YRKESHÖGSKOLAN NOVIA

Mechanical Design Concept for Top Dead Center, Valve Lift, and Camshaft Timing Tool

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Bachelor´s thesis

Degree Programme in Mechanical and Production Engineering

Vaasa 2024

BACHELOR´S THESIS

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Degree Programme and place of study: Mechanical production engineering, Vaasa
Specialization: Mechanical Construction Systems
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Title: Mechanical Design Concept for Top Dead Center, Valve Lift, and Camshaft Timing Tool

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Date: 8.4.2024 Number of pages: 29 Appendices: 1

Abstract

This thesis work was made on behalf of Wärtsilä Finland Oy, and the topic addresses the mechanical design concept of mounts for sensors and encoders for the W31 engine type. The sensors and encoders are used to make the engine’s timing process automated and to reduce possible measurement errors when measuring manually with dial gauges. This method of determining the absolute Top Dead Center and valve lift saves time and gives more accurate results compared to traditional measuring methods.

This thesis work only covers the concept design stage for the different mounts and the approach to the final concepts presented in the results. The thesis work enlightens the challenges encountered when designing a concept and how they were addressed.

The theory of this thesis work focuses on engine theory, product development, and design. The engine theory gives the reader a better understanding of the importance of how different parts correlate with each other, and the role of the timing in achieving successful combustion.

The results are design concepts that will be further developed to fit other engine types. This automated way of determining the engine’s timing reduces the measurement time and the errors that can be made given the human factor.

Language: English
Key Words: computer-aided design, valve timing, top dead center

EXAMENSARBETE

Författare: Allan Hellström
Utbildning och ort: Maskin- och produktionsteknik, Vasa
Inriktning: Maskinkonstruktion
Handledare: Fredrik Berg (Wärtsilä) och Leif Backlund (Novia)

Titel: Mekaniskt designkoncept för övre dödläge, ventillyft och kamaxeltiming verktyg

Datum: 8.4.2024 Sidantal: 29 Bilagor: 1

Abstrakt

Detta examensarbete utfördes åt Wärtsilä Finland Oy, och ämnet behandlar det mekaniska designkonceptet åt fästen för sensorer och pulsgivare för W31-motortypen. Givarna och pulsgivarna används för att automatisera motorns timingprocess och för att minska eventuella mätfel vid manuell mätning med mätklockor. Denna metod för att bestämma absolut övre dödläge och ventillyft, sparar tid och ger mer exakta resultat jämfört med traditionella mätmetoder.

Detta examensarbete täcker endast konceptdesignfasen för de olika fästena och tillvägagångssättet för de slutliga koncepten som presenteras i resultaten. Examensarbetet belyser de utmaningar som uppstod vid utformningen av ett koncept och hur de hanterades.

Teorin i detta examensarbete fokuserar på motorteori, produktutveckling och design. Motorteorin ger läsaren en bättre förståelse för vikten av hur olika delar korrelerar med varandra, och timingens roll för att uppnå lyckad förbränning.

Resultatet är designkoncept som kommer att vidareutvecklas för att passa andra motortyper. Det här automatiserade sättet att bestämma motorns timing minskar mättiden och de fel som kan begås på grund av den mänskliga faktorn.

Språk: Engelska
Nyckelord: datorstödd konstruktion, ventiltid, övre dödläge

OPINNÄYTETYÖ

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Päivämäärä: 8.4.2024 Sivumäärä: 29 Liitteet: 1

Tiivistelmä

Tämän opinnäytetyön toimeksiantaja on Wärtsilä Finland Oy, ja aiheena on W31-moottorityypin antureiden ja koodareiden kiinnikkeiden mekaaninen suunnittelukonsepti. Antureiden ja koodareiden avulla moottorin ajoitusprosessi saadaan automatisoitua ja mahdolliset mittausvirheet pienenevät, kun mittaus tehdään manuaalisesti mittakelloilla. Tämä menetelmä absoluuttisen yläkuolokohdan ja venttiilin noston määrittämiseksi säästää aikaa ja antaa tarkempia tuloksia kuin perinteiset mittausmenetelmät.

