at figures 20, 21 and 22, the height of the auxiliary unit's bottom section was naturally defined by the total height of the Genset CBF. Often when shipyards plan and design engine rooms suitable for Gensets or main propulsion engines, the Gensets are mounted to the ship tank top and the floor is in line with the CBF top plates. This means the piping from the vessel going through the auxiliary to an engine and generator/gearbox will be beneath the floor. This will further benefit the height of the auxiliary unit, as the E&A cabinet, instrumentation and critical components are conveniently above the floor level.

5 Critical examination and discussion

This chapter summarises the design work with the cooling and fuelling unit and critically discusses and concludes the problems and challenges throughout the work. Finally, suggestions are contributed for further development, evaluation of the product development as well as own reflections on the task.

5.1 Problem areas

The starting point for the Auxiliary Unit for Power Supply thesis work was clear. A cooling and fuelling auxiliary had previously been developed for the Wärtsilä 20, and the main goal was to initiate development of a similar auxiliary unit concept for the Wärtsilä 31. Developing a modular product by adapting an existing modular product accordingly was challenging, fortunately there were many talented internal and external stakeholders involved throughout the entire process. In this chapter, some of the problem areas that occurred are discussed.

The strategy for the thesis work was to first make a thorough literature study and identify problems and solutions for similar cases. The main point of theory is from Krook (2015) which is a key to developing a good understanding in how modular auxiliary products work, especially in the Wärtsilä Power Supply context. As there were several various sub-goals throughout the thesis work, developing a good understanding for all the subjects was important. Considering product development methods and processes – the literature that proved to be most suitable and useful for developing a modular auxiliary product or nearly any type of industrial product were H. Johannesson, et al. (2013) and G. Pahl, et al. (2007).

The auxiliary unit's main functionality is to feed and regulate cooling water and fuel to a W31 engine installation on-board an eligible vessel. The foundation of functionalities that the auxiliary unit adapted were originally functionalities received through a functional break down of an Offshore Vessel's auxiliary systems. There are at least 50 known vessel types (Chapter 2.3.3) from the targeted segments Offshore, Merchant, Cruise & Ferry and Special Vessels. Investigating and identifying deviations in functionalities from segment to segment and sub-group to sub-group is problematic, fortunately the Offshore segment is the most demanding marine market segment where the auxiliary unit's functionalities apply – generally the other segments are expected to have most of the functionalities in common.

This is a problem area that needs to be further analysed thoroughly to ensure that this factually applies as well.

To develop, produce and sell an auxiliary product to customers within a marine market is challenging. Customers want to conceive a product useful and easy to use among other attributes. The auxiliary product should have a value that the customer is ready to utilise and invest in. According to H. Johannesson, et al. (2013) the past and upcoming decades have a distinctive sign of market segmenting and customer adaptation – among new product demands such as sustainability, environmentally friendly, secure and design. As product development is a complex and time consuming process, a modern development process is systematic and structured (looking at figure 11 and 12). Following each process step will naturally benefit each area of responsibilities, increase efficiency and meet the demands.

The product development process described in Chapter 2.5 contains several phases. To successfully complete each step, requires notable amount of resources and knowledge from different departments within the organisation, and external sources and suppliers. The main goal for the thesis was conceptual design of the auxiliary unit. A problem area throughout the design phase was the functional mapping, which contributed as a spine throughout the design phase. It was critical that the functional map would be as accurate as possible, since it determined which system components, general components and connections would exist. Unexpected changes for the functional map directly caused further changes of components, connections and piping. Examining all the selected system components and corresponding technical specifications in comparison with the engine requirements shaped the size of the overall design.

Designing an auxiliary unit based on a functional map proved to be challenging, as I had never designed a snake nest of pipes. I identified and studied similar design solutions, while bouncing thoughts and ideas with my supervisor Tomas Södö and colleague David Klemets. This raised questions such as; how similar solutions have been designed, where are the components commonly assembled, what profiles and materials were used for the frame structures, and what pipe lengths, radiuses and isolation should be used. This gave me beneficial information to finalise the first-hand concept of the W12-16V31DF auxiliary unit assembly. The key in designing the auxiliary unit assembly was to re-use classified profiles, materials and models available in our PDM system and from different sources. I.e. the entire frame structure is designed by re-used materials. Another re-used product and model was the plate heat exchanger (4E03).

Time planning for the project proved to be important from the moment it started. Initially, the intended market research was replaced by a brief market analysis of the major marine market segments. A major part of the project schedule included the literature study. Other deviations throughout the project occupying excess time was the plate heat exchanger. Dimensioning the heat exchanger required additional time, calculating and analysing the solution.

