YRKESHÖGSKOLAN
NOVIA

Standard Flywheel

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Bachelor´s thesis

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BACHELOR'S THESIS

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Abstract

This thesis was made for Wärtsilä Marine Business, Project Management, Solution Engineering. The purpose of the thesis was to research the possibilities to standardize the flywheel component for selected types that Wärtsilä produce and develop.

A standardization of the flywheel component for an engine type would speed up the process of design deadlines and lower the amount of drawing and material numbers in existing portfolios. Also, it would save a lot of time which is today spent on making 3D-models and measurement drawings of flywheels. Instead of making the flywheels according to specific projects according to today's way of working, a new component is introduced: an adapter for the flywheel and coupling which would be much simpler designed than a flywheel, and not on Wärtsila's responsibility to design. This adapter would control the inertia and mass that project specified engines need.

The thesis demanded both studying overall subject theory and interviews with colleagues. Most of all it required analyzing and considering boundary conditions that were gathered from stakeholders such as different Wärtsilä departments and supplier. The results are an analysis of design variance drivers, cost driver analysis and a suggestion of technical solutions for a standard flywheel for the specially selected engine types W20/W20DF.

Language: English Key words: flywheel, standardization, W20

EXAMENSARBETE

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Abstrakt

Detta examensarbete är gjort åt Wärtsilä Marine Business, Project Management, Solution Engineering. Syftet med examensarbetet var att utforska möjligheterna att standardisera svänghjulen till vissa utvalda motortyper som Wärtsilä producerar och utvecklar.

En standardisering av maskinkomponenten svänghjulet till en motortyp skulle snabba upp processen med design-deadlines och förminska portfolion för ritnings- och materialnummer. Dessutom skulle det spara mycket tid som används på att göra 3D-modeller och måttritningar av svänghjul. Istället för att svänghjulen görs projektspecifika enligt dagens sätt att arbeta, så skulle det införas en ny komponent: en adapter för svänghjul och axelkoppling som designmässigt är mycket enklare än ett svänghjul. En adapter som dessutom inte skulle bli på Wärtsiläs ansvar att designa. Denna adapter skulle kontrollera tröghetsmoment och massa som projekt specifika motorer behöver.

Examensarbetet krävde både studier av teori om ämnet samt intervjuer med kollegor. Framförallt krävdes det analysering och beaktande av randvillkor från intressenter exempelvis olika avdelningar på Wärtsilä och underleverantörer. Resultatet var en analys över vad som driver varians av svänghjulsdesign för de valda motortyperna, en analys över vad som driver kostnader för svänghjulen samt förslag på tekniska lösningar för ett standard svänghjul till de skilt utvalda motortyperna W20/W20DF.

Språk: engelska Nyckelord: svänghjul, standardisering, W20

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Tiivistelmä

Opinnäytetyö tehtiin osastolle Wärtsilä Marine Business, Project Management, Solution Engineering. Opinnäytetyön tavoitteena oli tutkia mahdollisuuksia standardisoida vauhtipyöriä valittuihin moottorityyppeihin, joita Wärtsilä tuottaa ja kehittää.

Vauhtipyörien standardisointi yhdelle moottorityypille nopeuttaisi design-määräajan saavuttamista ja vähentäisi piirustus- ja materiaalinumerojen tietokantaa. Lisäksi säästyisi paljon sellaista aikaa, jota käytetään vauhtipyörien 3D-mallinnusten ja mittapiirustuksien tekemiseen. Sen sijaan, että vauhtipyörä tehtäisiin projektille tyypillisesti nykypäivän työtapojen mukaan, voitaisiin esitellä uusi komponentti: adapterilevy vauhtipyörälle sekä akselikytkin, joka muotoilultaan olisi paljon vauhtipyörää yksinkertaisempi. Tämä adapteri tarkastaisi hitausmomentin ja painon, joita projekteille tyypilliset moottorit tarvitsevat. Lisäksi, tämä adapteri levyn suunnittelu ei jäisi Wärtsilän vastuulle.

Tämä opinnäytetyö vaati sekä aiheeseen liittyviä teoriaopintoja sekä että kollegoiden haastattelua. Työ vaati erityisesti analysointia ja esimerkiksi Wärtsilän eri oasastojen ja alihankkijoiden reunaehtojen huomioimista. Opinnäytetyön tuloksena on valittujen moottorityyppien vauhtipyörädesignin vaihteluanalyysi, vauhtipyörien kustannusanalyysi sekä teknisiä ratkaisuehdotuksia erikseen valittujen moottorityyppien W20/W20DF vauhtipyörien standardeille.

Kieli: englanti Avainsanat: vauhtipyörä, standardisointi, W20

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Abbreviations

DF – dual fuel

TDC – top dead-centre

L engine - In-line engine, an engine with the cylinders in a row

V engine - Engine with the cylinders in a V shape

CW – Clockwise rotation

CCW – Counter-Clockwise rotation

Genset – Generator set, engine installed with a generator

Driving end – The end where the flywheel is located

Free end – Opposite side of the driving end

R_m – Tensile strength in materials

CBF – Common Base Frame, a frame for gensets

TA – Type Approval

1 Introduction

The aim of a standardization is a reduction of technical and commercial differences of a certain component. Standardization does not limit the possibilities, rather increases them. Standardization is a determination of an adaptability of components and is a definition of an adaption to complicated conditions and hence increases the amount of alternative solutions.

To standardize e.g. a machine component can be a costly action in preparation stages, but often result in a cost-reduction. Achievements of a standardization on a corporate level can take time, but in the end a standardization can be a good resource and of good use for the company is managing its objectives.

The marine business is filled with big actors whom all are working towards smarter designed engines and solutions. Today more and more of the different engine parts gets standardized and kept ready for assembly in stock. Standardization is a term that is becoming more important in the marine business. To standardize functions or engine parts for easier maintained, easier designed and better working engines is a preferable option.

1.1 Background

This thesis is made for Wärtsilä Finland. The thesis evolves analyzing the possibility to minimize the amount of different flywheel designs for Wärtsilä marine diesel and dual fuel engines. Today the different designs of flywheels count to a large number because the flywheel is still a variable part for the diesel engines, but this thesis evaluates the possibility to implement a standard flywheel as concept.

This thesis was assigned to me from the team Solution engineering, within Project engineering, in the division Marine Business which is responsible for providing customers for Wärtsilä with marine engines and products. I met the Solution engineering team when I worked closely with them as a trainee in the team Mechanical engineering in the summer 2019.

The marine business used to be quite conservative. Every new engine was designed project specific and very much of the engine design was made by the company that sold the engine. Today on the other hand many tasks and much of the designing gets outsourced or standardized. A flywheel design is still chosen from existing different designs or made from scratch for every new engine ordered. This has led to hundreds of different flywheel designs varying for the different engine types.

To have a standard flywheel would reduce time waiting for the flywheel design to be chosen from the design teams and move on faster in production. This thesis subject was then formed as a first step towards this goal. The coupling for the flywheel is still a variable component, made by a subcontractor. To have standard flywheel, to which then the coupling supplier would customize their products would be preferable.

1.2 Purpose

The intention with this Bachelor´s thesis is to analyze the possibility to implement a standard flywheel as a concept. To analyze what options and constraints there are when choosing a flywheel design, analysis of cost drivers and which steps are needed to be researched in an implementation of a standard flywheel. The purpose is also to have taken these steps and having a result of a standard flywheel for one selected engine type.

1.3 Delimitation

This thesis limits the concept study of a standard flywheel to an evaluation of the existing and possibly needed variance drivers for the flywheel design of selected engines. The concept study also includes cost drivers for the existing flywheel designs.

A case will also be presented in which a detailed 3D-model of a standard flywheel for one selected engine type is designed, along with which variance drivers that led to that choice of design. A cost analysis of this standardization will be shown. The steps for implementing standard flywheels to further engines can be adapted from the standardization suggestion of the flywheel for the one selected engine type.

1.4 Wärtsilä

Wärtsilä is one of the global leaders in smart technologies and solutions for whole lifecycles in the marine and energy market. Wärtsilä emphasizes sustainable innovation, total efficiency and data analytics, through this the environmental and economic performance of the company´s vessels and power plants maximize. In 2018 the net sales for Wärtsilä counted to EUR 5.2 billion with approximately 19,000 employees. The company is operating in over 200 locations in more than 80 countries in the world. [1]

1.5 Disposition

This thesis is built up in different chapters. Chapter one is this one which is an intro chapter explaining why this thesis is being done, background and purpose etc. The second chapter is a theory chapter describing what this standard flywheel concept is based on. The third chapter describes how the theory for this thesis was collected and which sources that was used. In the fourth chapter results of the work that was done in this thesis work is presented, E.g. designs of a standard flywheel, cost analyses. Lastly the fifth chapter, a conclusion.

1.6 Secrecy

Some parts of this thesis contain classified information belonging only to Wärtsilä corporation and are therefore prohibited to be published in the public version of this thesis. Information such as actual cost numbers or detailed drawings of Wärtsilä engine components.

2 Theory

This chapter will explain theory for which this standard flywheel concept is based on, such as: basics about marine diesel engines, flywheel purpose, torsional vibration theory and coupling basics. The process of establishing the concept of a standard flywheel is described. This chapter contains listing of flywheel design variance drivers for selected Wärtsilä engines including cost drivers. An analysis of stakeholder's requirements in the flywheel design is presented.