Tässä opinnäytetyössä käsitellään ainoastaan eri kiinnikkeiden konseptisuunnitteluvaihetta ja tuloksissa esitettyjen lopullisten konseptien lähestymistapaa. Opinnäytetyö valottaa konseptin suunnittelussa kohdattuja haasteita ja sitä, miten niihin vastattiin.

Tämän opinnäytetyön teoria keskittyy moottoriteoriaan, tuotekehitykseen ja suunnitteluun. Moottorin teoria antaa lukijalle paremman käsityksen siitä, miten eri osat korreloivat keskenään ja mikä on ajoituksen merkitys onnistuneen palamisen kannalta.

Tuloksena on suunnittelukonsepteja, joita kehitetään edelleen muihin moottorityyppeihin sopiviksi. Tämä automatisoitu tapa määrittää moottorin ajoitus vähentää mittausaikaa ja virheitä, joita inhimillinen tekijä voi aiheuttaa.

Kieli: Englanti

Avainsanat: tietokoneavusteinen suunnittelu, venttiilin ajoitus, yläkuolokohta

Table of Contents

1 Introduction

This thesis enlightens sensor brackets' construction/design process for the Wärtsilä 31 production engines. The sensors will be used when determining Top Dead Center (TDC) /Camshaft (CAM) timing and the goal is to make the process more automated while minimizing human measurement errors. This optimized and automated way of determining TDC/CAM will also facilitate the work steps for the mechanics at the production.

1.1 Background

The customer for this thesis is Wärtsilä Finland Oy. The division is Marine Power, the department is Research and Development/ Testing and Validation. I have worked in the W31 testing team since the summer of 2020 and was offered this thesis work by Instrumentation and Measurements (I&M).

1.2 General Introduction to Wärtsilä

Wärtsilä is one of the global leaders in lifecycle solutions and innovative technologies for the energy and marine markets. Wärtsilä's businesses are Energy Solutions and Marine Solutions. The company has locations in 79 countries and a team of 17500 professionals. Wärtsilä's main goals are to strive for decarbonization and sustainability in energy and maritime business. (Wärtsilä, 2024)

The W31 team I worked with specializes in engine testing (performance and components). The thesis work is done for I&M, which is also a part of the testing and validation department.

2 Problem definition

The task is to design four sensor brackets using the computer-aided design (CAD) program Siemens NX. The brackets are meant to fit seven different engine types listed in Table 1. The brackets with attached sensors must be light enough for one mechanic to handle and robust enough to get precise measurements. Easy installation must be considered for the measurements to be correct regardless of who is performing the task.

Table 1. Engine type and the power for each cylinder.

Engine type	Power
W25	283 kW/ per cylinder
W31	600 kW/ per cylinder
W32	500 kW/ per cylinder
W34	520 kW/ per cylinder
W46F	1200 kW/ per cylinder
W46TS	1300 kW/ per cylinder
W50	1150 kW/ per cylinder

The number for the different engines indicates the cylinder diameter in centimeters. All engines can be made as inline or V configuration. The inline engine has one cylinder bank, and the V-type engine has two cylinder banks. The V configuration is the most common engine produced at Wärtsilä at present.

2.1 Current measuring method

In the Wärtsilä engine production, TDC and valve timing are done manually with mechanical measurement tools. Due to differences in procedures, mechanics, etc., the variation of measuring results can differ too much for each measurement. Absolute value cannot be known since it is subjective to each mechanic doing the work. Therefore, a tool needs to be developed that guides the process by using various sensors (absolute angle sensors, displacement sensors). The aim is that the result will be the same regardless of which mechanic is doing the work and the measurement process automated.

2.2 Delimitations

The task given was that four measurements were to be made. Angle encoders on the end of the camshaft and crankshaft flywheel end and displacement sensors on the valve lifters and TDC. Part, tool, and drawing numbers had to be made for each design and assembly. It was decided that the final drawings, part numbers, and material numbers would be done externally since there were some difficulties with gaining access to the software used.

Brackets for all seven different engine types were limited to the W31 engine type, meaning four brackets were to be designed for this thesis work. Some brackets may be missing the sensors/encoders in the assembly because the decision of which sensors/encoders to use had not yet been defined. A concept design for the brackets was chosen as the main task.