Throughout the work, modular thinking and the importance of auxiliary products grew ever stronger. Developing an auxiliary product within Wärtsilä is no news, since Wärtsilä has developed several successful standardised auxiliary products throughout the years i.e. the LNGPac product line along with the Gas Valve Unit (GVU). Modular auxiliary products have previously and mainly been designed on demand for specific projects on request from the specific shipyard or shipowner.

It is also worth mentioning that according to H. Johannesson, et al. (2013, 130-131) engineering in modules is beneficial from an environmental perspective, since it gives opportunities to replace modules with more environmentally adapted modules in the future. This instead of phasing out the product completely.

Demands for various types of auxiliary product solutions vary from customer to customer. Developing an auxiliary product solution for each individual divided demand will cause many product variants, which means maintaining all the variants will be costly. However, maintaining lower amount of product variants will potentially be more beneficial.

Certain components within the auxiliary unit are cost sensitive to customers. Mainly the HT-preheater (4E03 and 4P04) and LT-preheater (02 and 4P04) modules. Commonly, shipbuilders prefer a single or few preheaters when considering a vessel with several installed engines. The intended idea is to have one auxiliary unit per engine arrangement, which means the shipbuilder will potentially be overwhelmed of the number of preheaters. Thus, it is beneficial using interchangeable HT-preheater and LT-preheater modules, as the customer can choose the preferred number of preheaters. However, preheating will approximately take 10-15 hours when recommended heating power is 5 kW/cylinder – having a single preheater for several engines will increase the preheating time

Other interchangeable module solutions to consider are LT circulating stand-by pump (4P03) and connection E457, and HT circulating stand-by pump (4P05) as well as connections E106 and E107. Depending on engine configuration, in some cases E457 is not applicable. Thus, LT circulating stand-by pump (4P03) is not needed. When an engine fuel driven pump is not used, there is either no need for connection E106 or E107.

5.2 Further development

Wärtsilä's strategy is guiding future product development. The following quote: "decrease sourcing costs and increase standardisation and modulation of products" (Roger Holm, President Marine Business & EVP Wärtsilä Corp 2019) indicates this is the correct path to take when considering development of auxiliary products.

Further design development for the auxiliary unit would be finding a proper solution for the interchangeable module options, which were dependable of the engine configuration or preferred number of interchangeable modules. As the engine room space is commonly tight, it is optimal to reduce the footprint by designing even further on height. Pipe design development to consider is pipeline length, pipe routing and bending radius optimisation, as well as pipe isolation for pipes with temperature 50 °C or more. Other design aspects to consider is development of the E&A cabinet and integration of preheating unit cabinets, pump motor starter cabinets and automatic filter cabinet. Adding pump motor starter cabinets for each pump requires additional space than the current E&A cabinet size.

Throughout the work, the conceptual design was mainly in focus. By identifying and finding solutions for the essential problems in the functional mapping – an adapted function structure was established which further resulted in a principle solution for the auxiliary unit. The principle solution for the auxiliary unit was evaluated against technical criteria throughout the design phase. However, the principle solution further require a thorough evaluation against economic criteria. A cost estimation and analysis of the auxiliary unit variant needs to be made. Financial viability is required prior to working out the detail design. The product must be offered, sold and added to a project delivery scope of supply to receive required financing. If it is difficult to add the auxiliary unit to a scope of supply, a solution is to use a pilot project. During the pilot project, Wärtsilä will manage the risk of the auxiliary unit for testing, validation and classification.

Along with the financial viability, more layouts of the auxiliary unit needs to be produced – to determine advantages and disadvantages of the different layouts. This should lead to a definitive layout, which is the final design. Following remaining steps in figure 11 and Chapter 2.5, along with internal product development methods and processes, will eventually lead to manufacturing the product. Once shipbuilders and shipowners are persuaded of the cooling and fuelling unit, we are likely to see similar products developed in the future.

5.3 Conclusion

Personally, the idea of designing an auxiliary product had never come to mind. However, the thought of a challenging thesis project to work with had always been in my mind. The thesis project proposal my supervisor Tomas Södö presented, was initially meant for a master's thesis due its comprehensive content.

I believe that the objectives and requirements that were set at the start of the project have been fulfilled accordingly. The main objective was to initiate development of a W31DF cooling and fuelling unit, and through a thorough literature study clearly describe product development methods for developing new products in the power supply context. Hopefully the development of the auxiliary unit continues towards standardisation, once the cooling and fuelling unit concept is added in a scope of supply for a delivery project.

I have learned a lot throughout the work. Such as concrete understanding for product development, modularisation of products and the basics of the marine market segments, as well as thoughtfully engineering and solving problems. Throughout the entire project I was simultaneously managing my own area of responsibility and coordinating internal and external stakeholders. Other contributions to my professional development were pipe design, thinking in terms of material classifications and standards, and utilising Siemens Teamcenter.