2.1 Diesel Engine

Diesel combustion engines are built with one or more cylinders. The combustion of air and fuel drives a piston in each cylinder in an up-and-down movement. From the force working on the piston from the combustion, a connection rod attached to the piston acts in a linear movement. Work made by the linear action of the connection rod gets converted into rotational movement of a crankshaft, onto which the connection rod is attached. [2]

A **flywheel** is a large circular disk with a big inertia that is attached to the crankshaft. The width varies along with the diameter of the flywheel. The purpose of the flywheel is to even out variations in speed and torsional vibration of the engine. A flywheel can also be used for storing kinetic energy. A big amount of inertia for the flywheel is desired in both cases. The torsional force that is developed in the engine has a significant irregularity. To avoid vibrations in further transmission a flywheel is assembled in the rear end of the engine. [4]

Figure 1: A Wärtsilä 20 engine and flywheel

2.2 Torsional vibration

Shafts are used for torque transfer in many mechanical structures such as engines, turbines and rotor systems. The transmitted torque in these systems may vary in cycles, resulting in an oscillating torsional vibration. In Figure 1 there is shown a disk with a mass moment of inertia *I*. The disk is attached to a shaft with the length *l* and diameter *D*. When the disk is affected by a rotating movement θ, the shaft will produce a torque when trying to restore the disk to its starting position. This correlation between the enforced torque *T* which results in the angular movement of the disk θ can be explained by:

$$\theta = \frac{Tl}{GJ} \qquad (1)$$

where the length of the shaft is *l*, the polar moment of area for the shaft is *J* and the modulus of rigidity is *G.* [5]

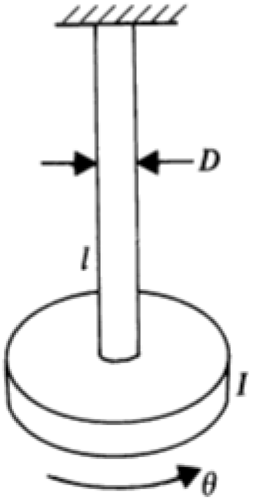


Figure 2: Disk attached to shaft

Torsional vibrations can also be displayed as oscillations and variations of speed, when measured on the running speed of an engine. It is either a natural frequency of the torsional system or forced by external powers. When the natural frequency lines up with the frequency of an external force, resonance will take place. [3]

Torsional stresses appear on E.g. the crankshaft as high velocity twisting vibrations. They occur when a crank throw is in the compression stage I.e. when the piston is moved upwards under compression stroke. Under this sequence, the speed of the crank throw is a bit slower than average crank speed. This same crank throw though, is on power stroke moving with a bit higher speed than normal crank speed. Resulting in already mentioned speed fluctuations and twisting torsional vibrations that must be considered when designing the crankshaft and calculating against resonance. [12]

Inertia is what makes an object stay in motion. Or the opposite, what makes an object remain at rest. E.g. when a piston is moving in one direction it's travel will ultimately stop. Then the kinetic energy of that piston must be channeled to the crankshaft and the connecting of the piston. The principle of inertia is used on the flywheel component and harmonic balancers of the engine. The weight of the flywheel, i.e. the inertial mass is to be greatest in a four-stroke engine with only one cylinder. With increased number of cylinders, the mass of the flywheel can be reduced. This is because with more cylinders there is more mass of rotating components and more occurrence of power strokes. [12]

Acceleration value (A-value) is an expression of speed change in percentage during one second of rated speed. That if the rated torque is used for acceleration of the inertia.

$$a - value = \frac{P * 30^2}{J * \pi^2 * rpm^2} * 100$$

Figure 3: a-value equation

In figure 2 above: *P* stands for pressure, *J* for total mass inertia and *rpm* for revolutions per minute. E.g. if the a-value is 40 the speed is theoretically changed 40% over one second time period, if the inertia is accelerated by the full torque. Thus, will the speed be changed by 10% within 10/40 = 0.25 seconds. [15]

Balancing of the engine is used usually when the crankshaft isn't symmetric. E.g. for 7- or 9-cylinder configurations. Due to asymmetry, mass forces will create force couples which can be balanced by balancing masses in the flywheel and the free end gear wheel. Balancing masses in the flywheel and in the free end gear wheel can be replaced by removing the same amount of mass on the opposite side of the flywheel. Unbalance of the engine comes partly from rotation of the crankshaft and connecting rod's lower part. That part can also be balanced by counterweights. [17]

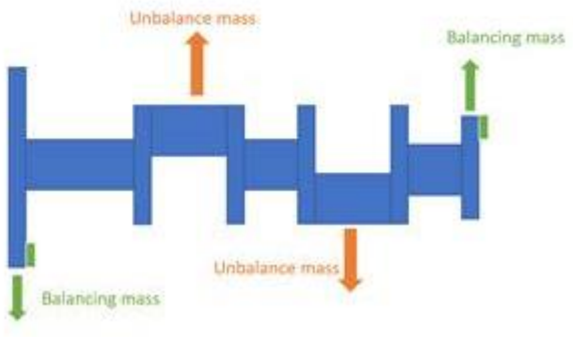


Figure 4: Illustration of crankshaft/flywheel and forces

2.3 Couplings

Couplings are used for connecting two shaft ends so that a torque or rotational movement can be transferred. Common usages for example can be:

- The shaft ends are on different mechanical systems
- Long shafts that must be made in sections because of production or assembly reasons. [4]

Stiff couplings can E.g. be a torque stiff coupling connects two shaft ends fixed to each other. They are used when a fixed connection that prevents all radial movement between the shaft ends is desired. Some types of stiff couplings allow axial movement. Other than torque, a stiff coupling also transfers eventual radial force and bend force. [13]

Flexible couplings connect two shaft ends through a resilient element. Hence the shafts are allowed a certain movement in different directions. Through the resilient construction of the coupling, damages are prevented in occurrence of E.g. bad alignment. Also damages in unpredicted power strokes are prevented. Flexible couplings are mostly designed to be flexible in the rotational direction of the coupling.

Flexible couplings are constructed with rubber elements or with metal springs. From a dynamical perspective, flexible couplings lower the torsional frequency of the shaft line. However flexible rubber couplings give oscillation damping. [13]

2.4 Variance drivers in flywheel design for selected Wärtsilä engines

Below will be listed what drives variance in flywheel design for Wärtsilä engines. Overall and in more detail for selected engines. For all following engine types, the amount of inertia varies widely for the flywheels. This is due to different vibratory calculations, component selections and engine type properties. Hence thickness and diameter of the flywheels varies widely. [7]

UNIC, short for Unified Control, is the automation system used for Wärtsilä engines for controlling the engine functions. Controls functions such as starting, controlling the engine, collecting data and slow turning etc. This automation system exists in several different generations. All engines are now to be manufactured with UNIC 2nd generation. The 2nd generation has brand new electrical components and sensors. This means that E.g. **speed-pick up holes/slots** on the flywheels for speed-pick up sensors varies along with which UNIC generation it’s regarding. Speed-pick up holes are used for knowledge of in which speed the engine is running in. These holes together with the sensors can be used for knowing how much power is produced and fuel consumption etc. These holes/slotted holes vary if the engine is a CW or CCW rotating engine. [11]

Grooves are marked all the way around all flywheels for following engine types. At certain degrees there are marked TDC and which cylinder it refers to. This is used for knowledge of which position the crankshaft is in E.g. under maintenance. Some of the flywheel designs also have extra degree marking. These extra markings are for knowledge of positioning for extra weights E.g. attached on the crankshaft. [9]

The flywheels all have different sets and varying amount of **bolt patterns**. These are used e.g for assembling the flywheel to the coupling, connecting the flywheel to the crankshaft or connecting test run adapters for generators in the factory.

2.4.1 W20/20DF

The W20/20DF engine is an in-line engine with four different cylinder configurations: 4,6,8 and 9 cylinders. These different cylinder configurations make the flywheel design vary because of E.g. different needed amount of inertia or balancing. [8]

The diameter size varies along with two different options, 950mm or 1050mm. This is mainly because if a larger amount of inertia is needed, a 1050mm flywheel will be cheaper than a 950mm. Because then it is possible to choose a smaller width of the flywheel. Resulting in less material use. [6]

A gear rim is bolted on to the flywheel for the W20 and 20DF engine. This is used for the starter motor, and turning the crankshaft thus moving the pistons to correct positions in E.g. maintenance. This differ between UNIC generations. UNIC 1st generation gear rim for the W20 has no speed pick up sensor holes, while the W20DF have simple round holes in the gear rim for speed-pick up sensors. Automation system UNIC 2nd generation have slotted speed pick up sensor holes in the gear rim for both W20 and W20DF. [8]

Balancing holes for the W20/W20DF engines are only needed for the 9-cylinder configuration. These are placed according to existing guidelines. [7], [8]

2.4.2 W31/31DF

The W31/31DF engine is a V-engine with five different cylinder configurations. 8,10,12,14 and 16 cylinders. This is a given variable in the flywheel design, because of inertia, vibration calculations and balancing. There are no differences between the diesel or DF options with regards to the flywheel design of this engine. This engine type has slotted holes on the flywheel for the speed-pick up sensors for all cylinder configurations. [9]

The diameter for the W31/31DF engine is 1280mm and is a “standard”, except for only one engine built with a 1140mm diameter flywheel. The one engine with a smaller diameter flywheel was only for a needed lower inertia. Meaning this is also a possible option in design for the moment. [9]

The flywheel for this engine has no gear rim, internal mechanisms in the engine are used for turning the engine over so that the pistons are in desired positions. Grading marks on the flywheel for these engines are also used for knowing the position of the pistons. In existing design-guideline it is listed for all the different cylinder configurations at which angle an A or a B cylinder for these V-engines has the piston at TDC. Additionally, the flywheels for the 8V and 10V cylinder configurations for the W31/31DF also have extra angle markings for knowledge of positions of balancing unit weights attached to the crankshaft. Angle markings tells at which position it is possible to remove said weights. [9]

2.4.3 W32 and W34DF

The W32 and W34DF engines are L or V-engines with 6,7,8,9,12 or 16 cylinders. As for these this makes the flywheel design vary along with different vibration calculations for the different cylinder configurations along with the needed amount of inertia etc. [9]

The diameter of the flywheel for the W32 and W34DF is always the same for all the cylinder configurations, though varies if it’s a V or a L-engine. The flywheel for the L-cylinder configuration has a diameter of 1272mm. While the V-cylinder configuration has a diameter of 1312 mm. This is because the flywheel is also used on this engine for the same purpose as on the W20/20DF, to turn the engine over so that the pistons are in desired position. The turning gear that makes this happen, with the help of the flywheel, is in different positions for the L-engine and for the V-engine. The gear rim that applies to the turning gear is a part of the flywheel for these engines, not a separately bolted on gear rim. The diameter on the L-engine is also smaller because these engines uses smaller sized couplings. [9]

Balancing holes for these engines are needed for some of the L-cylinder configurations. For the W32 balancing holes are needed on 7L and 9L-cylinder configurations. But for the W34DF they are needed only on the 9L-cylinder configuration. [9]

Both holes and slots for speed-pick up sensors are located on the flywheels for these engine types. Speed-pick up holes are used on both W32 and W34DF engine types for 1st generation UNIC automation system. On the W32 they are used on the W32-Common Rail. On W34DF holes are used on all engines with 1st generation UNIC. For UNIC 2nd generation the flywheels for these engine types all need slotted holes for the speed-pick up sensors. [10]

2.5 Stakeholder’s requirements

Stakeholders that hold some sort of interests, or other variance drivers that affect the designing the flywheel component are presented in the following chapter.