2.3 The brackets

The brackets or mounts will be used to fasten the sensors and encoders and ensure that they stay in place during the measurements. The mounts must be easily installed and light enough for one mechanic to assemble. The mounts' preferred manufacturing method is additive manufacturing. Wärtsilä has its own additive manufacturing campus, therefore this method is preferred.

The mounts will only be needed in small batches, hence additive manufacturing will be more cost-effective. Should the mounts be made from example steel externally, large batches would have to be ordered, which is not needed in this case.

It is crucial that the sensors are placed correctly and maintain a fixed position in the process, therefore brackets according to the sensors chosen had to be made. The sensor bracket must be robust, easily installed, and light to handle.

2.4 Choice Of Theory

The theory of this thesis focuses on engine theory and how the engine components correspond to each other. To give the reader a better understanding of how timing is a crucial part of the engine's performance, engine theory was chosen as well as product development.

3 Theory

In this chapter CAD will be introduced and the software used for this thesis. Product development is also addressed.

3.1 Product Development

The focus of this thesis work is product development. Developing a product successfully that can be used requires a few main steps that will be briefly explained in the following chapters.

3.1.1 Developing Successful Products

The key factor in product development is to establish what is needed of the product and what features are desirable. An example can be seen in Figure 1. Current products must be studied and changes in market size must be taken into consideration to make a competitive product. Knowledge of what the market needs is essential when developing innovative concepts. Product development that does not consider these will often lead to failure.

One key factor when developing a successful product is uniqueness. Uniqueness can consist of many different factors, for example, the product provides superior value according to the price of the product and has excellent quality compared to the competitors, according to customers. The product meets the customers’ needs and has useful benefits compared to the competitors.

Before a product can be developed there has to be an idea or a concept of what needs to be developed or produced. One concept or idea is usually not enough, there must be a few promising concepts or ideas that seem promising. The most promising ideas will then be analyzed and developed before a more detailed plan is made to start the development of the concept or product. (Mital, Desai, Subramanian, & Mital, 2008).

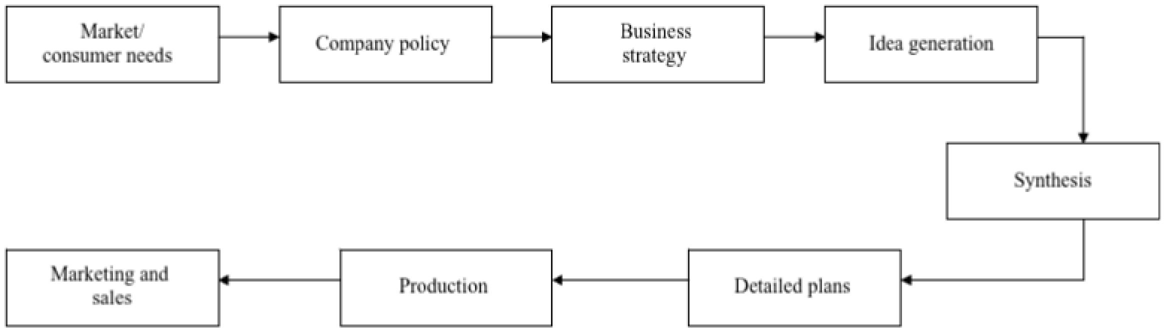

Figure 1: Example of progression of actions in new business activity. (Mital, Desai, Subramanian, & Mital, 2008).

3.1.2 Production Cost and Profitability

The production cost is what sets the sales price, and that in turn makes the product attractive to the market. It is often the price that makes a product attractive but also quality is a main factor. The price always correlates with quality. A high-quality product is often more expensive due to manufacturing costs, labor costs, and product development. These three are what set the market price, and the product is not profitable if the cost of these three is not fully recovered.

One other factor that contributes to a product's profitability is how quickly the product reaches the market, however, the quickness of the product reaching the market cannot affect the quality of the product. (Mital, Desai, Subramanian, & Mital, 2008).