To summarise my own performance, I have with an open mind tackled the project and adapted the tasks as needed. If I would have the opportunity redoing the project, I would use the same strategy. If I would have the opportunity redoing the design, I would set aim on a more minimised footprint. This would eventually lead into rearranging components in the second section of the auxiliary unit frame and create a third section. Overall, I am very pleased with my own performance and the design solution, and I am grateful for the thesis project opportunity. The work continues during spring 2019, when a cost estimation and analysis will be applied for all included components and materials.

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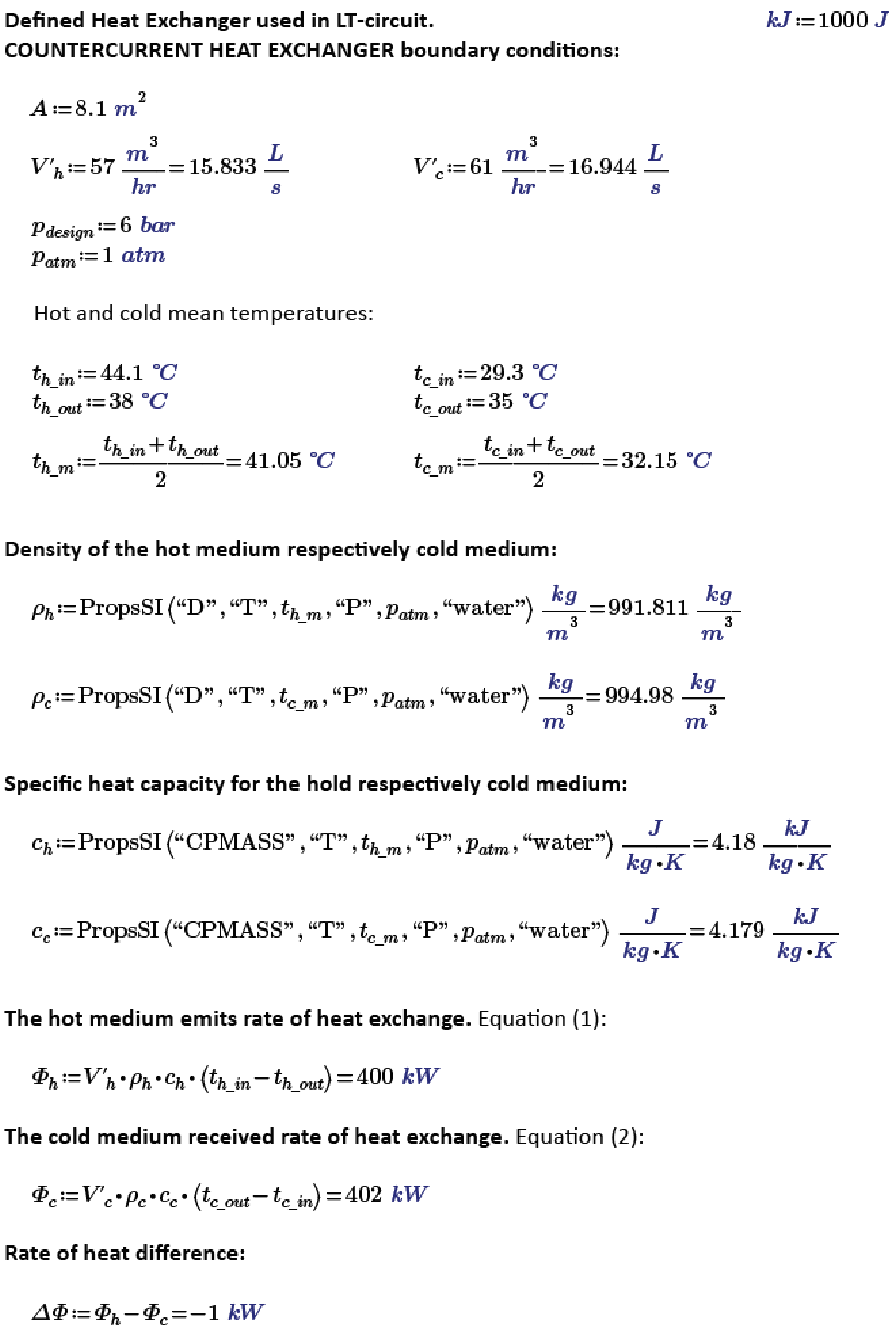
Appendix A. Countercurrent Heat Exchanger for LT-circuit, defined as boundary condition.