2.5.1 Classification societies

There are of quite large amount of different classification societies regarding the marine business. They all have their own rules and standards that regulate the designing and construction of marine vessels and engines. Mentionable societies are E.g. DNV GL, Bureau Veritas, Lloyd´s Register.

DNV GL states about inertia for ships in general: When in major critical resonance when running below idling speed and a lower amount of inertia from the engine to the driven machinery inertia, temporary vibration torque must be considered. This is applicable to e.g. diesel gensets with couplings of high elasticity. [16]

DNV GL states about that approved materials for flywheels construction must be nodular cast iron, preferably ferritic grades **$R_m \geq 350$ N/mm^2** or lamellar/grey cast iron with **$R_m \geq 200$ N/mm^2**. [18]

DNV GL says for rotating machinery equipment: for **flanges** the coefficient of friction, µ, reads: shall be at least 0.15 for steel against bronze and steel against steel. For steel against nodular cast iron it shall be at least 0.12. **Pre-stressed bolts**, for example bolts that connects a flywheel and a coupling, can have a pre-stress of 70% of the yield strength. This is in the smallest section of the bolts. Meaning utilization factor of 0.7. However, the procedure of tightening and the thread lubrication must be considered when using 10.9 or 12.9 bolts. The tightening of these bolts must be done by twist angle or better. For example, by using an elongation measurement. The pre-stress can be up to 90% of the yield strength of rolled threads. [21]

Marine products must be **type approved**. This is a procedure that is mandatory for any product installed on a classified marine vessel, this is critical for safe operation and voyages of the vessels. E.g. DNV GL, Bureau Veritas or MS Testing are instances which can certify a type approved marine product. DNV GL describes the following: The company and other responsible parties if any, must be described through attached information with the product for which a TA quotation is requested. Documents such as product drawings, calculations of the products (if needed), function description, report of the type testing and material specifications must be submitted for TA certification. Testing of the product must be conducted by verified personnel. E.g. test specifications, description over method used and results must be submitted. [22]

Though the flywheel, being a fundamental component with old and far used design principles, this standardization of a flywheel would not have to be re-evaluated from a type approval point of view. Wärtsilä already orders many flywheels continuously and a new standard flywheel would fall under the same way of working. [23]

2.5.2 Coupling suppliers

According to today’s way of working, the coupling supplier’s needs are met through the designing of flywheels for every project according to needed bolt pattern for the chosen coupling. This work is today done by Wärtsilä personnel. Along with this thesis project the way of working would change radically in relation to how it is done today.

There are several different coupling suppliers. In this thesis work one supplier was contacted when taking the steps to implement the standard flywheel concept. Instead of designing the flywheel for every single project, a flywheel / coupling adapter would be manufactured instead. Mainly to control resisting needed inertia for the projects, inertia that would remain needed due to the standard flywheel always having the same mass and inertia.

The idea is that an adapter is much easier to design than a flywheel. An adapter with much simpler geometry is faster to design according to needed mass and inertia, than a flywheel which you must consider many flanges and bolt patterns. To instead simplify the flywheel along with the usage of a new adapter, designed and manufactured by the coupling suppliers for every project. This way of working was also suitable according to the coupling supplier contacted. If these new adapters are ordered with forecast in advance, manufacturing of them shouldn’t slow down the delivery time of couplings ordered for the projects.

2.5.3 Factory

Standard flywheels for each of the engine types is also in interest for the assembly of the engines in the factory. Since the flywheel is one of the components assembled quite early, and as said used for rotating the pistons to the correct TDC positions, it would be an improvement to have the flywheel drawings already done and ready to be ordered in the first stages of a project along with other standard components for the engine types. According to input from product managers working closely with the factory, things like different drawings for CW and CCW rotating flywheel still is a must. Also e.g. eventual engine balancing holes on a flywheel must be placed in different sets of drawings, resulting in a smaller risk of confusion. I.e. design drivers that will be preserved for now.

2.6 Cost drivers

Fixed costs such as machining of any flywheel. If the flywheel has a gear rim, the machining of that is also a cost. The material cost is a price €/kg which varies along with the thickness of the flywheel. All flywheels in general that are thicker than 170mm can be considered as expensive. Material costs also come into consideration when choosing the diameter size of the flywheel, which is naturally a cost that gets higher along with bigger diameters and more material use. [14]

A driver in cost is the cost of **engineering hours**. When a new component E.g. a flywheel is designed, the salary of the design engineer and other expenses relatable to the employee are notable drivers. The amount of new flywheel drawings made per year varies along with if other design changes have been made for an engine type of several engine types, which alters the design of the flywheels. Below, is the variation in the amount of flywheel drawings made per year by the Mechanical Engineering team, shown in a graph. These drawings are made for the selected engines.

For a couple of years at a time it can be “normal” years, when the amount of designs of the flywheels are stable. No other new revolutionary designs are made for the engine types that also would alter the flywheels. Only a few new drawings are made per year in those periods, main reasons can be due to some small altering in inertia or some other project specific reasons. But once every couple of years something is renewed or invented, which leads to an altering in the flywheel designs.

This can even lead to a whole new portfolio of designs for all the selected engines. E.g. the years 2016-18 when a brand-new engine, the W31, was beginning to grow in sales numbers. Resulting directly in more new flywheel drawings to make. Also, a new generation of the automation system UNIC was made. Which led to a skyrocketing of the amount of flywheel designs for all the selected engines. In the graph it is also shown an average of hours spent making new flywheel designs. Which also is a varying curve line. Factors that brought the line downwards around 2011-12 was the inventing of a parametric tool for designing the flywheels, cutting the time spent designing flywheels roughly in half. [19], [20]

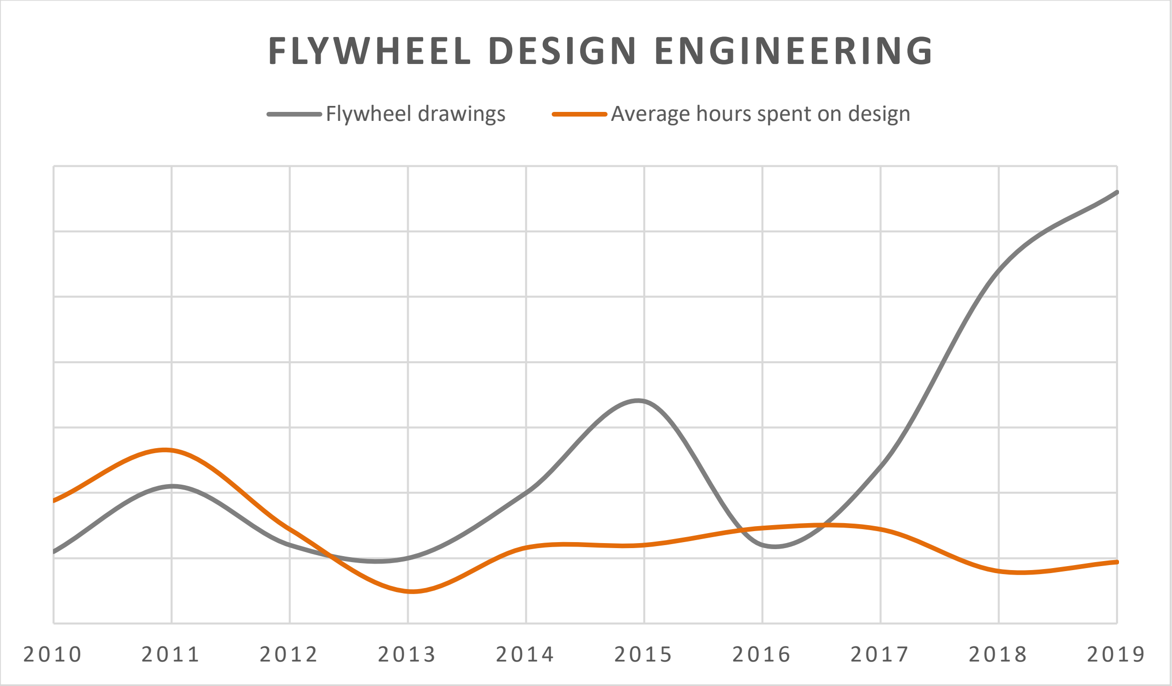


Figure 5: Graph over flywheel design engineering

For example: standard flywheels would be designed for the all the selected engines, designs that wouldn't be affected by another varying factor for the engine. E.g. a factor such as the UNIC automation system which is happening right now in 2019. Assuming, for the coming 5 years 2020-2024, that the curve referring to the amount of flywheel drawings made per year would move in a similar way as it did E.g. in the years 2011-15. I.e. two high peak years and three "normal" years. Then if it instead existed one specific standard flywheel design for each of the selected engine types, the cost of flywheel design engineering for them would be reduced in the coming 5 years by almost 95 percent.

An already mentioned adapter would of course be a big driver in cost. But these costs would hopefully be evened out by simpler designed standard flywheels for the engine types. Flywheels that would not be as expensive and complicated as they have been before. The adapter design and manufacturing would as said be outsourced. And outsourcing that still of course is open for the most economic choice of supplier, local or international. Also depending of where it makes most sense to manufacture these adapters, in logistical perspective.