3.1.3 Design Process

Design can be described as the process of turning an idea or a concept into a physical form. Depending on what kind of product is to be designed there are mainly two aspects to consider, engineering perspective and industrial perspective. The engineering perspective and its design mainly focus on the mechanics, arrangement of parts, and functionality of the finished product. The industrial perspective focuses more on the appearance of the finished product, it must look appealing to the customer, such things may be textile products, furniture, and other things. From the engineering perspective, the function of the design is at focus, such as engines, gear trains, and building foundations.

These two perspectives usually need to be put together when making a customer product. For example, a car. The car must look appealing, and it also must function properly as well.

The degree to which design will dominate varies depending on the product. Generally engineering design is the more expensive due to the nature of engineering, more complex design, and functionality among others. (Mital, Desai, Subramanian, & Mital, 2008).

Different design processes go under different names, examples can be seen in Figure 2 and in Figure 3. They can generally be summarized like so:

- **Problem definition:** Studying needs and environment.
- **Value system design:** Stating objectives and criteria.
- **System synthesis:** generating alternatives.
- **System analysis**
- **Selecting the best system:** Evaluating alternatives.
- **Planning for action**

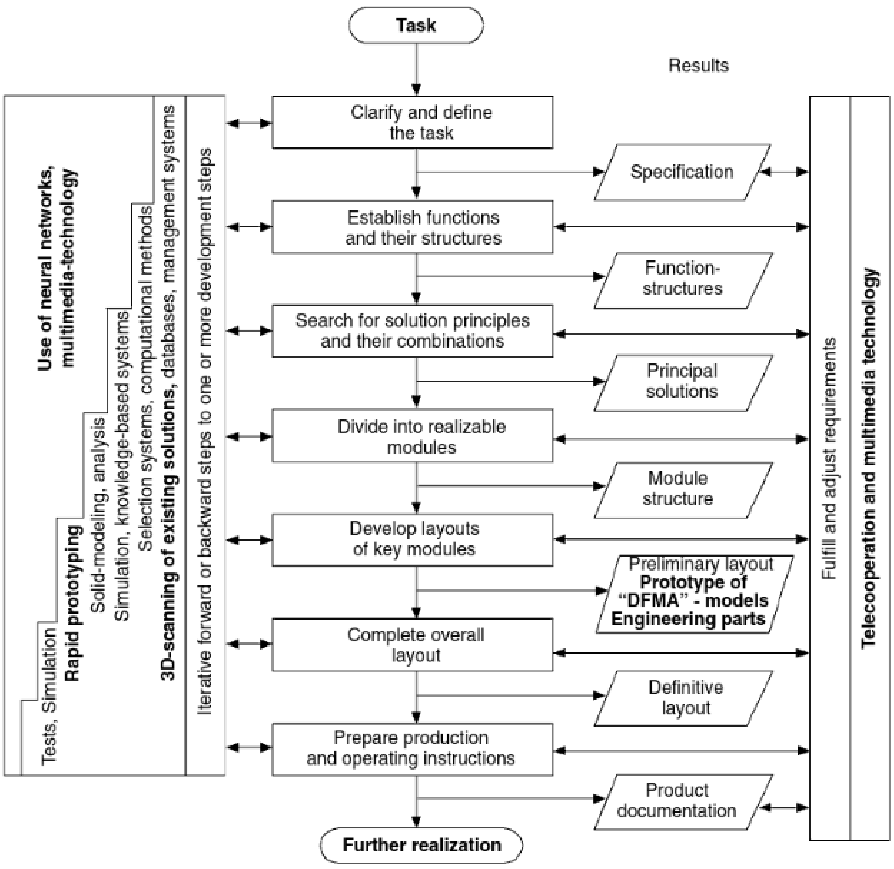

Figure 2: A general approach to engineering design (VDI 2221). (Mital, Desai, Subramanian, & Mital, 2008).