Defined Heat Exchanger used in LT-circuit.
COUNTERCURRENT HEAT EXCHANGER boundary conditions:

$kJ := 1000\ J$

$A := 8.1\ m^2$

$V'_h := 57\ \frac{m^3}{hr} = 15.833\ \frac{L}{s}$ $\quad V'_c := 61\ \frac{m^3}{hr} = 16.944\ \frac{L}{s}$

$p_{design} := 6\ bar$
$p_{atm} := 1\ atm$

Hot and cold mean temperatures:

$t_{h\_in} := 44.1\ °C$ $\quad t_{c\_in} := 29.3\ °C$
$t_{h\_out} := 38\ °C$ $\quad t_{c\_out} := 35\ °C$

$t_{h\_m} := \frac{t_{h\_in} + t_{h\_out}}{2} = 41.05\ °C$ $\quad t_{c\_m} := \frac{t_{c\_in} + t_{c\_out}}{2} = 32.15\ °C$

Density of the hot medium respectively cold medium:

$\rho_h := \text{PropsSI}\left(\text{“D”}, \text{“T”}, t_{h\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{kg}{m^3} = 991.811\ \frac{kg}{m^3}$

$\rho_c := \text{PropsSI}\left(\text{“D”}, \text{“T”}, t_{c\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{kg}{m^3} = 994.98\ \frac{kg}{m^3}$

Specific heat capacity for the hold respectively cold medium:

$c_h := \text{PropsSI}\left(\text{“CPMASS”}, \text{“T”}, t_{h\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{J}{kg \cdot K} = 4.18\ \frac{kJ}{kg \cdot K}$

$c_c := \text{PropsSI}\left(\text{“CPMASS”}, \text{“T”}, t_{c\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{J}{kg \cdot K} = 4.179\ \frac{kJ}{kg \cdot K}$

The hot medium emits rate of heat exchange. Equation (1):

$\Phi_h := V'_h \cdot \rho_h \cdot c_h \cdot \left(t_{h\_in} - t_{h\_out}\right) = 400\ kW$

The cold medium received rate of heat exchange. Equation (2):

$\Phi_c := V'_c \cdot \rho_c \cdot c_c \cdot \left(t_{c\_out} - t_{c\_in}\right) = 402\ kW$

Rate of heat difference:

$\Delta\Phi := \Phi_h - \Phi_c = -1\ kW$

Logarithmic mean temperature difference - 1. co-current and **2. countercurrent.**
Equation (7.1-7.4) and (6):

$$\vartheta_{1\_1} := t_{h\_in} - t_{c\_in} = 14.8\ K$$
$$\vartheta_{1\_2} := t_{h\_out} - t_{c\_out} = 3\ K$$

$$\vartheta_{lm1} := \frac{\vartheta_{1\_1} - \vartheta_{1\_2}}{\ln\left(\frac{\vartheta_{1\_1}}{\vartheta_{1\_2}}\right)} = 7.393\ K$$

$$\vartheta_{2\_1} := t_{h\_in} - t_{c\_out} = 9.1\ K$$
$$\vartheta_{2\_2} := t_{h\_out} - t_{c\_in} = 8.7\ K$$

$$\vartheta_{lm2} := \frac{\vartheta_{2\_1} - \vartheta_{2\_2}}{\ln\left(\frac{\vartheta_{2\_1}}{\vartheta_{2\_2}}\right)} = 8.899\ K$$

Overall heat exchange coefficient for co-current and countercurrent.
Equation (8):

$$U_1 := \frac{\Phi_h}{A \cdot \vartheta_{lm1}} = 6.7\ \frac{kW}{m^2 \cdot K}$$

$$U_2 := \frac{\Phi_h}{A \cdot \vartheta_{lm2}} = 5.6\ \frac{kW}{m^2 \cdot K}$$

Heat flow transmitted from hot fluid to cold fluid for both co-current and countercurrent.
Equation (8):

$$\Phi_1 := U_1 \cdot A \cdot \vartheta_{lm1} = 400.4\ kW$$

$$\Phi_2 := U_2 \cdot A \cdot \vartheta_{lm2} = 400.4\ kW$$

Temperature difference between incoming hot flow and cold flow:

$$\Delta t_h := t_{h\_in} - t_{h\_out} = 6.1\ K$$

$$\Delta t_c := t_{c\_out} - t_{c\_in} = 5.7\ K$$

$$\theta := t_{h\_in} - t_{c\_in} = 14.8\ K$$

Temperature efficiency for cooling of the hot medium. Equation (3):

$$\eta_h := \frac{\Delta t_h}{\theta} \cdot 100 = 41.2$$

Temperature efficiency for heating of the cold medium. Equation (4):

$$\eta_c := \frac{\Delta t_c}{\theta} \cdot 100 = 38.5$$

Appendix B. Countercurrent Heat Exchanger for HT-circuit.

