YRKESHÖGSKOLAN NOVIA

Torque Measurement

A Study on Different Measurement Methods for IC Engines

Wärtsilä Finland

Rasmus Wahlberg

Bachelor's Thesis

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EXAMENSARBETE

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Handledare: Kaj Rintanen

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Abstrakt

Detta examensarbete är gjort för gruppen Engine room systems inom Wärtsilä Marine Solutions. Syftet var att undersöka om en ny metod att mäta vridmoment på Wärtsiläs motorer kunde ersätta den befintliga metoden och vad fördelarna med den nya metoden skulle vara.

Målet med uppgiften var att undersöka marknaden för möjliga metoder att mäta vridmoment, jämföra dessa med varandra med fokus på den nya kontaktlösa metoden och den metod Wärtsilä använder sig av idag. Även en konsol skulle designas för att den nya kontaktlösa metoden skall kunna testas på en motor i Wärtsiläs laboratorier.

Målet var att få en slutgiltig konsol designad för den nya metoden, samt att undersöka om denna kontaktlösa metod verkligen kan fungera i praktiken. Även en affärsmöjlighet skulle bli en del av resultatet. Examensarbetet involverar studier om vridmoment, magnetfält samt om hur dessa mäts. Även förklarningar om hur diverse tillverkare mäter vridmoment med hjälp av olika metoder behandlas i arbetet.

Det utvalda designkonceptet kan användas för tillverkning av eller som grund för vidareutveckling av konsolen.

Språk: engelska Nyckelord: vridmoment

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Nimike: Vääntömomenttimittaus - Polttomoottoreiden Eri Mittausmenetelmien Tutkimus

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Tiivistelmä

Tämä opinnäytetyö on tehty ryhmälle Engine room systemsille, Wärtsilä Marine Solutionsille. Tarkoitus oli tutkia, voisiko uusi menetelmä mitata vääntömomenttia Wärtislän moottorilla korvata nykyisen menetelmän, ja mitkä uuden menetelmän edut voisivat olla.

Tehtävänä oli tutkia erilaisten vääntömomenttia mittaavien menetelmien markkinoita, ja vertailla nämä, pääasiallisesti uutta kontaktitonta menetelmää menetelmään jota Wärtsilä käyttää tänään. Myös kannatin suunniteltaisi uuteen kontaktittomaan menetelmään, jotta tätä voisi testata Wärtsilän moottorilaboratoriossa.

Tavoitteena oli suunnitella lopullinen kannatin uuteen menetelmään, ja myös tutkia voisiko tämä toimia käytännössä. Myös liikemahdollisuus tulisi olla osa tuloksesta. Opinnäytetyö sisältää opintoja vääntömomentista, magneettikentästä ja miten nämä mitataan. Myös selitys miten erilaiset valmistajat mittaavat vääntömomenttia eri menetelmillä on mukana.

Valittu suunnittelukonsepti voidaan käyttää valmistukseen tai perustana kannattimen kehittämiseen

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Kieli: englanti Avainsanat: vääntömomentti

BACHELOR'S THESIS

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Abstract

This thesis is made for Engine room systems, which is a group of Wärtsilä Marine Solutions. The purpose was to investigate if a new possible torque measurement method for Wärtsilä's engines could replace the existing method and what the benefits of this would be.

The assignment was to investigate the market for possible methods of measuring torque and later on compare these methods, mainly the new contactless method with the method that Wärtsilä is using to measure torque today. In addition, a bracket would be designed for the new contactless measurement methods sensor, so that it could be tested in an engine laboratory.

The goal was to make a final bracket design for the new method, along with investigating if it would work in praxis. Also a business case would be a part of the result. The Thesis involves studies about torque, magnetic fields and how to measure these. Furthermore, an explanation of how different manufacturers measures torque with different methods.

The final conceptual design can be used for manufacturing or as a base for developing the bracket.

Language: english Key words: torque

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1 Introduction

This thesis work is made for Wärtsilä marine solutions, for a group named Engine room systems located in Runsor, Vasa. It is about investigating the method of measuring torque on Wärtsilä's marine engines. Torque measurement is necessary to get the optimal performance results from the installation, especially on common rail engines such as the Wärtsilä W31.

The initial chapter consists of the purpose and background of the thesis, as well as a a problem explanation and a short introduction to the company.

The reason for conducting my thesis for Wärtsilä is mainly because of earlier years as a summer trainee, I have learnt a lot thanks to the company. In the summer of 2017 a discussion was started about the opportunities of making a thesis work for the company, this resulted in a couple of options to choose between. It was agreed that a thesis with the topic of torque measurement would be most beneficial.

1.1 Company introduction

Wärtsilä Oyj Ab is an industrial company, founded back in 1834 as a sawmill in Finland. Today Wärtsilä is quite much different, the company has a revenue of 5 billion euro (2015) and has about 18 000 employers around the world. Wärtsilä is a world leading company in delivering advanced technology and complete lifecycle solutions for the energy- and marine market. Wärtsilä is divided into three bigger segments which are:

- *Marine solutions* who are mainly focused on products for customers in the marine, oil and gas industry.

- *Energy solutions* delivers power plants which are based on large combustion engines and solar cells. Another thing is terminals and LNG distribution systems.

- *Services* is there to support the customer throughout the whole life cycle of the installations. Both with spare parts and optimization for the installations.

1.2 Problem

By measuring torque on the drive shaft the control unit can provide the engine the most efficient data when it needs it, by adjusting the fuel injection. This has been done for a long time already but the method of measuring the torque is not optimal. The method used today works by connection a torque flange to the drive shaft which makes the whole arrangement longer. This might not seem like a big problem, but the length of an installation is always important. So, the solution that the new product is providing is to put a contactless sensing module against the drive shaft that measures torque thanks to the magnetic field between the sensor and the spinning shaft.

On diesel engines without common rail, the torque can be measured by fetching the engine load from the fuel rack. On dual fuel engines, running on gas mode, and common rail engines this is not a possibility. Due to this, the torque needs to be measured by an external component, such as a torque flange that uses the strain gauge method. Alternative solutions needs to be evaluated due to the many disadvantages with the current used technology.

1.3 Purpose

2017 Wärtsilä Marine Solutions started an investigation to find a new method of measuring torque on their engine installations. A company from Germany provided Wärtsilä the possible solution for this. The purpose of this thesis is to evaluate the product in context to the application, design a bracket for laboratory testing and determine a test procedure if time allows. A business case will be made to highlight the benefits of the product. Still, there will be an investigation considering other manufacturers and possible competing products on the market.

1.4 Delimitation

This thesis work will be restricted to a market research about different torque measurement methods, with focus on a new method that uses contactless torque measurement. Also, a business case and a conceptual bracket design for the new contactless method will be made for the Wärtsilä W8V31 Diesel engine.

1.5 Disposition

Chapter 1: This chapter introduces the reader to the purpose of this thesis and its extent.

Chapter 2: Consists of theory around the methods used now and possible methods to be used in the future.

Chapter 3: The method describes the different approaches used to complete this thesis.

Chapter 4: The Result shows the conceptual design, and theory around the design. Furthermore implementation and a short business case.

Chapter 5: Discussion about the thesis, what went well and what could have been made better.

Chapter 6: References

2 Theory

This chapter will help to get a better understanding of this thesis work and will include an explanation about torque and other subjects that this thesis is about, such as how torque measurement works and a short briefing about magnetic fields. This will be followed up with explanations on different torque measurement devices on the market and finally a theory part about product development.

2.1 Torque

Common symbols: τ, M

SI unit: N*m

Shafts that transmit torsional loads, torques, are common in engineering applications. A robot driven by a motor, automobile wheels driven by the engine, a milling machine in a factory, a jet engine, all have shafts of various types, shapes, and material. Uniform shafts of circular cross section are common in these applications, and they often carry purely torsional loads, torques.

If a load is applied to an engine shaft, it exerts a reaction torque on the shaft. The two equal and opposite torques at the two ends of the shaft will deform (twist) the shaft. (De Silva, 2014)

Torque is a rotational force (Serway & Jewett, 2003), defined mathematically as the rate of change of angular momentum of an object. It can be thought of as a twist to a specific object. The magnitude of torque depends on three things:

- The amount of force applied to the object.
- The length of the lever arm.
- The angle between the lever arm and the force vector. (Tipler, 2004)

An example of torque is a rotational force applied to a shaft causing acceleration, in this case the engine is the force driving a drive shaft. When load is applied to the engine the torque also increases. Not to be misunderstood with the term moment, which is a force applied to an object that does not change its angular momentum. (Kane & Levinson, 1985)

There are two types of torque; static and dynamic. There is one simple difference between them: dynamic torque involves acceleration while static torque does not. For example, when you unscrew the lid from a glass jar, you apply both static and dynamic torque. The torque that is applied initially is of the static variety because the lid is stationary. Once the lid begins to turn, however, the applied torque is dynamic. It is more difficult to measure dynamic torque than it is to measure static torque. (Torque sensors, 2011)

Standard torque, τ, calculations can be as simple as:

$$\tau = F * r * \sin(\theta)$$

Where F is the force vector applied to the object, r is the position vector and sin (θ) is the angle between the force vector and the moment arm. The torque of an engine can easily be calculated if the power output, P and the angular velocity, ω is known, according to following equation:

$$P = \tau * \omega$$

(Kleppner & Kolenkow, 2013)

ω Is the angular velocity which in this case is the engines rotational speed, measured in radians per second.