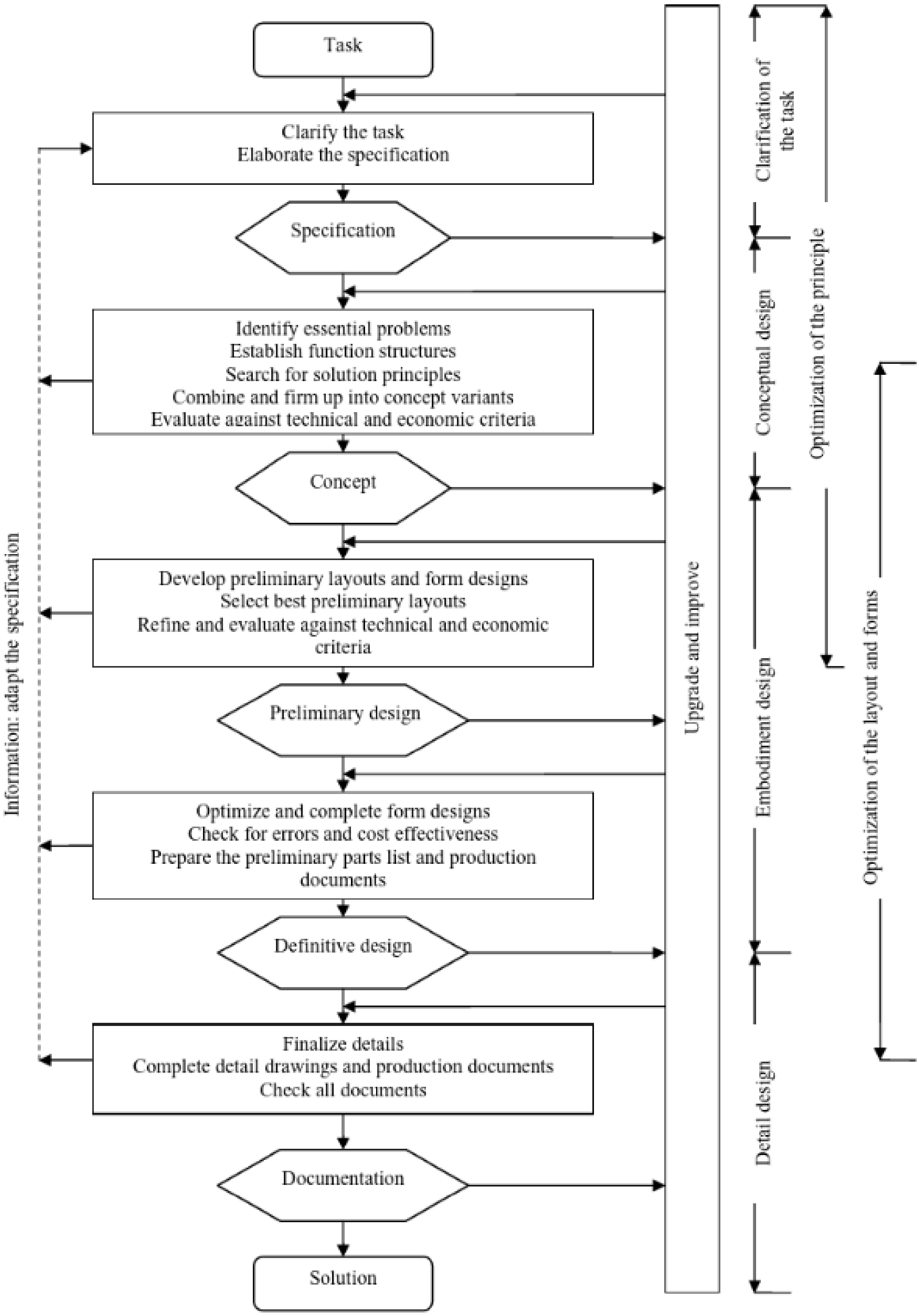

Figure 3: The basic engineering design process according to Pahl and Beitz. (Mital, Desai, Subramanian, & Mital, 2008).

3.2 Computer-Aided Design (CAD)

CAD is a technology that uses computer systems to assist in the design, creation, analysis, and modification of a design. CAD software Is a tool used in various industries such as engineering, product design, and architecture. The CAD systems replace manual hand drawing and drafting techniques. (Autodesk, (n.d.)).