Applied theoretical assumptions for a Heat Exchanger used in HT-circuit. $kJ := 1000\ J$

COUNTERCURRENT HEAT EXCHANGER boundary conditions:

$A := 8.1\ m^2$

$V'_h := 57\ \frac{m^3}{hr} = 15.833\ \frac{L}{s}$ $\quad V'_c := 61\ \frac{m^3}{hr} = 16.944\ \frac{L}{s}$

$p_{design} := 6\ bar$

$p_{atm} := 1\ atm$

Hot and cold mean temperatures:

$t_{h\_in} := 93\ °C$ $\quad t_{c\_in} := 57.3\ °C$

$t_{h\_out} := 75\ °C$ $\quad t_{c\_out} := 74\ °C$

$t_{h\_m} := \frac{t_{h\_in} + t_{h\_out}}{2} = 84\ °C$ $\quad t_{c\_m} := \frac{t_{c\_in} + t_{c\_out}}{2} = 65.65\ °C$

Density of the hot medium respectively cold medium:

$\rho_h := \text{PropsSI}\left(\text{"D"}, \text{"T"}, t_{h\_m}, \text{"P"}, p_{atm}, \text{"water"}\right)\ \frac{kg}{m^3} = 969.257\ \frac{kg}{m^3}$

$\rho_c := \text{PropsSI}\left(\text{"D"}, \text{"T"}, t_{c\_m}, \text{"P"}, p_{atm}, \text{"water"}\right)\ \frac{kg}{m^3} = 980.196\ \frac{kg}{m^3}$

Specific heat capacity for the hold respectively cold medium:

$c_h := \text{PropsSI}\left(\text{"CPMASS"}, \text{"T"}, t_{h\_m}, \text{"P"}, p_{atm}, \text{"water"}\right)\ \frac{J}{kg \cdot K} = 4.2\ \frac{kJ}{kg \cdot K}$

$c_c := \text{PropsSI}\left(\text{"CPMASS"}, \text{"T"}, t_{c\_m}, \text{"P"}, p_{atm}, \text{"water"}\right)\ \frac{J}{kg \cdot K} = 4.188\ \frac{kJ}{kg \cdot K}$

The hot medium emits rate of heat exchange. Equation (1):

$\Phi_h := V'_h \cdot \rho_h \cdot c_h \cdot \left(t_{h\_in} - t_{h\_out}\right) = 1160\ kW$

The cold medium received rate of heat exchange. Equation (2):

$\Phi_c := V'_c \cdot \rho_c \cdot c_c \cdot \left(t_{c\_out} - t_{c\_in}\right) = 1162\ kW$

Rate of heat difference:

$\Delta\Phi := \Phi_h - \Phi_c = -1\ kW$

Logarithmic mean temperature difference - 1. co-current and **2. countercurrent.**
Equation (7.1-7.4) and (6):

$$\vartheta_{1\_1} := t_{h\_in} - t_{c\_in} = 35.7\ K \qquad \vartheta_{2\_1} := t_{h\_in} - t_{c\_out} = 19\ K$$

$$\vartheta_{1\_2} := t_{h\_out} - t_{c\_out} = 1\ K \qquad \vartheta_{2\_2} := t_{h\_out} - t_{c\_in} = 17.7\ K$$

$$\vartheta_{lm1} := \frac{\vartheta_{1\_1} - \vartheta_{1\_2}}{\ln\left(\frac{\vartheta_{1\_1}}{\vartheta_{1\_2}}\right)} = 9.706\ K \qquad \vartheta_{lm2} := \frac{\vartheta_{2\_1} - \vartheta_{2\_2}}{\ln\left(\frac{\vartheta_{2\_1}}{\vartheta_{2\_2}}\right)} = 18.342\ K$$

Overall heat exchange coefficient for co-current and countercurrent.
Equation (8):

$$U_1 := \frac{\Phi_h}{A \cdot \vartheta_{lm1}} = 14.8\ \frac{kW}{m^2 \cdot K} \qquad U_2 := \frac{\Phi_c}{A \cdot \vartheta_{lm2}} = 7.8\ \frac{kW}{m^2 \cdot K}$$

Heat flow transmitted from hot fluid to cold fluid for both co-current and countercurrent.
Equation (8):

$$\Phi_1 := U_1 \cdot A \cdot \vartheta_{lm1} = 1160.2\ kW \qquad \Phi_2 := U_2 \cdot A \cdot \vartheta_{lm2} = 1161.5\ kW$$