When solving τ:

$$\tau = \frac{P}{\omega}$$

(Kleppner & Kolenkow, 2013)

From rad/s to the frequency of rotation gives:

$$\omega = \frac{rad}{s} = 2 * \pi * \frac{rpm}{60}$$

This gives the final formula for calculation torque when speed and power is known:

$$\tau = \frac{P}{2 * \pi * \frac{rpm}{60}}$$

2.2 Measuring torque

A torque sensor is a device for measuring the degree of rotational force that a system is experiencing. Torque sensors are also known as torque transducers. A transducer is a device that converts a physical property of some kind into a measurable signal, such as voltage or current.

There are two main torque measurement methods – inline and reaction. Inline torque measurements are taken by inserting the torque sensor between the agent of rotation and the object being rotated. Reaction torque measurements take advantage of Newton's third law of motion, which tells us that for every action, there is an equal and opposite reaction. When taking a reaction torque measurement, we are not measuring the amount of torque that is being experienced by a rotational system, but rather the amount of torque required to stop the rotation.

A typical torque sensor is using a device called a load cell to convert force into measurable electrical output. A load cell contains one or more strain gauges. The strain gauges changes their electrical resistance when they are affected by a physical force.

The difficulty in measuring torque is that, by definition, torque is a feature of rotational systems. This means that some sort of electrical connection has to be made between the rotating and stationary parts. Many different solutions to this problem have been found.

In this case the torque is to be measured on an output shaft from the engine, driving the installation. When this shaft is subjected to torque (M), sheer will occur in the shaft. As a result of this, two points on the shaft will move in respect to each other. This movement (Δy) is one way how to measure torque (Figure 1).

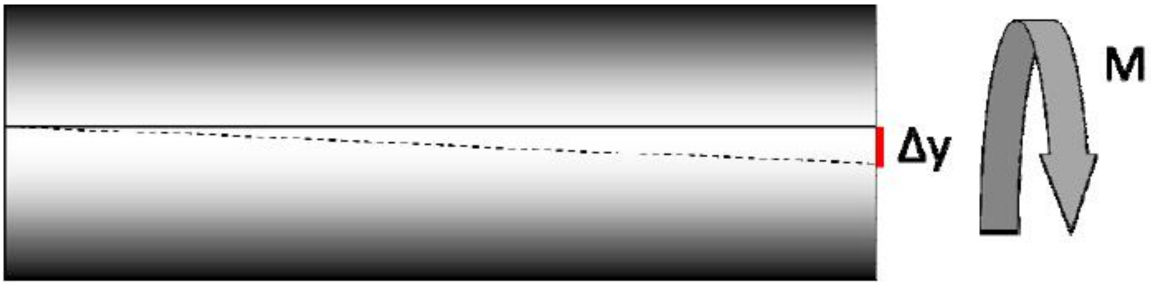

Figure 1. Torque and displacement on a shaft. (VAF, 2017)

(VAF, 2017) (Torque sensors, 2011)

2.3 Magnet field and how to measure it

A magnetic field is a picture that we use as a tool to describe how the magnetic force is distributed in the space around and within something magnetic. The magnetic field is with other words a force field that is created by moving electric charges (electric currents) and magnetic dipoles, and exerts a force on other nearby moving charges and magnetic dipoles. The field has a direction and a magnitude or strength at any given point.

The magnetic field is described mathematically as a vector field (Figure 2). This field can be plotted directly as a set of many vectors drawn on a grid. Each vector points in the direction that a compass would point and has a length dependent on the strength of the magnetic force.

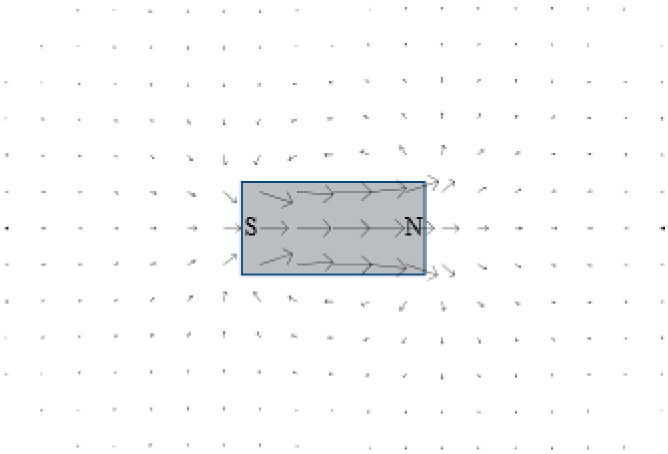

Figure 2. Vector field plot for a bar magnet. (Khanacademy, u.d.)

Another way to represent the information contained within a vector field is with the use of field lines (figure 3). Here we dispense with the grid pattern and connect the vectors with smooth lines.

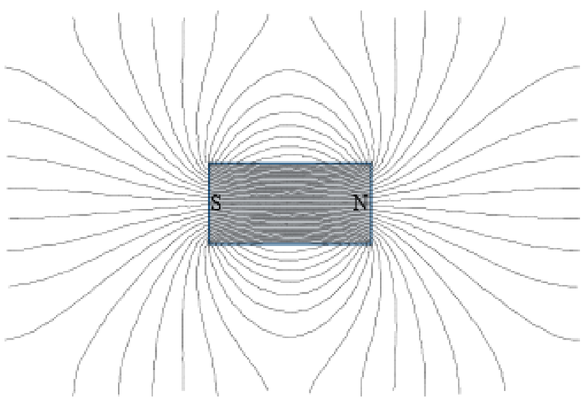

Figure 3. Field line plot for a bar magnet. (Khanacademy, u.d.)

Magnetic fields occur whenever charge is in motion. As more charge is put in more motion, the strength of a magnetic field increases. Magnetism and magnetic fields are one aspect of the electromagnetic force, one of four fundamental forces of nature.

There are two aspects that needs to be measured to describe the magnetic field: The strength and the direction. The direction is easy to measure and has been measured for a long time using compasses. Measuring the strength is however considerably more difficult, magnetometers has been used for some time, these works by exploiting the force an electron feels as it moves through a magnetic field. (Aston, et al., 2016) (Newton & Harvey, 1913)

2.4 Existing torque measurement methods

There are several different solutions for measuring torque on the market today. In this chapter the different solutions will be presented briefly, also the technology used today by Wärtsilä and other technologies on the market such as the new possible measurement method will be brought up. Benefits and drawbacks will be presented for each method.

2.4.1 Technology used today

The manufacturer used by Wärtsilä today goes by the name HBM, and they are the technology and market leader when coming to measurements and testing overall. The company has its headquarters in Germany, and production and engineering facilities are located in the USA, China and Portugal.

HBM has several various products to measure torque with, depending on size, speed and power output. The company present measuring as two different approaches to determining the torque: the direct and the indirect method. With the direct method the torque signal is determined through direct torque measurement in the drive train. This is where normally torque flanges are used (Figure 4), referred as a load cell in chapter 2.2. This kind of measuring method offers many technological benefits. For example, the company itself describes the design extremely short, but when looking from the customers of Wärtsilä's point of view, every millimeter counts when talking about the engine room space. So, the design might be short, but it still takes up space.

Other benefits with the direct measuring method according to HBM is the accuracy they can provide despite high rotational speed. These benefits are very important from Wärtsilä's point of view. The higher the accuracy, the better. The engine speed for a Wärtsilä engine is about 750-1000 rpm so to be able to measure torque at very high speed is not necessary.

Now to the indirect measuring method, where the torque is indirectly determined through measuring the electric motor’s power at the converter in the drive train. Calculating torque can be done together with rotational speed measurement according to equations in chapter 2.1. Together with modern equipment, measuring electric power and rotational speed are done quite easily. However, quite large errors and thus measurement uncertainties may be caused when calculating torque, since the machine’s operating states and power loss are also used in the calculation. Calibration is also another thing that is very difficult.