An Explanation of computer-aided design and its features are as follows:

1. **Digital modeling**

   CAD enables designers to create digital models of physical systems or objects. The digital models of these can then be modified and analyzed before the physical objects/prototypes are manufactured.

2. **Efficiency**

   CAD allows for easy and quick modifications to the design. The CAD system allows the user to quickly review different design options and explore the alternatives for said design.

3. **Accuracy and precision**

   The CAD tools provide precision and accuracy in the design and very complex and detailed designs can be made, which could be very important in some industries.

4. **Simulation and analysis**

   Cad software, not all, includes simulation and analysis tools that allow the user to analyze the weak and strong spots of a design. The characteristics of said design can be properly analyzed and different materials can be chosen which is important before a physical object is made.

5. **Integration with manufacturing processes**

   Finished CAD models can be integrated into computer-aided manufacturing (CAM). The integration can reduce errors in the design and modify the design without changing its characteristics. The result is a more efficient manufacturing process,

6. **Visualization and communication**

   CAD software allows realistic visualization of the design. This helps with understanding the final product and decision-making. Most CAD software is cloud-based, which means that the designs are accessible anywhere. Design teams, production, and development all have access to the designs. This is important for the finished product to be as good as possible considering manufacturing, design, and characteristics. (goodwin.edu, 2022).

3.3 Diesel engine

This chapter will briefly explain how the diesel engine functions providing a brief explanation of how internal combustion works and the different operating cycles.

3.4 Engine Theory

The diesel engine is a type of internal combustion engine. The internal combustion engine produces power by combustion of an oxidizer (air) and a fuel. The combustion of the diesel engine occurs when air is compressed, which leads to heat, which ignites the injected diesel fuel. This combustion process is then transferred to mechanical energy. (Cummins Inc, 2023).

This theory focuses on larger medium-speed diesel engines within a range of 250 rpm to 1200 rpm. The difference in components between internal combustion engines for industry and marine diesel engines may vary from, for example, the automotive industry.

3.5 Operating Cycles

The diesel engine can operate in two different cycles, two-stroke, and four-stroke. The number of strokes determines when a complete engine cycle is done. The two-stroke engine uses two-strokes which means the piston moves up and down once the cycle is completed.

As for the two-stroke diesel, the cycle begins with air that enters the cylinder and dispels exhaust gases. When the piston moves toward the top of the cylinder compression process starts and at the same time diesel fuel is injected. The compression of air ignites the fuel which pushes the piston down and the cycle is complete.

two-stroke diesel engines are not as common as four-strokes since they are more susceptible to wear and tear. (Cummins Inc, 2023).

3.5.1 Four-stroke engine

As mentioned in the previous section the four-stroke diesel engine is more common than a two-stroke diesel engine. The four-stroke engine can be spark-ignited (SI) or compression-ignited (CI), these are illustrated in Figure 4 and in Figure 5. As for the four-stroke, each cylinder requires four strokes of its piston and two revolutions of the crankshaft to produce one power stroke. The four strokes work as follows:

1. *An intake stroke,* which begins with the piston at TDC and ends with the piston at the Bottom dead center (BDC). When the piston moves towards BDC the inlet valve opens and draws the fuel-air mixture into the cylinder. For compression ignited four-stroke diesel engines only air will be drawn in during this stroke.

2. *The compression stroke* begins with the piston at BDC and ends with the piston at TDC. When the piston moves towards TDC it compresses the fuel-air mixture to a fraction of its initial volume. Both the inlet and exhaust valves are closed during this stroke.

   For compression-ignited four-stroke diesel engines, only air is compressed, which raises the temperature of the air. Fuel is injected when the piston closes in at TDC and the hot air ignites the fuel-air mixture. A compression ignition has occurred. Four-stroke engine which draws in a fuel-air mixture during the intake stroke is usually ignited by spark ignition using a spark plug, for example, gasoline-powered engines.

3. *The power stroke,* also known as the expansion stroke, begins with the piston at TDC and ends with the piston at BDC. The combustion that occurs in the compression stroke produces high-pressure and high-temperature gases (exhaust gases), which push the piston back down towards BDC and force the crankshaft to rotate.