Temperature difference between incoming hot flow and cold flow:

$$\Delta t_h := t_{h\_in} - t_{h\_out} = 18\ K$$

$$\Delta t_c := t_{c\_out} - t_{c\_in} = 16.7\ K$$

$$\theta := t_{h\_in} - t_{c\_in} = 35.7\ K$$

Temperature efficiency for cooling of the hot medium. Equation (3):

$$\eta_h := \frac{\Delta t_h}{\theta} \cdot 100 = 50.4$$

Temperature efficiency for heating of the cold medium. Equation (4):

$$\eta_c := \frac{\Delta t_c}{\theta} \cdot 100 = 46.8$$

Extra calculation: **MAXIMAL VOLUME FLOW RATE**

Applied theoretical assumptions for a Heat Exchanger used in HT-circuit.

COUNTERCURRENT HEAT EXCHANGER boundary conditions:

$$\text{clear}\left(t_{v\_in}, t_{v\_ut}, t_{k\_ut}, t_{k\_in}, q_v, q_k, \Phi_v, \Phi_k\right)$$

$$\Phi_h := 2600\ kW \qquad \Phi_c := 2600\ kW$$

$$t_{h\_in} := 93\ °C \qquad t_{c\_in} := 60\ °C$$

$$t_{h\_out} := 75\ °C \qquad t_{c\_out} := 92\ °C$$

$$t_{h\_m} := \frac{t_{h\_in} + t_{h\_out}}{2} = 84\ °C \qquad t_{c\_m} := \frac{t_{c\_in} + t_{c\_out}}{2} = 76\ °C$$

Density of the hot medium respectively cold medium:

$$\rho_h := \text{PropsSI}\left(\text{“D”}, \text{“T”}, t_{h\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{kg}{m^3} = 969.3\ \frac{kg}{m^3}$$

$$\rho_c := \text{PropsSI}\left(\text{“D”}, \text{“T”}, t_{c\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{kg}{m^3} = 974.2\ \frac{kg}{m^3}$$

Specific heat capacity for the hold respectively cold medium:

$$c_h := \text{PropsSI}\left(\text{“CPMASS”}, \text{“T”}, t_{h\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{J}{kg \cdot K} = 4.2\ \frac{kJ}{kg \cdot K}$$

$$c_c := \text{PropsSI}\left(\text{“CPMASS”}, \text{“T”}, t_{c\_m}, \text{“P”}, p_{atm}, \text{“water”}\right) \frac{J}{kg \cdot K} = 4.194\ \frac{kJ}{kg \cdot K}$$

The required hot medium mass flow rate. Equation (1):

$$\Phi_h = V'_h \cdot \rho_h \cdot c_h \cdot \left(t_{h\_in} - t_{h\_out}\right)$$

$$V'_h := \frac{\Phi_h}{\rho_h \cdot c_h \cdot \left(t_{h\_in} - t_{h\_out}\right)} = 127.7\ \frac{m^3}{hr}$$

The required cold medium mass flow rate. Equation (2):

$$\Phi_c = V'_c \cdot \rho_c \cdot c_c \cdot \left(t_{c\_out} - t_{c\_in}\right)$$

$$V'_c := \frac{\Phi_c}{\rho_c \cdot c_c \cdot \left(t_{c\_out} - t_{c\_in}\right)} = 71.6\ \frac{m^3}{hr}$$

Logarithmic mean temperature difference - 1. co-current and **2. countercurrent.**
Equation (7.1-7.4) and (6):

$$\vartheta_{1\_1} := t_{h\_in} - t_{c\_in} = 33\ K \qquad \vartheta_{2\_1} := t_{h\_in} - t_{c\_out} = 1\ K$$

$$\vartheta_{1\_2} := \left| t_{h\_out} - t_{c\_out} \right| = 17\ K \qquad \vartheta_{2\_2} := t_{h\_out} - t_{c\_in} = 15\ K$$

$$\vartheta_{lm1} := \frac{\vartheta_{1\_1} - \vartheta_{1\_2}}{\ln\left(\frac{\vartheta_{1\_1}}{\vartheta_{1\_2}}\right)} = 24.122\ K \qquad \vartheta_{lm2} := \frac{\vartheta_{2\_1} - \vartheta_{2\_2}}{\ln\left(\frac{\vartheta_{2\_1}}{\vartheta_{2\_2}}\right)} = 5.17\ K$$

Overall heat exchange coefficient for co-current and countercurrent.
Equation (8):

$$U_1 := \frac{\Phi_h}{A \cdot \vartheta_{lm1}} = 13.3\ \frac{kW}{m^2 \cdot K} \qquad U_2 := \frac{\Phi_c}{A \cdot \vartheta_{lm2}} = 62.1\ \frac{kW}{m^2 \cdot K}$$