A method for determining torque indirect is the reaction force measurement method, where the force applied to the end of the lever arm is measured using a force transducer (figure 4). Torque is then determined indirectly through measurement of certain auxiliary quantities in the drive train. This includes measurements either of the shaft’s torsion angle or of the strain resulting from shaft torsion on its surface. In both cases, the result is calculated using the determined auxiliary quantity.

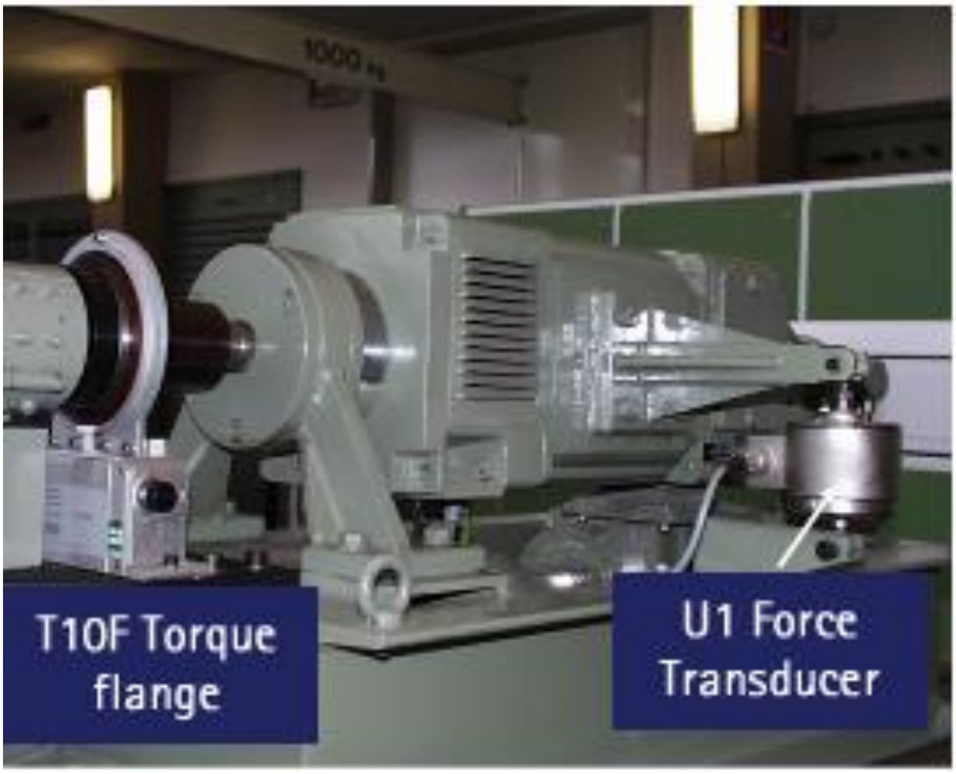

Figure 4. Torque flange to the left and force transducer to the right. (Hoffmann, 1987)

Drawbacks using a force transducer is that it requires complicated mechanics. Interference effects such as expansions of the lever arm resulting from variations in temperature. This needs to be taken into account when calculating, otherwise they can cause measurement errors. Also, when large masses are involved it makes the method less suitable for dynamic tests. (Hoffmann, 1987) (Kuchling, 2007)

The method Wärtsilä is using today is the torque flange provided by HBM. The product named T40MAR is according to HBM a high precision torque sensor that can measure torque up to 400 kN*m. with a long service life, without any maintenance. The sensor is also as required marine-certified for DNV-GL, ABS, BV, KR, CCS, RINA, Ice class BV1A.

Pros:

- Direct torque measurements up to 400 kN*m
- Very high accuracy (HBM accuracy class 0.15)
- Fast control and regulation ensuring very low signal delay
- 100% maintenance free
- Long service life
- Extremely rigid sensor design for high vibration resistance
- Ensures significant fuel savings
- Marine certified

Cons:

- Expensive
- Space required on installation

Wärtsilä has been a customer of HBM for a while and both companies agree that it is required to use a torque flange. Especially for Wärtsilä’s Dual Fuel engines with direct driven propulsion. These engines can run on either natural gas (LNG), marine diesel oil or heavy fuel oil. The Dual Fuel engines may be switched from operating in oil mode to gas mode and vice versa while it is running. A precise load signal is needed from the output shaft when the engine is running. While running on gas, the fuel injection system is receiving this signal from the torque flange which measures the torque on the output shaft, creating the load signal. The T40MAR torque flange is installed between the engines flexible coupling and the driven component.

2.4.2 Other technologies on the market

Other companies that provide torque measurement equipment on the market is VAF instruments. VAF instruments is the most preferred supplier of the top 100 shipyards and market leader in maritime measurement systems today.

VAF instruments offers two kinds of torque sensors, the T-sense and the TT-sense (Figure 5). The firs mentioned is an optical torque measuring system and the second is an optical thrust and torque measuring system. Both of them works by mounting two rings on the driven shaft. The rings which has a measuring arm attached, is partly overleaping each other. On one of the arms a light source is mounted, on the other a photo-electric sensor. This sensor captures any movement of the light source induced by the movement of the rings. The torque and thrust can be calculated by knowing the dimension of the shaft and the distance between the two rings.

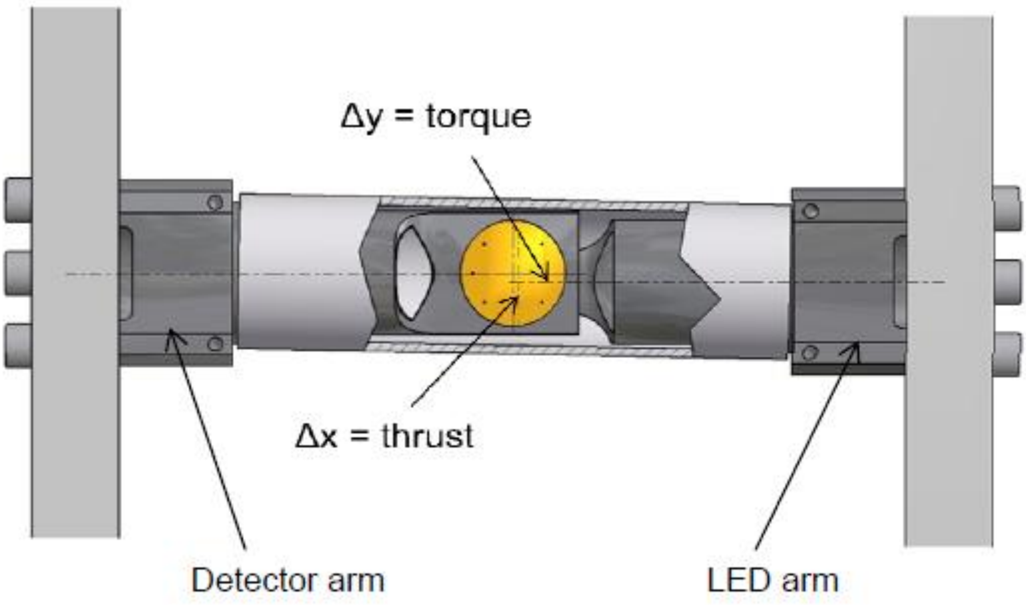

Figure 5. The working principle of the TT-sense system. Both Δy and Δx measured. (VAF, 2017)

The TT-sense system works as previously explained. Except that in the TT-sense thrust and torque measuring system Δx is also measured, which gives the thrust output. (VAF, 2017)

The Δy movement has a direct connection to the explanation in chapter 2.1, Torque, where De Silva explains it as If a load is applied to an engine shaft, “it exerts a reaction torque on the shaft. The two equal and opposite torques at the two ends of the shaft will deform (twist) the shaft.”

Pros:

- Precise measurement
- Reliable

Cons:

- Cost
- Size

2.5 New possible torque measurement method

A possible new method that will be tested to measure torque on Wärtsilä's engines is a contactless measuring devise from a new manufacturer, the product itself is a small but effective sensor called Active-3-Professional torque sensor. Taking the step from a strain gauge method connected to a shaft to a contactless method that in theory only needs to be pointed at the shaft to give results. If this method shows to be successful, it will be a huge difference in as already mentioned earlier, space saving and cost reduction.

The company, named Torque And More GmbH, that is making this sensing module is founded in Germany, it is a research, testing and production management company. Torque And More's engineering team is claimed to be well trained in sensor development and custom specific solutions with a combined relevant knowledge-history of 120-years. They have worked together with automotive certified production partners. Over the past years, Torque And More has created an outstanding and very competitive portfolio of patents and patent applications, in the field of magnetic principle based sensing technologies. (Tam-sensors, 2017)

Torque And More develops and produces custom and standard non-contact torque, bending, angle, linear position and motion & speed sensors, all based on magnetic principles. The technologies used for the Torque And More sensor products are invented, developed and patented (or patent pending) by Torque And More.