3 Methodology

3.1 Methodological approach

The approach to this thesis task was to learn along the way to ultimately understand as much as of what was needed to make it possible to fulfill the tasks in the plan of this thesis work. To learn gradually, creating a base to stand on. Dividing the quite big amount of knowledge into smaller bits felt essential, due to the information being very detailed quite often. Making the learning curve less steep. This thesis work is done mostly through qualitative studies, due to being more to the nature of this subject. A few quantitative methods were used, e.g. for the gathering of a few but essential numbers. For example, when gathering and using number for prices of components, costs of engineering and numbers for e.g. sold engines or the amount of flywheel drawings made through the years.

3.2 Methods of data collection

To gather knowledge needed for this thesis assignment, a great number of different kinds of methods were used. The methods varied and switched back and forth along the way according to what was most useful for each day of working.

The methodological approach to this thesis assignment started with gathering of basic knowledge about the flywheel component, combustion engine theory, torsional vibration theory etc. Searching for **books** and a considerable amount of reading was done in the beginning stage, with the idea that the flywheel component and combustion engines are old news and there should exist lots of written info already. As the work continued, the way of working started to circle around **discussions** and **interviews** with colleagues at Wärtsilä due to the need of information about selected Wärtsilä engine types. The co-workers at Wärtsilä quickly became very essential, due internal documents describing components or functions of the engine types being hard to find or non-existing. Recorded presentations and PowerPoint files were also used. Gathering of info from colleagues meant quickly not only talking the closest co-workers. Usage of Skype and other similar tools for a broader network of connections was a big help in this thesis work. The colleagues that had needed knowledge were often stationed elsewhere. A big amount of emails, chatting and phone calls were conducted along the way. Not only with colleagues in the same company, also gathering of info from suppliers of e.g. flexible couplings were conducted through these kinds of medias.

Reading **standards,** considering what is stated was for making sure the outcome of this thesis work would be along with e.g. type approvals and rules of the marine branch.

For designing the flywheels components, both as a concept and the detailed model and drawing, the usage of tools such **3D-designing** program Siemens NX and already developed **Microsoft Excel calculators** done by Wärtsilä personnel were used. For the 3D-designing part, a lot were made through parametric Excel tools which could convert data into parametric files. Files which then were imported into template NX files which constructed a big part of the flywheel component. But the most essential details were designed through sketching so that all needed properties of a standard flywheel, needing much simplification than other flywheels, worked together. E.g. when researching the inertia of the flywheels, ultimately leading to a choice of diameter and width of the standard flywheel for the engine type as described in Chapter 4, Siemens NX was an essential tool in quickly checking and changing the inertia of the flywheel. Excel tools were also used when calculating the mechanics of e.g. coupling bolts and engine balancing. Some input for these calculations were taken from older projects of torsional vibration calculations, done in the program **Torsio,** a program which is developed and used by Wärtsilä noise & vibration experts.

3.3 Methods of data analyzation

All the data and knowledge gathered were always analyzed by comparing with older flywheel drawings, standards, mechanics formulas, what colleagues said, what books and internal documents said. Due to the thesis work progressed in smaller steps, always compared to an outer element e.g. an experienced co-worker, a certainty that the progress made also was correctly done.

3.4 Evaluation and justification of methodological choices

The methods used and the outcome results in this thesis work are all discussed and checked by co-workers in several different departments and teams in Wärtsilä which can be evaluated as a secure way of constructing a thesis work with correct information. The choice of gathering information in the way that it was done in this thesis work, little by little and from many aspects, can be justified by that a whole picture of the problem that is approached is then built up from the beginning to the end. [24]

4 Results

4.1 Choice of engine type for flywheel standardization

As stated, the outcome of this thesis was not only to contain analyses, but also designs for a standard flywheel for one selected Wärtsilä engine type. Both on a conceptual level and as a detailed final standard flywheel for the engine type.

The chosen engine type for which further research for standardization of the flywheel component was made is the **W20/W20DF**. The flywheel for this engine type seemed suitable to have as pilot for this thesis task. Reasons for that along with both design options that remain the same and new design drivers, are presented here:

4.2 Standard Flywheel on conceptual level

General idea for flywheel, adapter and coupling

An essential idea that this thesis builds up on is that an adapter between the flywheel and coupling would work. An adapter that would have the standard bolt pattern for being connected to the flywheel and a bolt pattern that varies along with project specified choice for flexible coupling, along with varying mass and inertia for the projects.

In **appendix 3 and 4** are screenshots from a W9L20 engine in the tool Torsio, a program developed by Wärtsilä personnel. Showing that the general idea of having a flywheel / coupling adapter does not change the vibratory torque for the whole engine systems. The torque is simulated on the crankshaft flange in both the screenshots. Being the component handling the most torque. The simulation was done accordingly to the general idea of an adapter. The original inertia that the flywheel for that W9L20 engine had was split up into the inertia that the new standard flywheel will have and a mass controlling the resisting, this mass being an adapter. Just like a real adapter would do.

1050mm versus 950mm diameter

A design option that could be chosen from previous flywheels is for instance the choice of diameter. Research about the possibility for **smaller diameter 950mm** was conducted, if only this smaller diameter could have been the future for the W20 engine type. The 950mm size was at first a considerable option and due to no need of a cutaway in the CBF for gensets when using this diameter. Also, because this flywheel is not as visible beneath the flywheel cover as the bigger 1050mm diameter. Making it a choice in work safety perspective.

The thought was that the 1050mm diameter size would have been no longer necessary since the flywheel will always be same i.e. always same cost and e.g. resisting needed inertia will be controlled by the flywheel/coupling adapter. That hopefully only the smaller size of the diameter could have been enough, if an adapter fitting to that diameter would be enough to control the project specified inertia.

A first concept of a standard flywheel with 950mm diameter size is shown below. Ultimately this concept did not work, after many failed tries to design a 950mm diameter flywheel plus an adapter. The attempts to get a highest needed inertia of ~120 kgm^2 with this smaller diameter made the flywheel/coupling adapter much too wide. Driving up the material need and costs along with it. Also, the bolt pattern for the adapter on this flywheel would not be a big enough pitch diameter, making some coupling types colliding with the bolts for the adapter when designed with the idea that every bolt would be assembled with the head facing the generator side. If the connecting bolts for the adapter and flywheel would be assembled with the bolt heads facing the engine, the threaded holes in the adapter might not be deep enough to be safe if the adapter would have a small width according to some projects.

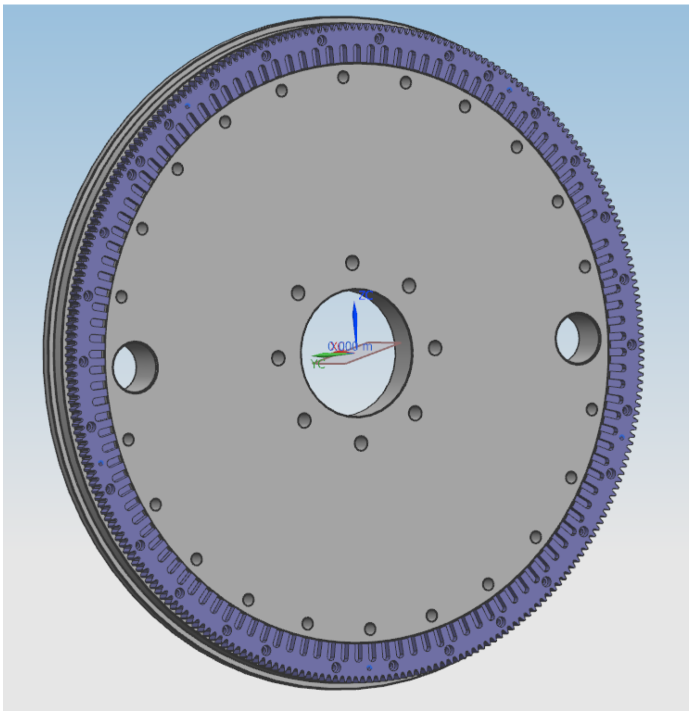


Figure 6: Conceptual 950mm diameter flywheel with UNIC 2.0 gear-rim

4.2.1 Evaluation of technical solutions

Essential for a standard flywheel design would be that a flywheel / coupling adapter would be connected to the flywheel via a bolt pattern that always would be the same. Even though the coupling suppliers would be the ones to start manufacturing new the flywheel / coupling adapters, main ideas and designs were needed to be created. A flywheel / coupling adapter was designed very simple. A flat surface meeting the flywheel, with only a centering ring with tolerances going into an inner flange on the flywheel. Sent as an example to the coupling supplier. The flywheel / adapter bolt pattern must be of enough pitch diameter so that all coupling types used for this engine type fit onto the adapter. This along with the inertia criteria, that some project needing low amount of inertia, made the design choice of the **biggest and the thinnest** flywheel possible most preferable. Big enough diameter so that the width measurement and material use could be lowered instead.

Another design driver that must and can remain the same for this engine type’s flywheels is **two large holes** placed going through the flywheel. These holes are needed because adjusting the intermediate gear (camshaft transmission gear wheels) is done through these holes. An adapter covering these holes though, does not matter since some coupling types already covers them when assembled. Since the flywheel of this engine type have the slots for the speed-pick up holes placed on the **gear rim**, the new 2.0 version of the UNIC automation system does not require any holes or slots made on the actual flywheel. Even though the gear rim for the W20 engine type will be updated in the future, the bolt pattern for it on the flywheel could remain the same for both W20 and W20DF. Also, the bolt pattern for the **crankshaft** will remain the same due to no need for an update.

The flywheels for this engine type have TDC markings at certain degrees for all it’s different cylinder configurations. Along with the standardization of the flywheel for this engine type, this would now be approached in a new way of working. The standard flywheel of this engine type would have a **generic marking**, 5-360 degrees with 5 degrees increment, and a table of TDC positions for all pistons for each cylinder configurations would be included along with the engines. Also stamped 30-330 marks degrees with 30 degrees increment, for helping when turning the engine over to the right TDC position. But along with the still needed both CW and CCW rotating flywheels, different sets of drawings for different rotating flywheels had to be made.