Heat flow transmitted from hot fluid to cold fluid for both co-current and countercurrent.
Equation (8):

$$\Phi_1 := U_1 \cdot A \cdot \vartheta_{lm1} = 2600\ kW \qquad \Phi_2 := U_2 \cdot A \cdot \vartheta_{lm2} = 2600\ kW$$

Temperature difference between incoming hot flow and cold flow:

$$\Delta t_h := t_{h\_in} - t_{h\_out} = 18\ K$$

$$\Delta t_c := t_{c\_out} - t_{c\_in} = 32\ K$$

$$\theta := t_{h\_in} - t_{c\_in} = 33\ K$$

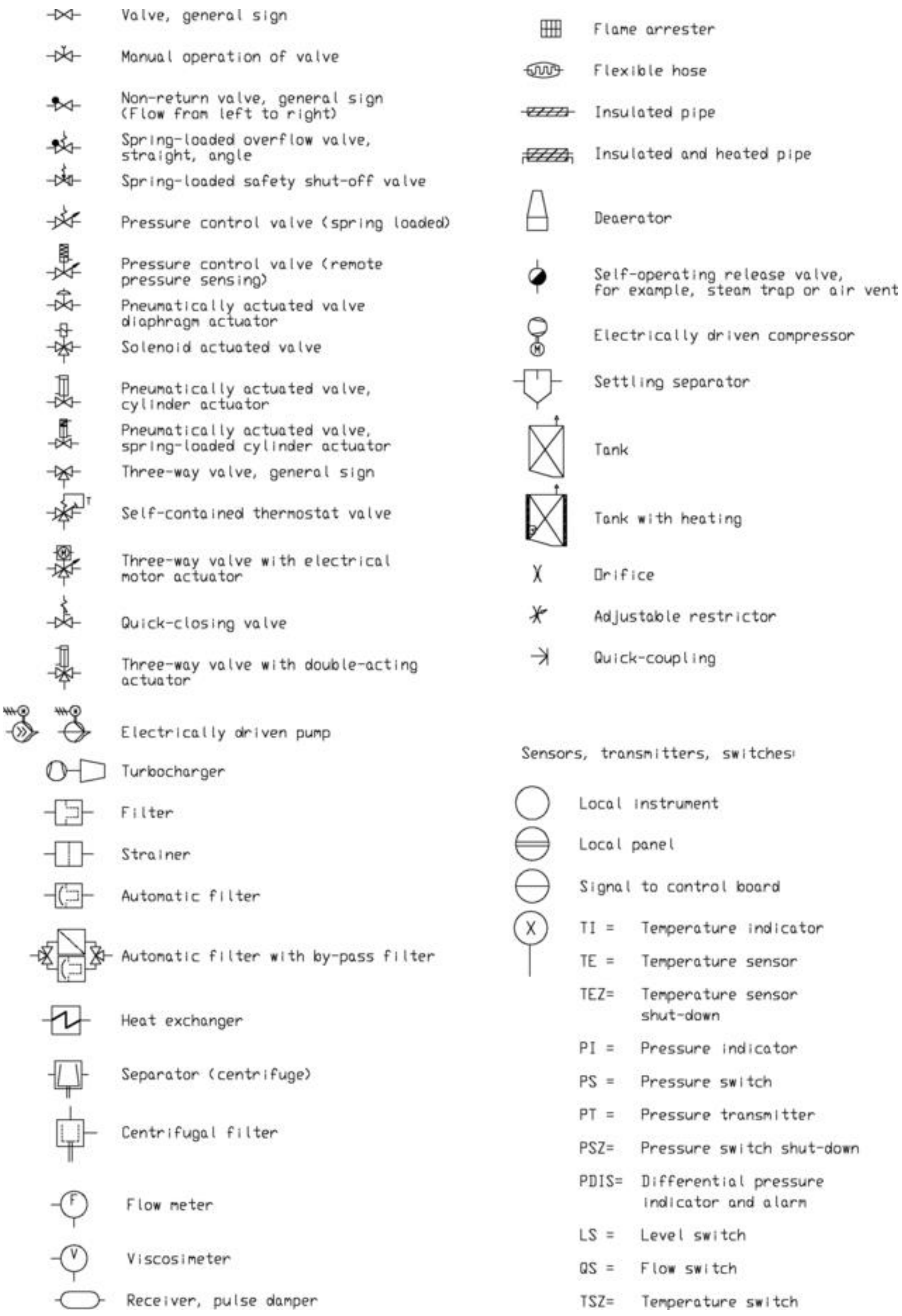
Temperature efficiency for cooling of the hot medium. Equation (3):

$$\eta_h := \frac{\Delta t_h}{\theta} \cdot 100 = 54.5$$

Temperature efficiency for heating of the cold medium. Equation (4):

$$\eta_c := \frac{\Delta t_c}{\theta} \cdot 100 = 97$$

Appendix C. General function symbols. (Wärtsilä)