2.5.1 Function

The Active 3 sensor (Figure 6 & 7) works thanks to a magnetic field between the sensor and the rotating shaft. The sensor is capable of measuring Torque, bending and axial load (using the correct sensing module).

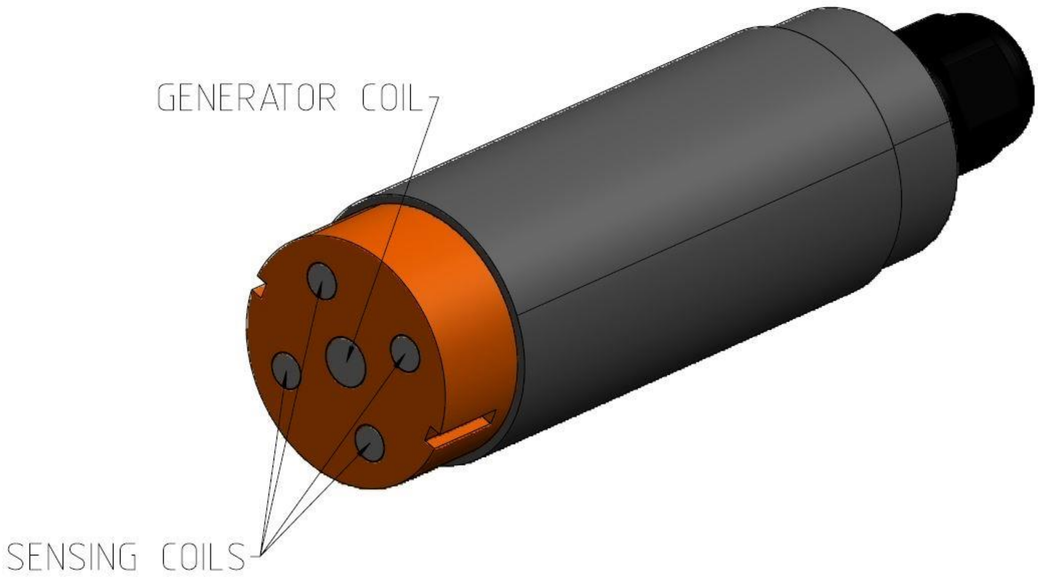

Figure 6. Sensing module function

The way the sensor works is when the driven shaft starts rotating, the generator coil (Figure 6) inside the sensing module emits a small alternating magnetic field using a Class-D power amplifier that will penetrate the surface of the shaft. The returning magnetic response from the shaft is then received by the sensing coils (Figure 6) and passed-on for further processing in the sensor electronics. The alternating magnetic field which passes through the shaft surface will be influenced by the mechanical forces that are applied to the shaft from the engine. The mechanical forces will alter the characteristics of the initial alternating magnetic field. More deeply explained the mechanical tensions change the properties of the material and one of the effects is the change in permeability, which is the measure of the ability of a material to support the formation of a magnetic field within itself. Meaning when there is stress in the material, the generated magnetic field, created by the generator coil, will change in direction and amplitude, which in turn will cause a change in the signal that the 4 sensing coils are measuring. These measured changes are detected by the sensing element and then converted into a 0 to +5 Volt analogue signal output. (Tam-sensors, 2017) (Trujillo, 2018)

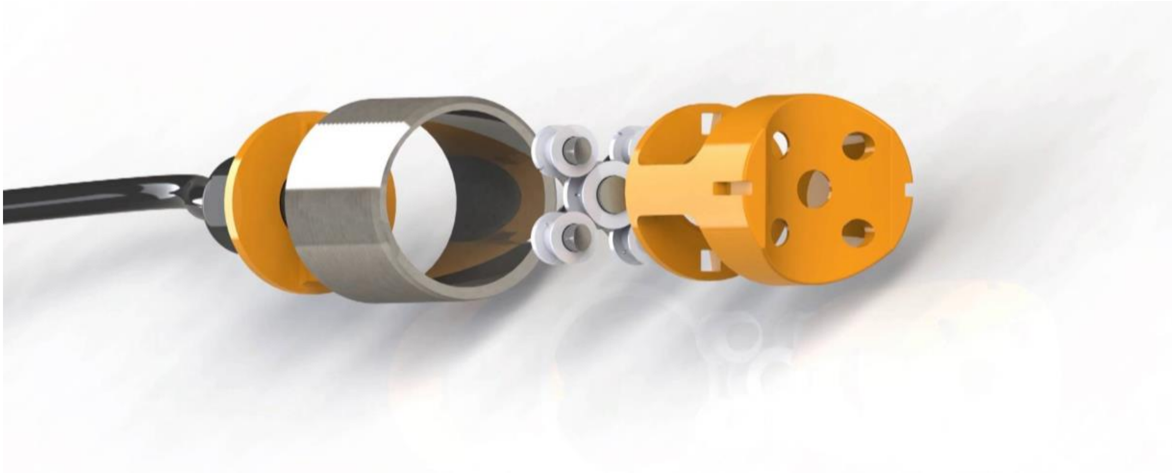

Figure 7. Torque And More's Torque sensor (Tam-sensors, 2017)

In Wärtsilä's case the signal will go through the sensor electronics which will provide the engines control unit with the signal. The sensors initial output signal unit is Volt (0 - 5 V), but the engines control unit needs current, somewhere between 4-20 mA. In the lab testing however, voltage output could be used. This due to the fact that the sensor will be tested on an engine that already is equipped with a torque flange. This way both sensors can be run in parallel and output can be compared.

2.5.2 Requirements

In order to get the new sensor technology to work there are internal requirements stated by Wärtsilä that must be fulfilled if this sensor will be a standard equipment in the future.

- The most important being the tolerance needs to be under 1%, ideal would be 0.3%. The reason for this is obvious, precision measurements is key to get the engine running optimal.

- The sensor will be used on marine applications, so another requirement for the sensor is to have Marine Classification. At the moment the sensor would need re-designing to be able to be classified for Marine use. But the sensor as it is today will only be tested in laboratory environment.

- Along with this classification the requirement of IP 55 is needed, this means that the sensor need to have complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but cannot enter in an amount sufficient to interfere with satisfactory operation of the component. Also, water projected by a nozzle against the enclosure from any direction shall have no harmful effect. (FANTECH 2008)

- The components around the sensor and the sensor itself has to withstand vibration levels of 28 mm/s. As the sensor will be connected to the engine, vibrations will occur. These vibrations must not harm the sensor or affect the output.

- The signal to the engine has to be analogue and around 4-20 mA. At the moment the “of the shelf” sensor gives output in Voltage, but according to the manufacturer, an output in Amperes is not a problem.

External requirements that the provider of the sensor has stated during meetings and e-mail conversations are:

- The measured material used, in this case, the crankshaft, has to be Ferro-magnetic in order for the sensor to register the magnetic field. The material used for the crankshaft on the W31 is hardened steel.

- The air-gap between the sensing module and the shaft is preferred to be around 0.5 – 1 mm (maximum 3 mm), the closer the sensor is to the shaft, the better the readings gets. Also, the bracket needs to be rigid enough so the air-gap doesn’t change during working condition. Sensor needs to be pointing straight against the shaft.

- The shaft diameter from where the measurements are taken has to be in relation to the targeted torque measurement range. Best is to have a mechanical stress of 40 MPa as nominal mechanical stress.

Pros

- Cheap compared to the other alternatives

- Space saving

- Easy installation (according to manufacturer)

Cons

- Lacks marine classification

- Doubts about functionality, more in discussion.

2.6 Product development

In engineering, product development covers the complete process of bringing a new product to the market. A central point in product development is product design, along with various business considerations. Product development could be described as the transformation from an opportunity on the market into a product available for sale. (Oxford University, 2009)

A typical framework that helps to structure the actual product development is the fuzzy front end (FFE) approach. Where it is defined what steps that should be followed but selected to make most sense for the specific product that is being developed. The five elements of FFE product development are:

- *Opportunity identification,* involves brainstorming possible new products. Once an idea has been identified as a prospective product, a more formal product development strategy can be applied.

- *Opportunity analysis,* involves a closer evaluation of the product concept. Market research and concept studies are undertaken to determine if the idea is feasible or within a relevant business context to the company or to the customer.

- *Idea genesis,* involves turning an identified product opportunity into a tangible concept.

- *Idea selection,* involves creating a rapid prototype for a product concept that has been determined to have business relevance and value. A quick and easy model if created in this stage rather than the refined product model that will be tested and marketed later on.

- *Product development,* involves ensuring that the concept has passed muster and has been determined to make business sense and have business value.