The W20/W20DF is tested in the factory with a flywheel/coupling **test run adapter** for generators there, which have a bolt pattern that is always the same as on previous flywheels.

This bolt pattern could be removed along with the inventing of new flywheel/coupling adapters for the standard flywheel, since test run adapters for the generators in the factory could be manufactured with the same bolt pattern. Diameter and width of this adapter could always be the same, just as the standard flywheel is to be the same design every time.

4.3 W20/W20DF Standard Flywheel suggestion

Ultimately, the 1050mm diameter size was chosen to be the standard flywheel size for reasons stated in previous chapters. Along with a most outer width of 55mm for small enough amount of inertia need for some projects, but wide enough for existing bolt patterns to still be working. The bolt pattern for the flywheel / adapter connection is located on the most outer flange of the flywheel seen from the free end. This has a pitch diameter of 990mm, so that all coupling design used for this engine type fits ”inside” that diameter. Making sure no bolts collide with the components, making sure that a system of flywheel, adapter and flexible coupling works. An inner flange exists on the side facing the adapter for centering.

This new standard flywheel has an inertia 35,6 kgm^2, a weight of 288 kg and a 32 pieces bolt pattern for the adapter connection. To calculate the strength of the bolt pattern, an Excel tool developed by Wärtsilä noise & vibration personnel was used. Tool is shown in appendix 5. The cylinder configuration used for this calculation is the one with most power, 9L. Numbers for e.g power, rotating speed and vibratory torque at misfiring are a bit higher than real numbers for safety reasons. Vibratory torque numbers are taken also from Torsio projects for W9L20. As shown in the picture the additional safety factor is over 1 which is OK.

It’s very simple looking design compared to existing flywheels. Showing the detailed dimensional drawing in this thesis document is prohibited, but below are figures of the 3D-model of the W20/W20DF Standard Flywheel. Visible are e.g. the degree markings on the side and the adapter bolt pattern placed on the most outer flange. The inner flange in the middle of the flywheel used for adapter centering is visible in figure 8.

For the W9L20 cylinder configuration, **two balancing holes** are to be drilled. These can as stated not be just a mentioning in a drawing. Is must exist different sets of drawings for flywheels with balancing holes. The Figure 9 below shows the excel tools developed to calculate the position of these holes, according to the needed inertia to be removed. Beside these dimensions, they are placed in a 10 angle away from the zero point of the circle being the flywheel. These holes are drilled through the flywheel due to the small width. **Four different drawings** were made for this standard flywheel, due to 9L cylinder config. needing engine balancing holes and CW / CCW rotation for the flywheels. The balancing holes are visible to the left in Figure 8.

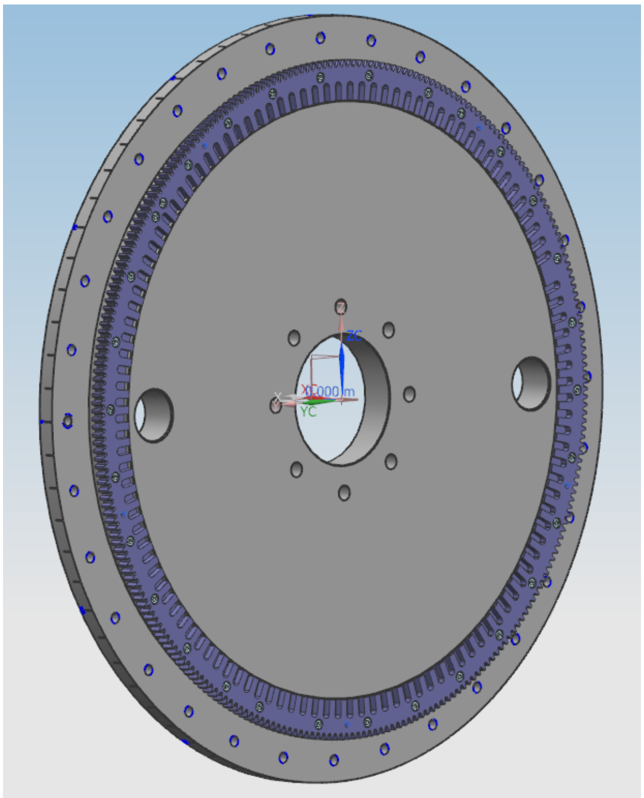


Figure 7 : W20/W20DF Standard Flywheel. 4,6,8L cylinder config. Side facing engine.

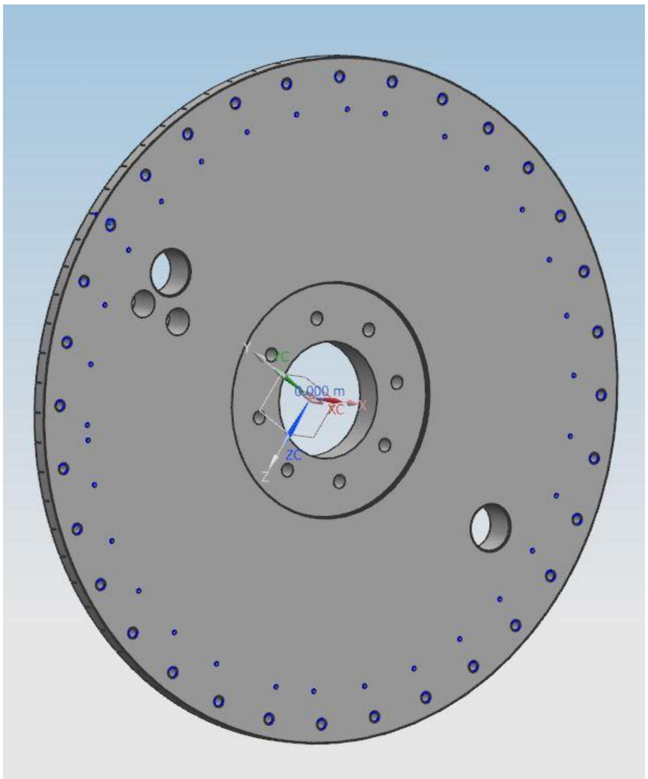
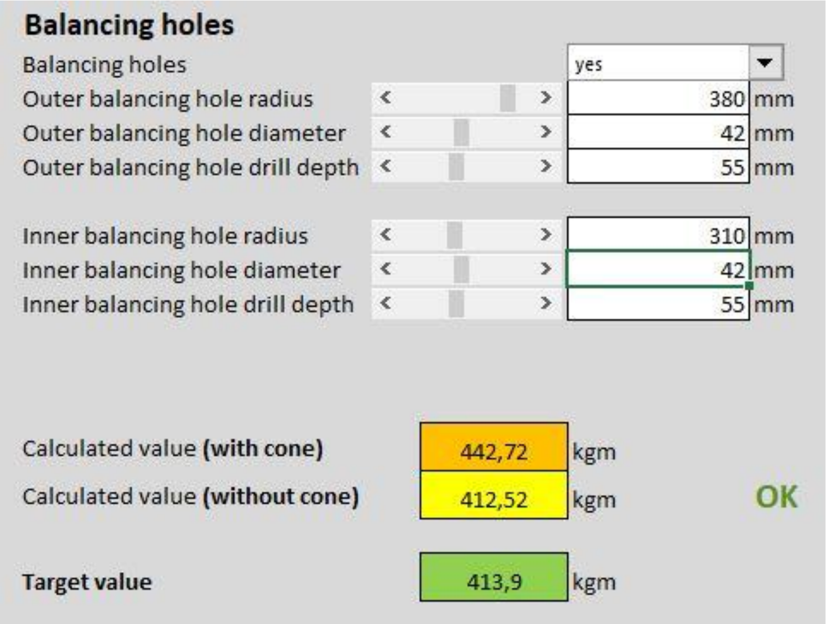


Figure 8 : W20/W20DF Standard flywheel. 9L cylinder config. Side facing flywheel/coupling adapter.



Balancing holes

Balancing holes: yes

Outer balancing hole radius: 380 mm

Outer balancing hole diameter: 42 mm

Outer balancing hole drill depth: 55 mm

Inner balancing hole radius: 310 mm

Inner balancing hole diameter: 42 mm

Inner balancing hole drill depth: 55 mm

Calculated value **(with cone)**: 442,72 kgm

Calculated value **(without cone)**: 412,52 kgm

OK

Target value: 413,9 kgm

Figure 9 : Engine balancing holes calculation

4.4 Standardization cost reduction analysis

If implementation of this concept would be done for the all selected engine types in this thesis work, the portfolio for them cold probably have the number of flywheel drawings lowered by all-in-all ~85%. Reducing the time spent by Strategic Purchasing personnel of Wärtsilä **reviewing material costs** for all these drawings of flywheels, which is done twice a year. The usage of different “blanks” for the manufacturing of flywheels are lowered. Flywheel blanks are disk shapes pieces of steel of which a flywheel is machined according to a drawing. With a standard flywheel for an engine type, only one blank could be enough. Which would be very preferable just for the simplicity of it [25]. This along with the cost-reduction of the minimizing of, already in Chapter 2.6 mentioned, design hours were included in the cost reduction analysis for if standardization of the flywheel component for all selected engine types would be done. Which showed that many tens of thousands of euros a year would be saved in just hours of work explained above, maybe even over hundred-thousand euros if new systems of flywheels plus adapters were to become cheaper to buy, depending on the design of them and supplier input.

The costs for the old way of working was added up by calculating an average of price for bought W20 flywheels over the last few years. This was multiplied with an average amount of W20 engines sold over same years. Added to that was the costs of designing flywheels for that engine type for the last few years. This sum was the numerator in the comparison with the costs for the suggested W20 standard flywheel and adapter plates. A cost for suggested standard components which was calculated by following: the price for the flywheel was multiplied with the same average of sold engines. The adapter plate had different prices according to width, but an average according to the width most needed and price for that was chosen. The sum for the suggested new way of working lacked the costs for designing drawings, due to that it would be almost non existing.