Valve, general sign

Manual operation of valve

Non-return valve, general sign (Flow from left to right)

Spring-loaded overflow valve, straight, angle

Spring-loaded safety shut-off valve

Pressure control valve (spring loaded)

Pressure control valve (remote pressure sensing)

Pneumatically actuated valve diaphragm actuator

Solenoid actuated valve

Pneumatically actuated valve, cylinder actuator

Pneumatically actuated valve, spring-loaded cylinder actuator

Three-way valve, general sign

Self-contained thermostat valve

Three-way valve with electrical motor actuator

Quick-closing valve

Three-way valve with double-acting actuator

Electrically driven pump

Turbocharger

Filter

Strainer

Automatic filter

Automatic filter with by-pass filter

Heat exchanger

Separator (centrifuge)

Centrifugal filter

Flow meter

Viscosimeter

Receiver, pulse damper

Flame arrester

Flexible hose

Insulated pipe

Insulated and heated pipe

Deaerator

Self-operating release valve, for example, steam trap or air vent

Electrically driven compressor

Settling separator

Tank

Tank with heating

Orifice

Adjustable restrictor

Quick-coupling

Sensors, transmitters, switches:

Local instrument

Local panel

Signal to control board

TI = Temperature indicator

TE = Temperature sensor

TEZ= Temperature sensor shut-down

PI = Pressure indicator

PS = Pressure switch

PT = Pressure transmitter

PSZ= Pressure switch shut-down

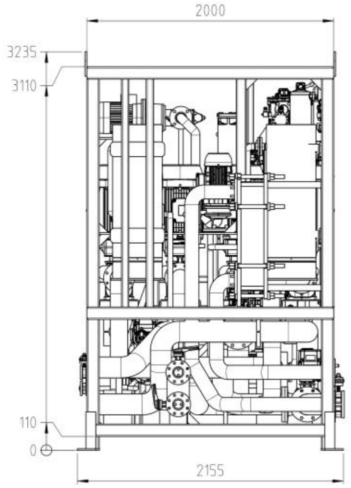
PDIS= Differential pressure indicator and alarm

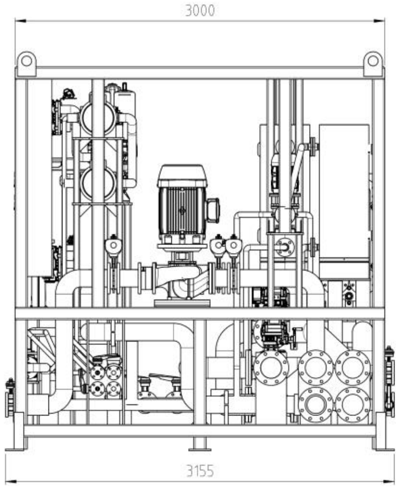
LS = Level switch

QS = Flow switch

TSZ= Temperature switch

Appendix D. Outline drawing of the W12-16V31DF cooling and fuelling unit assembly variant concept. Preliminary dimensions are shown along with component function codes and descriptions.





CODE	COMPONENT DESCRIPTION
1E04	Cooler (MDF)
1F04	Automatic filter (MDF)
1F05	Fine filter (MDF)
1F07	Suction strainer (MDF)
1I03	Flow meter (MDF)
1P03	Circulation pump (MDF)
1P08	Stand-by pump (MDF)
02	Heater LT (preheater)
4E03	Heat recover / (Evaporator)
4E05	Heater HT (preheater)
4P03	Stand-by pump (HT)
4P04	Circulating pump (preheater)
4P05	Stand-by pump (LT)
4P15	Circulating pump (LT)
4V02	TCV (heat recovery)
4V03	TCV (LT)
4V09	TCV (charge air)

CODE	CONNECTION DESCRIPTION
E101	To Engine fuel inlet
E102	From Engine fuel outlet
E106	Fuel to external filter
E107	Fuel from external filter
E401	To Engine HT-water inlet
E402	From Engine HT-water outlet
E406	Preheated water to Engine HT-circuit
E408	HT-water from stand-by pump
E451	To Engine LT-water inlet
E452	To Engine LT-water outlet
E457	LT-water from stand-by
G460	LT-water to generator/gearbox
G461	LT-water from generator/gearbox
E1	To Vessel CC/box cooler
E2	From Vessel CC/box cooler
E3	From Vessel fuel supply
E4	To Vessel fuel supply