(Koen & Ajamian, 2001)

For manufacturers, product decisions are among the most difficult because of the tremendous cost and risk involved in bringing a new product to the market. One type of research, conducted early in the product development process, is the concept test. It usually involves explaining the idea or concept of a product or service to a small sample of prospects. Often qualitative methods, such as in-depth focus group interviews, are used for this purpose. New insights into design modifications or possible ways to market the product often result. Especially with new product, it is hard to know what you like until you have seen different options. (Block & Block, 2005)

3 Method

This chapter explains the different approaches used to accomplish this thesis work.

The main tool used is the 3D CAD program Siemens NX to design the bracket. This tool is familiar from earlier summers as a trainee at Wärtsilä, but also from courses in school. All the planning and designing of the bracket has been done using Siemens NX. Using a full-scale 3D model of the engine ensures proper fitment of the final bracket design.

Other approaches such as meetings and conversations with the manufacturer of the new technology has also been very important completing this thesis.

3.1 3D Design

The Design of the 3D model for the conceptual design of the sensor bracket was made in Siemens NX 11 as mentioned. This is an advanced CAD/CAM/CAE software program for making 3D-models, concept design and even documentation.

Before the conceptual design started in NX, I thought of the fuzzy front end framework described in chapter 2.6. So while brainstorming, several different sketches were made and evaluated. After several ideas the sketches was transferred into simple 3D models, this way it was easy to see if there would be any collisions with the engine parts. After that the size and final form was thought thru and tested, again and again for minor changes to get the perfect fit.

When the final design was made in NX the main goals was to make it easy to mount it to the engine without any extra parts. Also lightweight, a simple robust design and function were the main focus points. The design is further explained in the result (chapter 4.1.)

3.2 Research and discussions

To gather the information needed, a lot of research has been done. Both in books and on the internet. Most of the information collected about the different measurement methods has been taken from the manufacturer's webpages. And most of the theory about torque and magnetic field was taken from books.

One of the key sources has been the companies own knowledge and the helpful staff of Torque And More. Because the new method from Torque And More is fairly new on the market, there were a lot of questions about how it works. Both Wärtsilä and Torque And More has provided me with function principles, explanations and theory about the different solutions.

3.3 Meetings

Meetings has been as mentioned a very important step working with this thesis. Discussions about the new contactless technology has been the main topic, if it will work on Wärtsilä's engines or not. Those who has been participating in these meeting is me, my manager and other involved in the project, such as purchasers and several engineers.

- First meeting was held 28.11.2017. At this point the requirements for the sensor from Wärtsilä's point of view was discussed, and prepared to present to the sensor manufacturer, Torque And More. (chapter 2.5)

  Also the most important topic for my part was the decision of what engine to test this sensor on. Without struggle the W31 was the best decision, because there is a W8V31 diesel engine with a torque flange installed in the engine laboratory in Vaskiluoto, Vasa. This allows testing the new torque measurement method while comparing the result to the torque flange already installed.

  Purchasing a test sensor was also approved and the design of the sensor bracket could start with choosing what material to use and the shape of the bracket, more about the design in chapter 4.

- The second meeting was held 20.12.2017. This time with the manufacturer of the torque sensor, Torque And More. The requirements were presented and discussed, also Torque And More presented their requirements for the sensor to work properly (chapter 2.5.2).

  Discussions about the installation and calibration of the sensor was another main topic in this meeting, helping me with the design. The choice of material was decided after the requirements stated that the bracket has to be made out of non-magnetic material such as stainless-steel or aluminum. (Chapter 4.1)

4 Result

In this chapter the result of this thesis will be presented. First the design concepts and the final design, with explanations why it was made the way it was.

The design will be followed up with implementation where I will discuss how to possibly implement the product into Wärtsilä's engine installations in the future. Last there will be a short business case regarding the new possible measurement method, followed up with a discussion about the thesis in general.

4.1 Design

As mentioned, a part of this thesis is to design the bracket holding the torque sensor in place. The engine this bracket will be design for is the new W31 (figure 8). This engine type was chosen for several reasons, the first being that it is Wärtsilä's newest engine model and rated as the most efficient 4-stroke engine in the world. Moreover, the engine is built using modularization, so even if the bracket is designed for a W8V31 with 8 cylinders the bracket should fit a W16V31 with 16 cylinders. In this case, the design will be made and tested on a W8V31 diesel engine.

4.1.1 Conceptual bracket design

To make a functional design, a good positioning is a very important decision in this case, where the sensing module has to be very close to the crankshaft. So, the design procedure begins with searching for a suitable place for the bracket. Choosing material is also very important for this bracket, the reason for this is that the sensor uses the magnetic field to measure torque as described in chapter 2.5.1, if the material of the bracket would be iron or any Ferro-magnetic material the signal to the sensor would be disturbed. A non-magnetic material such as stainless-steel or aluminum is preferred.

After investigating a possible place for the bracket, the best solution would be the end cover sealing flange in the flywheel end of the engine (figure 9). There are several fastening points and the requirement of the sensing module being maximum 3 mm from the crankshaft could be fulfilled. The material of the sealing cover is cast iron, but although that is a magnetic material it will not disturb the signal because the bracket itself will be made out of non-magnetic material.