Unfortunately, the actual costs for the suggested standard flywheel and adapter plate solution in this thesis didn’t yield any cheaper results yet. The suggested standard flywheel for W20/W20DF came back with a quite cheap price from the supplier, due to its low use of material and simple design. But the adapter plate is the factor that drove up the costs. The first example design needed expensive ways of manufacturing. Something which, according to the supplier, could be avoided with re-designing the adapter. The overall cost for the conceptual components and idea of this new system was double compared to today’s way of working. **This is a factor that would prevent a possible implementation.**

4.5 Steps for implementation

Actual steps that has been taken in towards a possible implementation of any standardization of the flywheel component for each the selected engines and for especially the W20/W20DF. For example, the reviewing and analysis of the biggest factors that drive variance in flywheel designing, what costs are driven by e.g. time-consumption of handling a large portfolio of drawings and the possible adapter plate. It has been designed and shown that this conceptual system of having a standard flywheel along with an adapter plate is very much possible and could be an optimized solution due to many simplifications. Many stakeholders have been involved in this thesis work and information about what would possibly be the future for flywheels has been quite widely spread.

The ball has been set rolling for this concept to become reality. If further choices are made for this to happen, steps that still needs to be taken for implementation are for example further discussions with suppliers of the flywheels and adapter plates. Also, discussions with managers that are responsible for the decisions if this concept would become real. Along with if those choices would be made, the factory would have to get more information about what would become the new way of working regarding flywheel assembly. E.g. test run supervisors and managers has already been involved, but more meeting with them would still to be had. E.g. about new flywheel adapters fitting the suggested W20 standard flywheel to the generators in the test runs. Also, most importantly, get the price numbers to align with wanted outcome. A small re-designing of the suggested W20 standard flywheel and the flywheel/coupling adapter would lower the costs significantly according coupling supplier. Discussions with every coupling supplier that would be involved in this suggested new way of working is also essential, to raise awareness of what would be the future.

4.6 Results discussion

The results of the overall analysis of flywheel design drivers and the different designed flywheels for this thesis concept are in my own opinion adequate and made with an idea of simplifying the whole system of flywheels and couplings along with an adapter. Every little detail of every flywheel design is not described in the design variance analysis, but the biggest factors are shown and give a view of factors that must be tackled in an eventual standardization of the flywheel for the selected engine types. The different flywheels that have been designed and described in this thesis are examples of how a standardization of the flywheel component can be a technical solution. The way of working described in this thesis should be easier than previous work methods, due to less designing of complicated flywheels with many flanges and bolt patterns. A much faster designing of an adapter would be done, which also is outsourced from Wärtsilä. Outsourced along with a today’s way of thinking, that a company personnel doesn’t have to do everything by their own. Making it hopefully cheaper in long term. Along with the already stated much simplified handling of drawing portfolios. The costs for the whole suggested new system are still not what is wanted, but with more designing hours on the new components, a preferred price of the whole concept would hopefully be achieved.

5 Conclusion

The thesis plan has been followed up as much as possible, every objective has in my opinion been evaluated in some sort of action. The purpose of the thesis has in my opinion been followed as much as possible and quite correctly. The thesis work has resulted an overall describing theory part of flywheels and flywheel designing for some Wärtsilä marine engines, a methodological part justifying choices made and actual produced designs that would be possible to be used. Also, a brief cost analysis.

5.1 Further work

One quite important thing would be following up an implementation of this thesis work. If e.g. the way of assembling the engine, rotating the crankshaft and doing maintenance with the help of **the piston TDC table** is functioning in the future. Or if it would be preferable from stakeholders to use the old way of working with stamped TDC piston positions on the flywheels. Which then would result in bigger amount of flywheel drawings than according to this thesis work.

The designing of flywheel adapters for the test runs of the W20 engine type is a must if designs from this concept are to be used, meaning it is a much needed further work. Which also means new vibration calculations for the test run systems. **A plan of action, design work and evaluation of this could be possible.**

Doing standardizations of the flywheel component for **the other selected engine** types according to similar ideas described in this thesis. For the other selected engine types, the speed-pick up sensor slots are a more complex problem to solve than it was with the W20 engine type since they do not have a separate gear rim with the slotted holes. Also, because of the size of the other engines being significantly bigger, the torsional vibration matter and other practical subjects like assembly of the components would probably have to be studied further than in this thesis.

Further work that I will do myself for the near future is the continuing the design of the flywheel/coupling adapter so make the price of it cheaper. Making the whole concept a preferable option if the costs were lowered, along with a standardization and simplification.

5.2 Discussion

Good things that came out of this thesis that I would like to mention are e.g. the suggested design for a W20/W20DF Standard Flywheel. I would like to think after much research that it is designed as simple as it can be, with many features that allows the whole system of flywheel and coupling to much simpler.

The cost analysis could have been more detailed if more time would have been put into it, and with even more exact numbers. Along with further input from e.g. factory and similar stakeholders. Of course, research was made in that area, but very few real factors was found that could've have an impact in the cost. Or as often happened the researching led to dead ends when the contacted personnel didn't have knowledge, didn't redirect or even reply. But these are, of course, factors that could've been tackled with more time spent and further personnel contacted.

If I could do it all again, I'd start designing the actual flywheels sooner. That's when I really learned what the different design variance drivers meant and what their purpose were. E.g. how inertia can be quite hard to get the amount that you want of, in exchange for losing other valuable features of properties of the flywheel. If I would have started sooner, there would have been more time to receive input from stakeholders that had a say in the design. I have learned tons about machine components, overall mechanics, product development, business contact's communication and taking responsibility. I would also spend more time on the cost analysis and start doing it sooner. There is probably a great number of factors that play a role which I'd gladly include if I were to start over.

Afterword

I’d like to say thank my supervisor at Wärtsilä Mr. Tomas Södö for giving me the opportunity to work with this interesting, challenging and very rewarding final thesis subject. Also, thanks for all your help and your uplifting feedback.

Thanks to my teacher and supervisor Mr. Kaj Rintanen for helping me especially in the beginning phase of the thesis work, and thanks for many educative and fun discussions regarding this thesis assignment and overall over the years.

A huge thanks to my colleagues in the teams Solution Engineering and Mechanical Engineering for helping me out a lot and having the patience to answer my questions, along with good and motivating feedback. Also, a thanks to anyone else reading this who I’ve contacted over the months and helped me, the list is long.

Vasa, April 2020

David Lund

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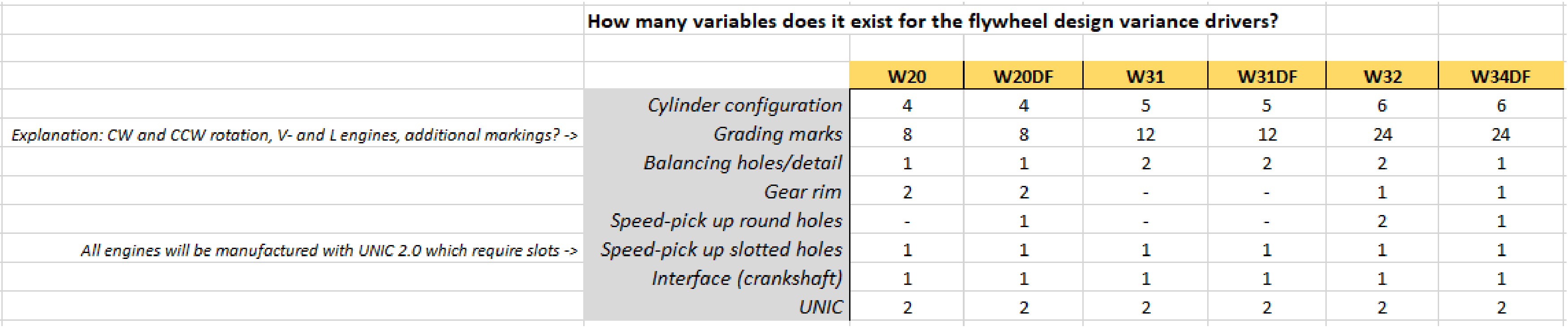
Appendix 1 : Table over flywheel design variance drivers.



How many variables does it exist for the flywheel design variance drivers?

		W20	W20DF	W31	W31DF	W32	W34DF
	Cylinder configuration	4	4	5	5	6	6
Explanation: CW and CCW rotation, V- and L engines, additional markings? ->	*Grading marks*	8	8	12	12	24	24
	Balancing holes/detail	1	1	2	2	2	1
	Gear rim	2	2	-	-	1	1
	Speed-pick up round holes	-	1	-	-	2	1
All engines will be manufactured with UNIC 2.0 which require slots ->	*Speed-pick up slotted holes*	1	1	1	1	1	1
	Interface (crankshaft)	1	1	1	1	1	1
	UNIC	2	2	2	2	2	2

Appendix 2 : Table over piston TDCs relating degree markings on flywheel.

Engine type W20 and W20DF

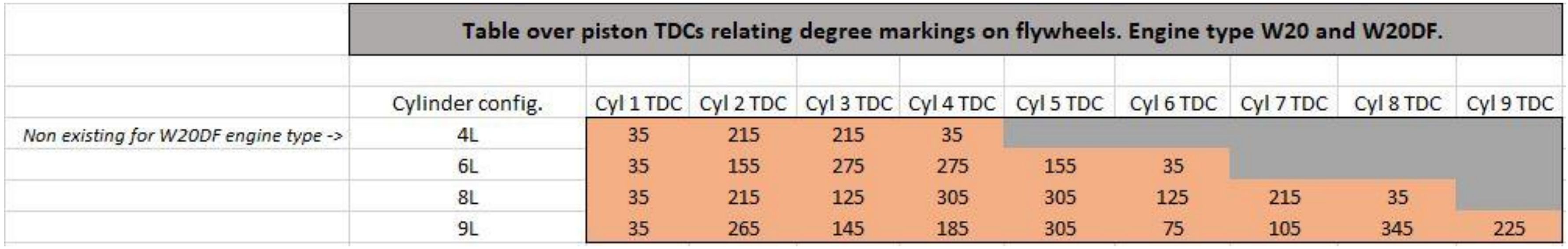
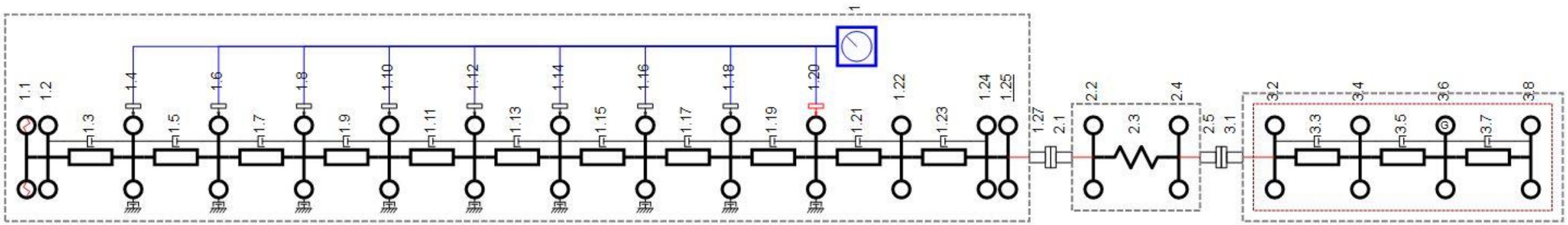


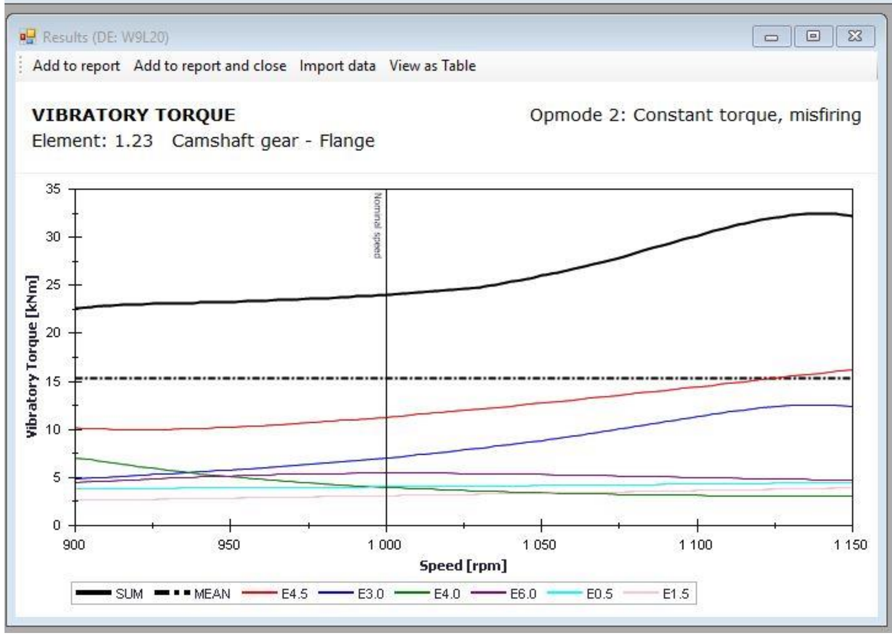
Table over piston TDCs relating degree markings on flywheels. Engine type W20 and W20DF.

	Cylinder config.	Cyl 1 TDC	Cyl 2 TDC	Cyl 3 TDC	Cyl 4 TDC	Cyl 5 TDC	Cyl 6 TDC	Cyl 7 TDC	Cyl 8 TDC	Cyl 9 TDC
Non existing for W20DF engine type ->	4L	35	215	215	35					
	6L	35	155	275	275	155	35			
	8L	35	215	125	305	305	125	215	35	
	9L	35	265	145	185	305	75	105	345	225

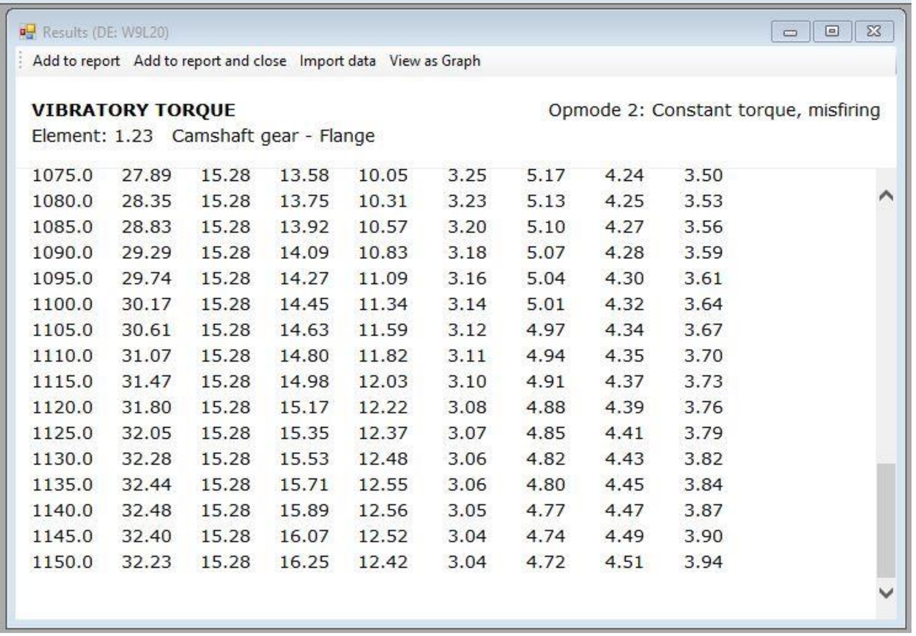
Appendix 3 : Normal W9L20 engine

Misfiring vibratory torque graph and table





VIBRATORY TORQUE
Element: 1.23 Camshaft gear - Flange
Opmode 2: Constant torque, misfiring

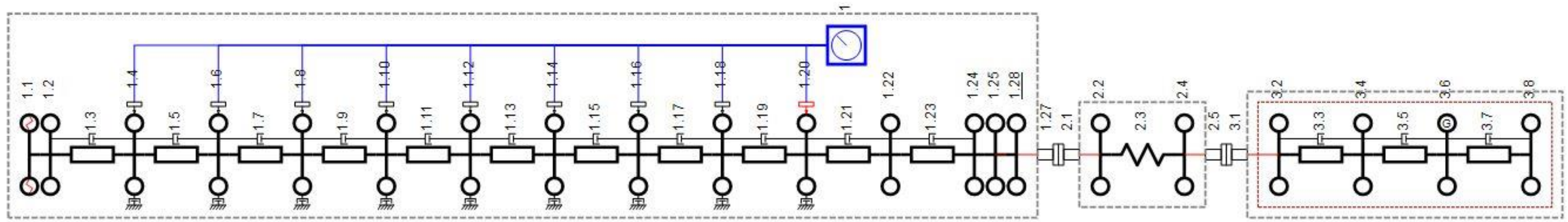


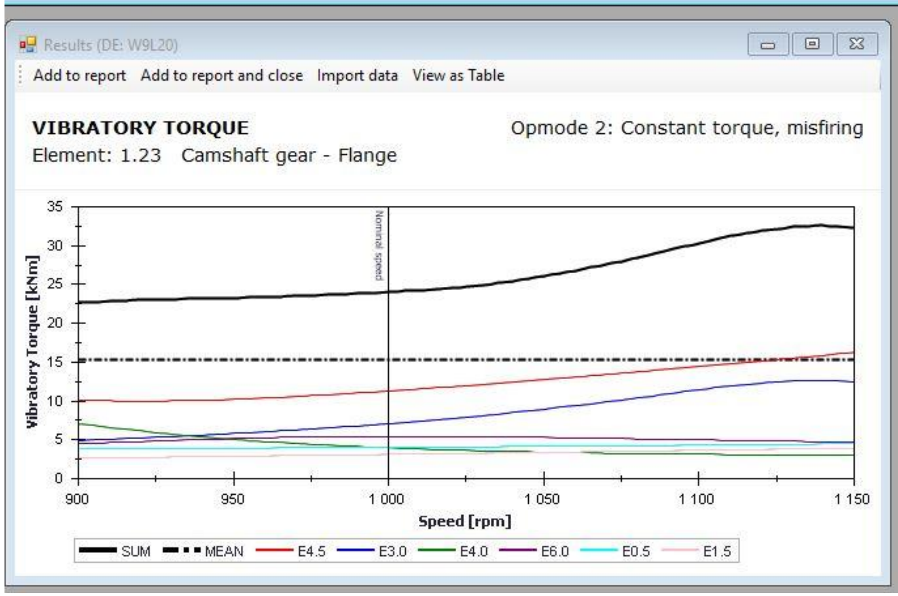
VIBRATORY TORQUE
Element: 1.23 Camshaft gear - Flange
Opmode 2: Constant torque, misfiring

1075.0	27.89	15.28	13.58	10.05	3.25	5.17	4.24	3.50
1080.0	28.35	15.28	13.75	10.31	3.23	5.13	4.25	3.53
1085.0	28.83	15.28	13.92	10.57	3.20	5.10	4.27	3.56
1090.0	29.29	15.28	14.09	10.83	3.18	5.07	4.28	3.59
1095.0	29.74	15.28	14.27	11.09	3.16	5.04	4.30	3.61
1100.0	30.17	15.28	14.45	11.34	3.14	5.01	4.32	3.64
1105.0	30.61	15.28	14.63	11.59	3.12	4.97	4.34	3.67
1110.0	31.07	15.28	14.80	11.82	3.11	4.94	4.35	3.70
1115.0	31.47	15.28	14.98	12.03	3.10	4.91	4.37	3.73
1120.0	31.80	15.28	15.17	12.22	3.08	4.88	4.39	3.76
1125.0	32.05	15.28	15.35	12.37	3.07	4.85	4.41	3.79
1130.0	32.28	15.28	15.53	12.48	3.06	4.82	4.43	3.82
1135.0	32.44	15.28	15.71	12.55	3.06	4.80	4.45	3.84
1140.0	32.48	15.28	15.89	12.56	3.05	4.77	4.47	3.87
1145.0	32.40	15.28	16.07	12.52	3.04	4.74	4.49	3.90
1150.0	32.23	15.28	16.25	12.42	3.04	4.72	4.51	3.94