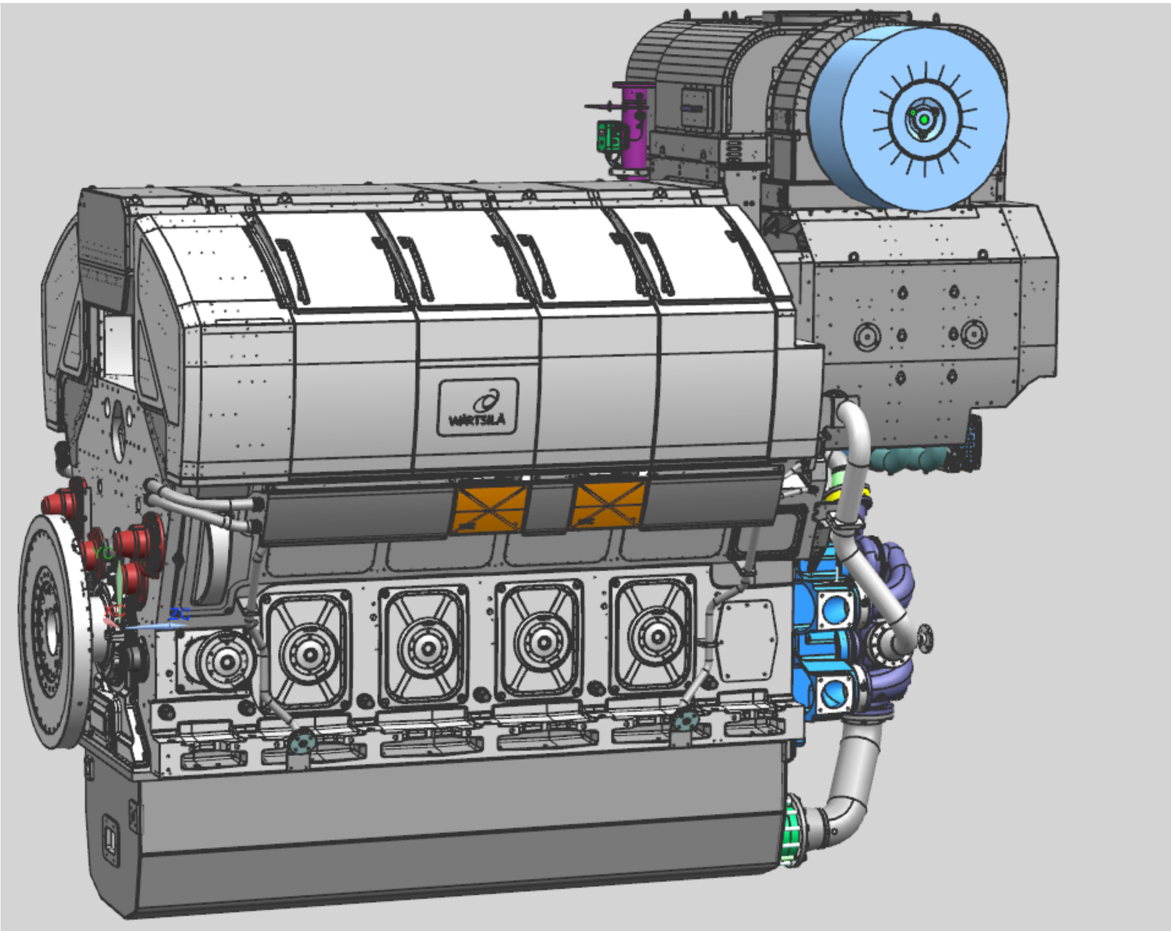

Figure 8. W31 engine

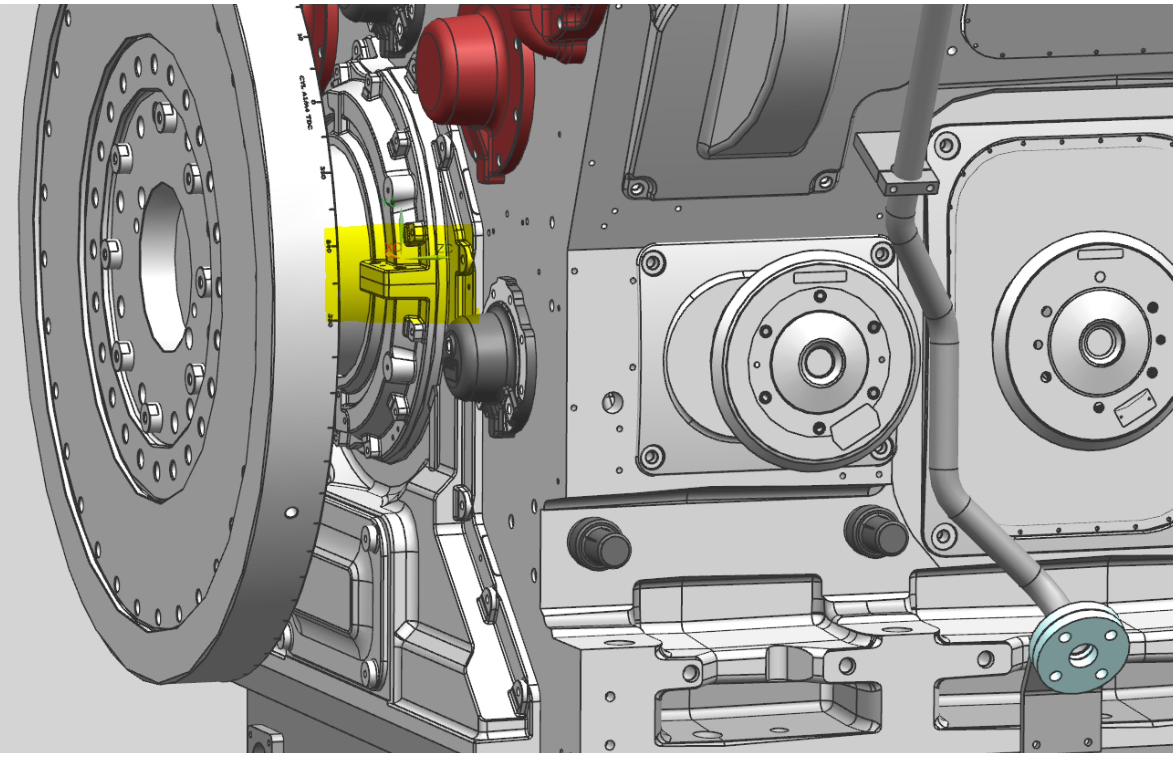

Figure 9. Positioning of the bracket on the sealing flange highlighted

4.1.2 Design prototyping

The first intention of the bracket was to make it as simple as possible yet steady. Since vibrations will occur when the engine is running, fastening points has to be chosen so that the bracket will not have its own vibrations. As shown in figure 10, the first intended fastening points, highlighted in yellow, would have been a good possibility to fasten the bracket to. The highlighted holes are threaded and that means no further machining on the engine itself would have been required. The problem with this fastening point was that the engine chosen for laboratory testing has an earlier version of the sealing flange. The earlier version does not have these holes. The holes are intended for fastening a grounding brush that is needed when the installation uses a permanent magnet generator.

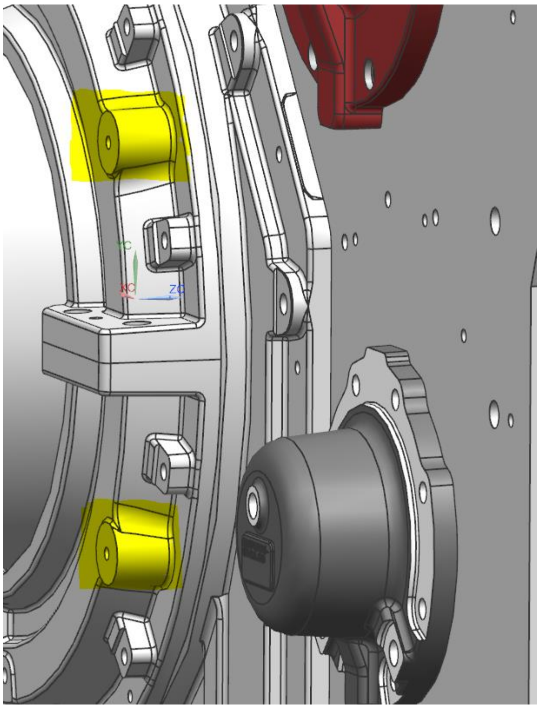

Figure 10 fastening point

Discarding the first option and moving on to the next, but still focusing on the same position, the sealing flange. A good thing about this flange is that there are several holes and bolts that eases the mounting of the bracket.

So, thinking back to the term simplicity and functionality a new position was decided. The sealing flange is made out of two pieces, an upper and lower part. As shown in figure 11 these two parts are bolted together vertically and horizontally. The requirement of stability so that the sensor can take readings without disturbances from vibrations due to the bracket, made it clear that the vertical placed bolts is another suitable option. If this fastening point was used, a very small and compact design of the bracket could be made, since no support arms would be needed that could cause vibrations. After a few ideas it was decided that this fastening point should be tested. Several different options were thought thru before starting the design. Options such as making the bracket in two pieces, and welding or using bolts to fasten the two pieces together. This solution could be made out of a U-profile as the lower part and machining the upper part where the sensor is fastened. But when considering that the bracket needs to be made out of aluminum, there will be the risk of deforming the upper part when welding the two pieces together.

Figure 11. Horizontal bolts used as fastening point

If the welding would deform the sensor bracket, it would cause problem with fitting the sensor and if it would twist, the measurement results could be affected as explained in chapter 2.5.2, the sensor needs to be pointed straight against the shaft. Bolting the two pieces together wouldn’t be as rigid as if the whole bracket would be made out of one piece.

As a result of these risks the final design was made from an aluminum block, machining out the shape of the bracket. This method will ensure correct measurements and a steady product that can withstand the vibrations caused by the engine. The fastening point remained the same as thought earlier. A new prototype of the bracket was made and fitted into a 3D model of the W8V31 diesel engine and shaped to suit the sealing flange. (Figure 12)