Appendix 4 : W9L20 engine with added flywheel / coupling adapter

Misfiring vibratory torque graph and table

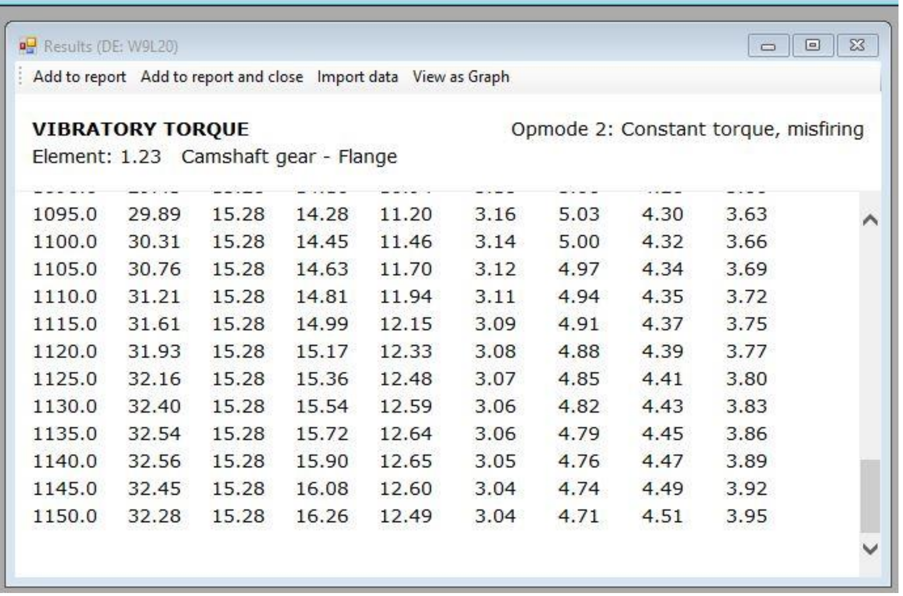




VIBRATORY TORQUE

Opmode 2: Constant torque, misfiring

Element: 1.23 Camshaft gear - Flange



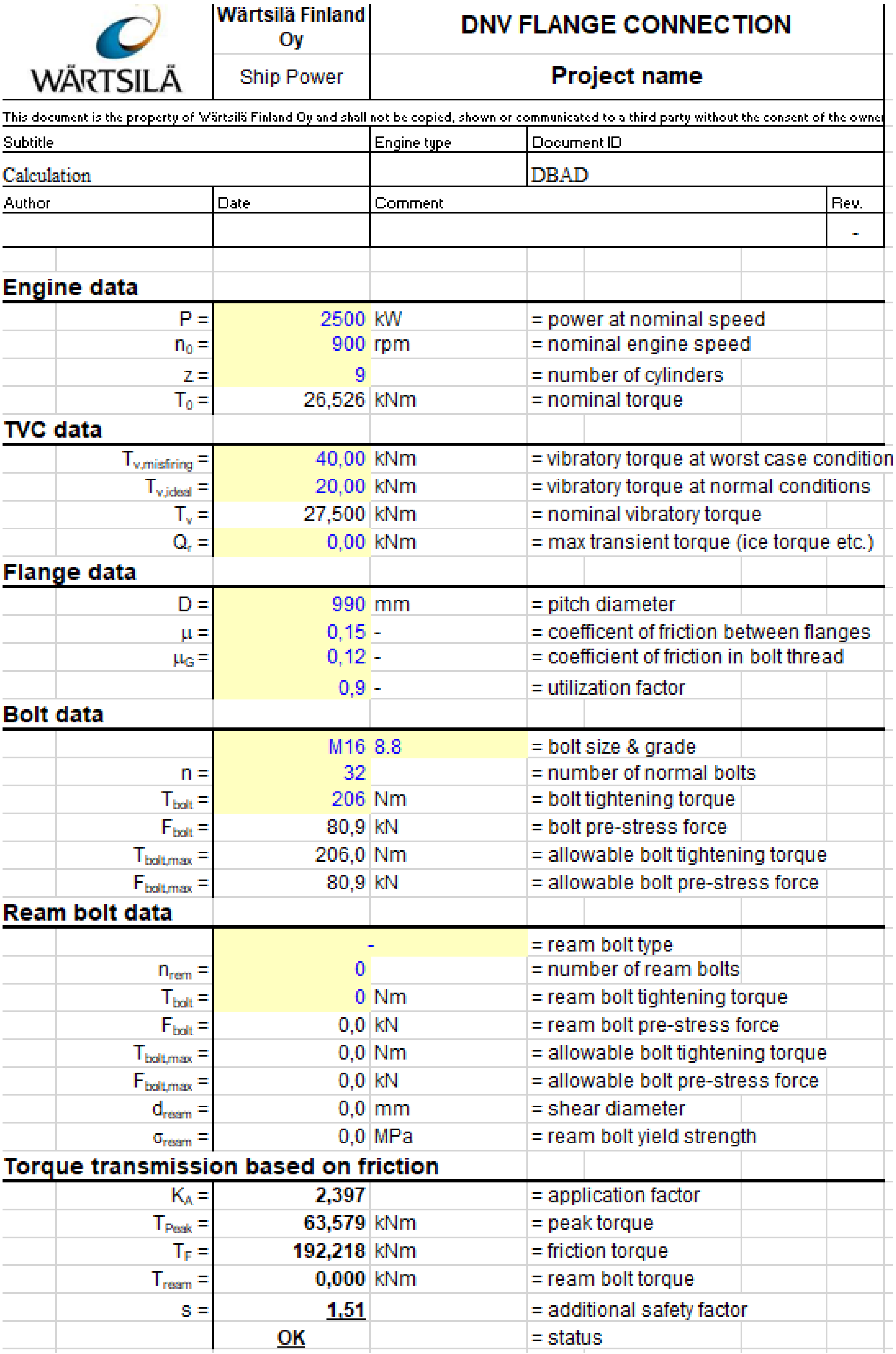
VIBRATORY TORQUE

Opmode 2: Constant torque, misfiring

Element: 1.23 Camshaft gear - Flange

1095.0	29.89	15.28	14.28	11.20	3.16	5.03	4.30	3.63
1100.0	30.31	15.28	14.45	11.46	3.14	5.00	4.32	3.66
1105.0	30.76	15.28	14.63	11.70	3.12	4.97	4.34	3.69
1110.0	31.21	15.28	14.81	11.94	3.11	4.94	4.35	3.72
1115.0	31.61	15.28	14.99	12.15	3.09	4.91	4.37	3.75
1120.0	31.93	15.28	15.17	12.33	3.08	4.88	4.39	3.77
1125.0	32.16	15.28	15.36	12.48	3.07	4.85	4.41	3.80
1130.0	32.40	15.28	15.54	12.59	3.06	4.82	4.43	3.83
1135.0	32.54	15.28	15.72	12.64	3.06	4.79	4.45	3.86
1140.0	32.56	15.28	15.90	12.65	3.05	4.76	4.47	3.89
1145.0	32.45	15.28	16.08	12.60	3.04	4.74	4.49	3.92
1150.0	32.28	15.28	16.26	12.49	3.04	4.71	4.51	3.95

Appendix 5 : Calculation for flywheel / adapter connection



WÄRTSILÄ	**Wärtsilä Finland Oy**	**DNV FLANGE CONNECTION**
	Ship Power	**Project name**

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Subtitle	Engine type	Document ID
Calculation		DBAD

Author	Date	Comment	Rev.
			-

Engine data

P =	2500	kW	= power at nominal speed
n_0 =	900	rpm	= nominal engine speed
z =	9		= number of cylinders
T_0 =	26,526	kNm	= nominal torque

TVC data

$T_{v,misfiring}$ =	40,00	kNm	= vibratory torque at worst case condition
$T_{v,ideal}$ =	20,00	kNm	= vibratory torque at normal conditions
T_v =	27,500	kNm	= nominal vibratory torque
Q_r =	0,00	kNm	= max transient torque (ice torque etc.)

Flange data

D =	990	mm	= pitch diameter
μ =	0,15	-	= coefficent of friction between flanges
μ_G =	0,12	-	= coefficient of friction in bolt thread
	0,9	-	= utilization factor

Bolt data

	M16	8.8	= bolt size & grade
n =	32		= number of normal bolts
T_{bolt} =	206	Nm	= bolt tightening torque
F_{bolt} =	80,9	kN	= bolt pre-stress force
$T_{bolt,max}$ =	206,0	Nm	= allowable bolt tightening torque
$F_{bolt,max}$ =	80,9	kN	= allowable bolt pre-stress force

Ream bolt data

	-		= ream bolt type
n_{rem} =	0		= number of ream bolts
T_{bolt} =	0	Nm	= ream bolt tightening torque
F_{bolt} =	0,0	kN	= ream bolt pre-stress force
$T_{bolt,max}$ =	0,0	Nm	= allowable bolt tightening torque
$F_{bolt,max}$ =	0,0	kN	= allowable bolt pre-stress force
d_{ream} =	0,0	mm	= shear diameter
σ_{ream} =	0,0	MPa	= ream bolt yield strength

Torque transmission based on friction

K_A =	**2,397**		= application factor
T_{Peak} =	**63,579**	kNm	= peak torque
T_F =	**192,218**	kNm	= friction torque
T_{ream} =	**0,000**	kNm	= ream bolt torque
s =	**1,51**		= additional safety factor
	OK		= status

Appendix 6 : Suggested W20/W20DF Standard Flywheel drawings

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