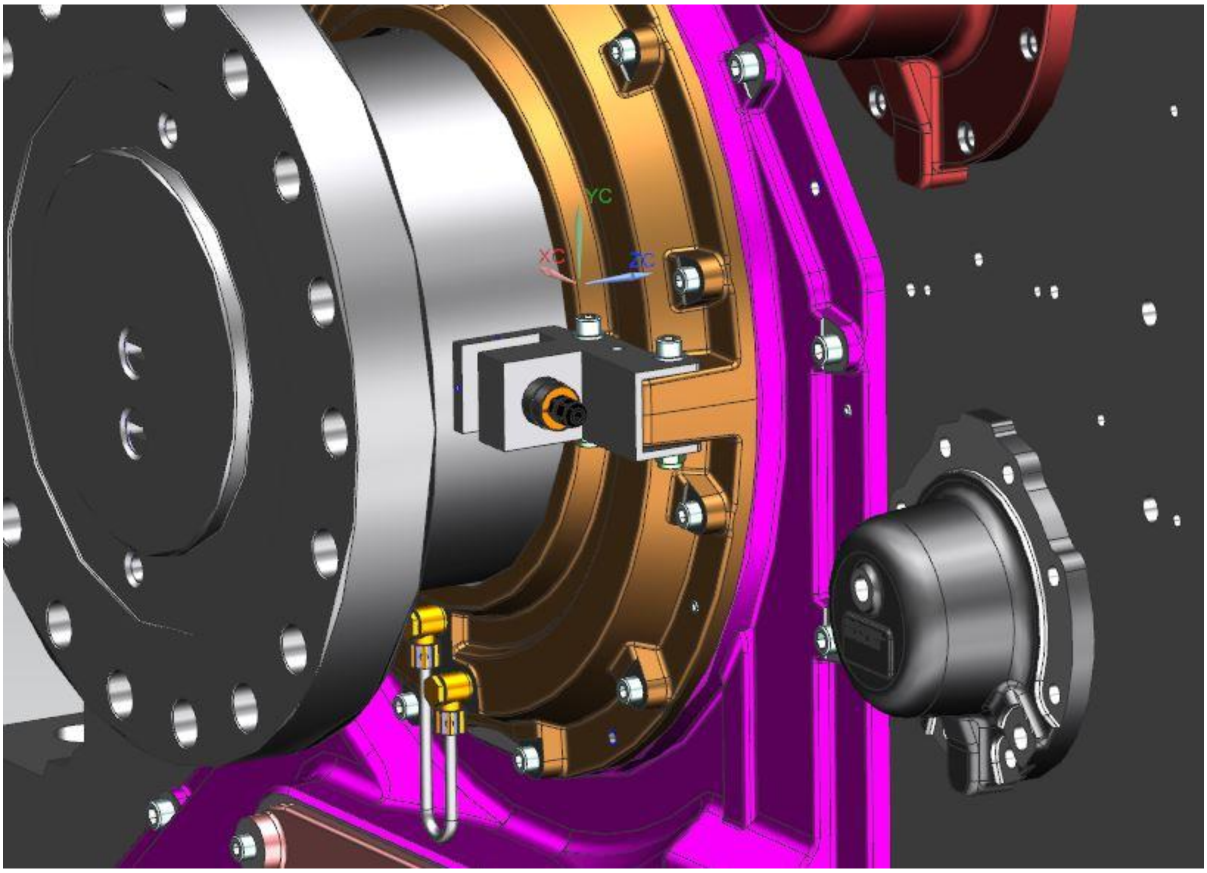

Figure 12. Final bracket design with sensor in place.

To ensure proper fastening of the sensor to the bracket, the upper part where the sensor is located, has a gap where one of the fastening nut will be located. This nut will be forcing the sensor to its position. The sensor has a guiding strip on the end pointed towards the crankshaft, and this strip will be used to lock the sensor in place using two set screws, preventing the sensor from rotating while mounted (Figure 13).

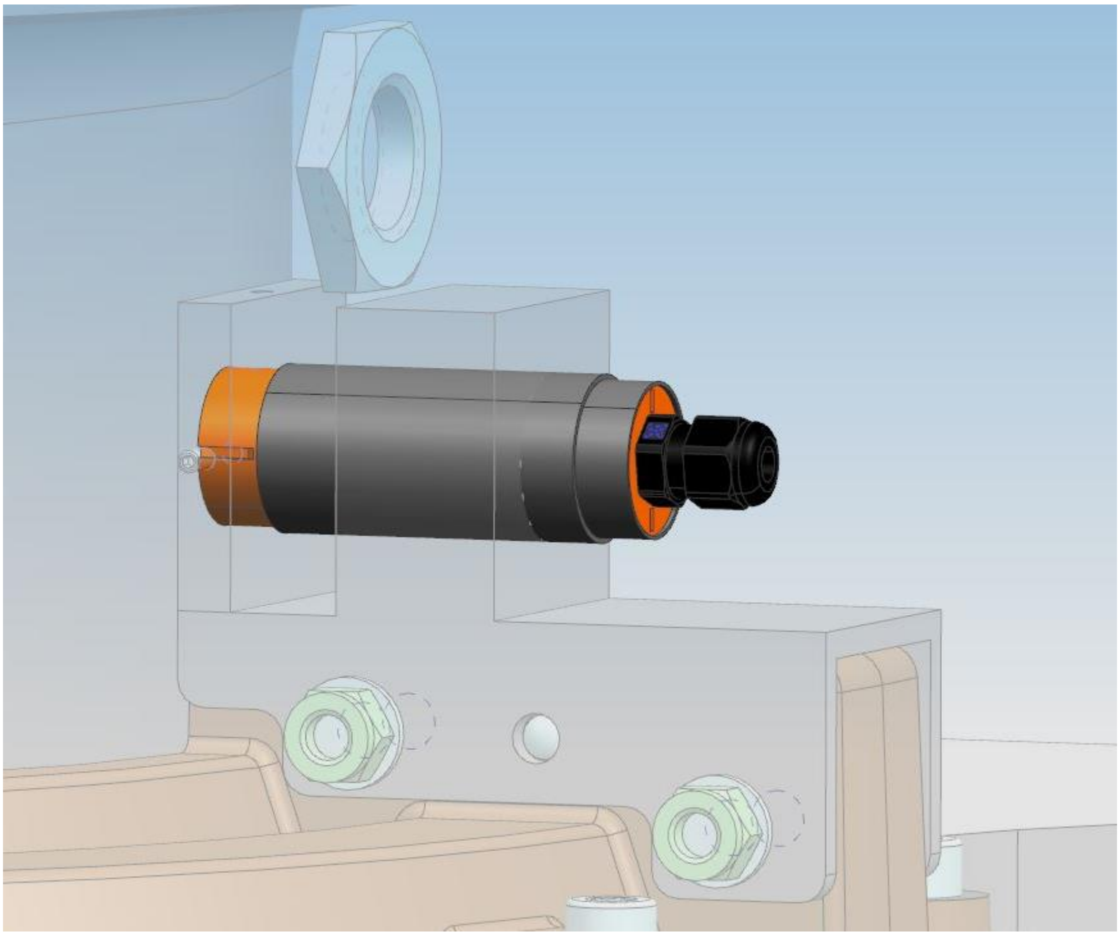

Figure 13. Fastening of the sensor to the bracket.

The whole thicker grey part of the sensor displayed in figure 13, is threaded. That is how the nuts will be tightening the sensor against the thicker bracket piece, while the smaller bracket piece towards the crankshaft is where the set screws will prevent the sensor from rotating as mentioned earlier (Figure 14). When the sensor is in its final position, the distance between the sensing surface and the crankshaft is 0.5 mm which fulfills the requirement stated in chapter 2.5.2, that the gap between the sensor and the measured shaft is preferred to be between 0.5 – 1 mm. (Figure 15)

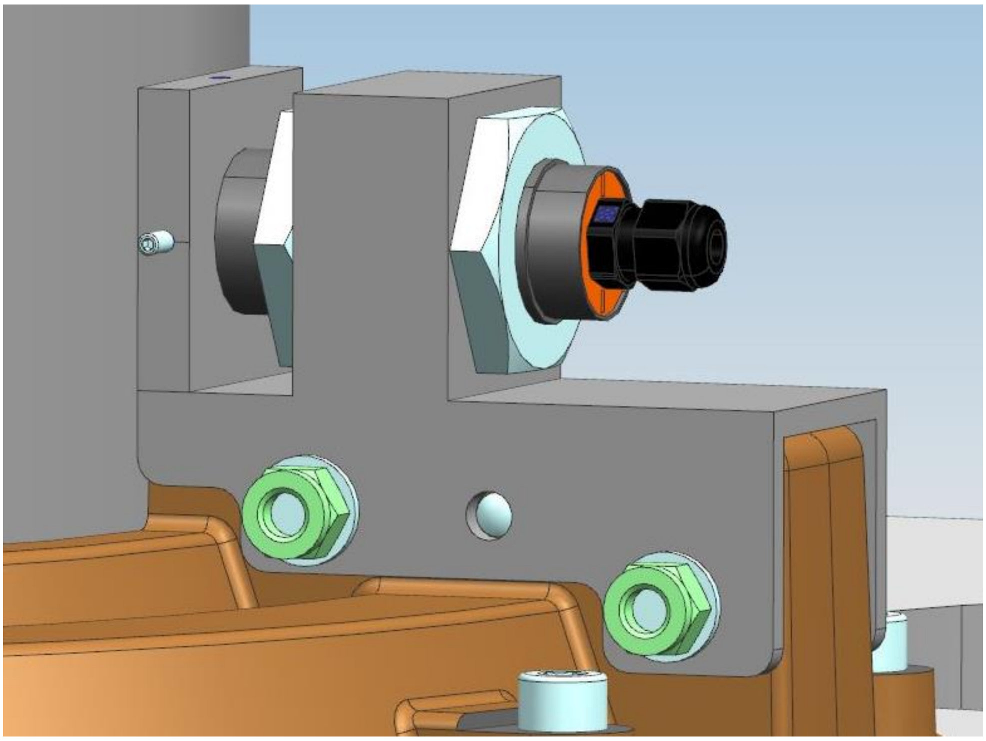

Figure 14. Sensor mounted to bracket

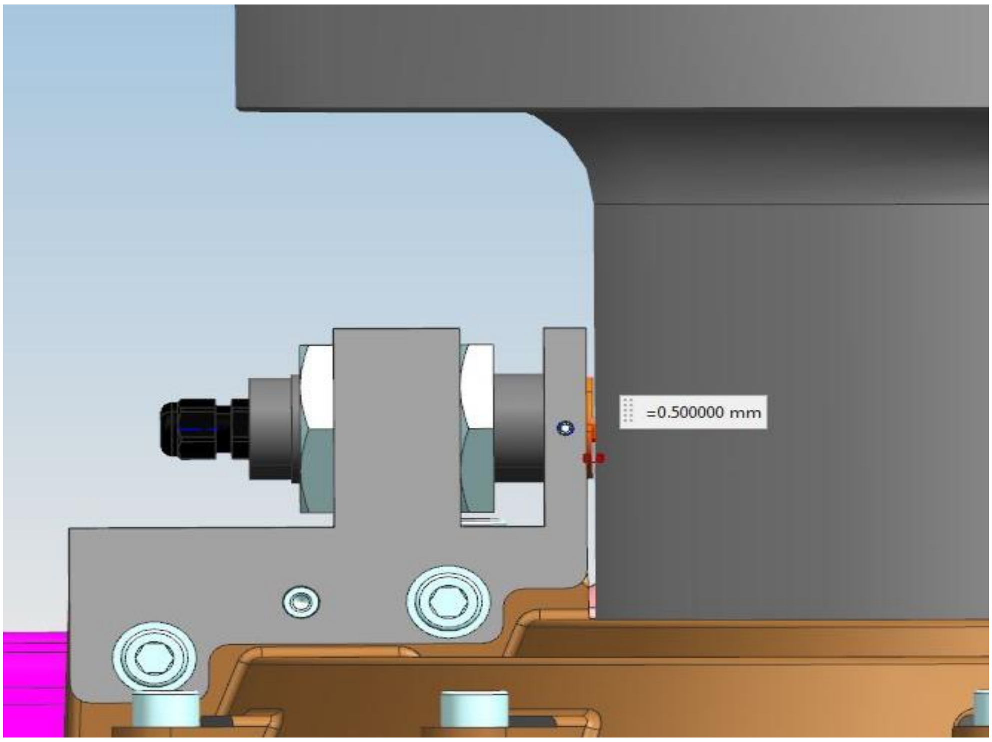

Figure 15. Distance between sensor and shaft.

4.2 Implementation

To implement this new contactless method the first stage will be the testing. As mentioned in chapter 3.2, the sensor will be tested in Wärtsilä's engine laboratory in Vaskiluoto, Vasa. If the testing, which will be carried out on the W8V31 Diesel, is successful and proves that the new method is working according to expectations and requirements, the next step will be to investigate if this will replace the existing method of measuring torque, the torque flange. To evaluate the torque sensor, it will be tested side by side with a torque flange, this way the comparison can be made on different loads to see how accurate the sensor is.

If the sensor proves to be accurate enough for Wärtsilä's installations there will be several steps before Wärtsilä is able to provide the sensor as a part of an engine installation, these requirements are stated in chapter 2.5.2, but the most important ones are:

- The sensor will be used on marine applications, so the sensor must have Marine Classification. At the moment the sensor would need re-designing to be able to be classified for Marine use. The sensor needs to work whether the vessel is operating in the tropics or Polar Regions. To get a marine approval for the sensor it has to be tested and certified by a recognized body such as Lloyd's Register, Germanischer Lloyd, Det Norske Veritas, American Bureau of Shipping or China Classification Society for use on a ship.

- Along with this classification the requirement of IP 55 is needed, this means that the sensor need to have complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented but cannot enter in an amount sufficient to interfere with satisfactory operation of the component. Also water projected by a nozzle against the enclosure from any direction shall have no harmful effect. (FANTECH 2008). It is also important that the sensor will withstand splashes of oil and fuel without being harmed or to cause changes in the measurements. The sensor will be located besides the crankshaft sealing flange, so there might be a risk of oil leaking out when the gasket gets worn out.

- The components around the sensor and the sensor itself has to withstand vibration levels of 28 mm/s. As the sensor will be connected to the engine, vibrations will occur. These vibrations must not harm the sensor or affect the output. The crankshaft will be rotating on an oil film while the engine is running, this oil film is very thin but will cause the crankshaft to vibrate in operating mode. This vibration is still so small that it shouldn’t affect the measurements.

If these requirements are fulfilled further on in the project, a new design needs to be made. This time for all Wärtsilä’s engine types. In that case there is two options:

- To keep the bracket but re-design it to fit engine types such as the W20, W32, W50. This requires the development of completely new products.

- The second option is to re-design the sealing flange on the engines so that the bracket is built in to the flange. The flange is casted iron so this is possible and will reduce the amount of parts on the engine. But then again, this also requires the sealing flanges to be revised and re-designed for all engine types. And might not work on other engine types than the W31.

For the testing in the engine laboratory there will be a test plan needed. The people needed to accomplish the tests of the sensor will be the chief test engineer for the engine that the tests will be carried out on. For the mounting of the sensor and bracket there will be mechanics and electricians needed, to do the mechanical mounting part and the electrical parts such as connecting and installing the cables and the power supply for the sensor. The estimated time spent on the mounting and installing of the sensor is between 1 – 4 hours depending on the fitment of the sensor bracket, and possible difficulties with the cable installation. When the installation is done the test schedule needs to be made. The sensor will be tested on different engine loads, beginning with the calibration at 0 % load, then rising the load slightly and comparing the results with the existing torque measurement method. For example, an interval of 0, 20, 40, 60, 80, 100 percent load could be used while comparing the output. The estimated time for testing any kind of sensor is about 8 hours after installation, so that could be a target.

4.3 Business Case

A part of this thesis is to compare the method used today with the new method of measuring torque. First of all, the cost plays a huge role in the market today, and when comparing the previous method to the new contact-less sensing module method, the annual cost reduction is considerable. The price of the sensing module kit is approximately 56 – 82 % cheaper than the torque flange depending on the engine type, if the engine is bigger the torque flange also needs to be bigger which causes the costs to rise. While the same sensor can be used for any engine type and size. The cost of the bracket for the sensor is insignificant, however, if the sealing flanges would be re-designed the cost of the work hours could be high. When comparing these two expenses a clear difference is shown. When comparing the cost of the torque flanges delivered 2016 with the estimated cost if the same amount of projects would have used the new method, the total cost would have been reduced by about 71%

If the use of a power take out (PTO), which could be a generator or an electric engine in the free end of the engine, also is included in the project, another torque sensor will be required in that end. Therefore, if all projects would have had a PTO delivered in 2016, the same saving percentage when comparing the prices between the torque flange and the torque sensor is achieved, but in larger numbers.

4.4 Summary

I am satisfied with the way the design of the bracket turned out, but the functionality is still to be tested. The market investigation was shown to be quite hard to get decent information for, but with the help of the sources used, there was enough facts to get a picture of what kind of solutions there is on the market. A more in-depth explanation and investigation about the different methods could have been made, but I wanted to focus more on the new contactless measuring method. So, when looking back to the purpose of this thesis, the only thing that left behind was an in-depth test plan. This is disappointing both for me and for Wärtsilä, but I will try to make a test plan outside of this thesis, that can be used for the first stages of laboratory testing.

The result of this thesis will be used to further investigate and test the new method of measuring torque. By using the bracket for laboratory testing and the business case for the stake holders will hopefully help finalizing this project.

5 Discussion

In the discussion, I am going to talk about the project in general, what has been done, what went well and what could have been done better, as well as a comparison of the result and the purpose.

The project has overall been going well, from the first meetings to the final design. The things that has been challenging is the research and understanding the function principal of the Sensor made by Torque And More. But after conversations and meetings with the helpful staff from Torque And More many things was solved. The bracket design was completely up to myself, and had its ups and downs, mainly because it is a completely new part for the engine. But with help and suggestions from co-workers, the prototyping has been a joy.

A thing that could have been done better was the business case, with little input and little knowledge about business, it came out a bit short.

When comparing the different torque measurement methods, it is clear which one that would be the best in theory. But many questions and doubts exist considering the function of the Torque Sensor. After meetings with the Torque And More staff, it is still unclear if the sensor will provide a clean enough signal to be used as data input. This is due to the hardening and diameter of the crankshaft for the W31 test engine. The W8V31 has a crankshaft diameter of 340 mm, this would, according to Torque And More, require a torque output of 670 kNm from the engine for optimal measurement results. While the max torque output from this engine according to chapter 2.1. Formula is:

$$\tau = \frac{P}{2 * \pi * \frac{rpm}{60}}$$

$$\tau = \frac{4880}{2 * \pi * \frac{750}{60}} = 62.13\ kNm$$

This means that the torque output will be over 10 times less than the optimal. However, there is a solution for this, the signal can be amplified. But by doing that, some other non-desired effects can also be amplified, i.e. noise. Meaning that the signal will not be as clean as it would have been if the torque output was optimal. This is how it could work in theory, to see how the sensor method works in practice, it must be tested in the engine laboratory.

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Figure explanation