As the piston approaches BDC the exhaust valve starts to open which initiates the exhaust process. This will also lower the cylinder pressure.

4. *The exhaust stroke* starts when the piston moves from BDC to TDC. The remaining burned gases exit the cylinder when the piston moves towards TDC. The exhaust valve is open during this process which allows the burned gases to exit the cylinder. When the burned gases have exited the cylinder, and the exhaust valve has closed the process starts over from the intake stroke. (Heywood, 2018).

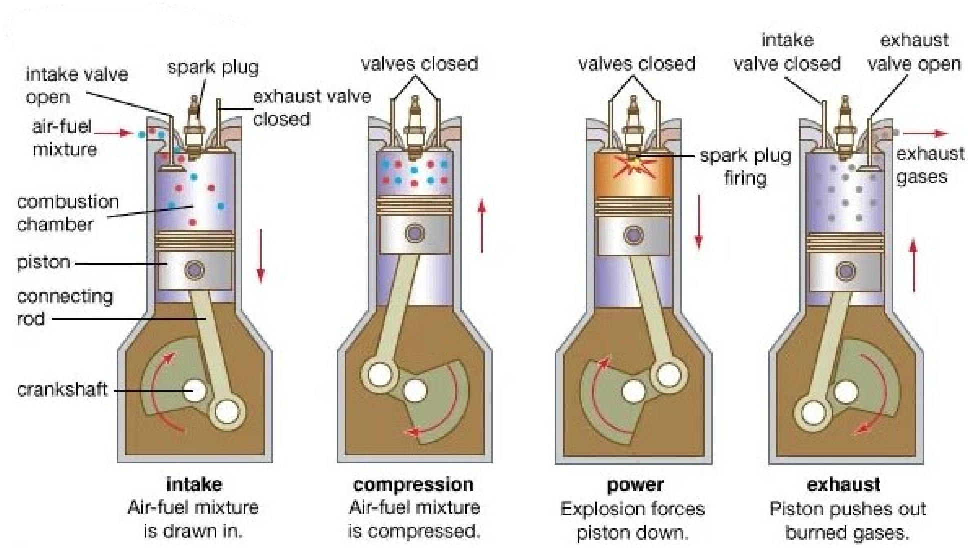

Figure 4. The sequence of cycles in a four-stroke spark-ignition engine (Armstrong & Proctor, 2024).

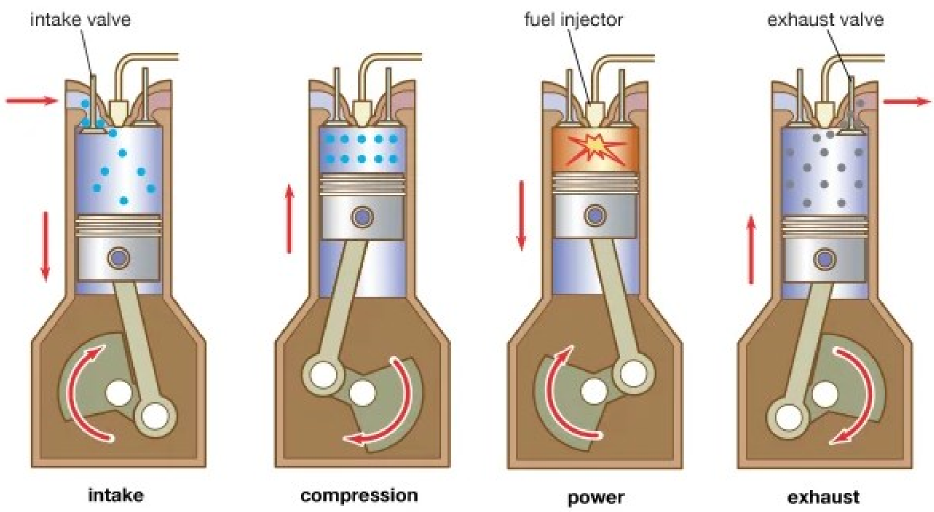

Figure 5. The sequence of cycles in a four-stroke compression ignition engine (Armstrong & Proctor, 2024).

3.6 Combustion Process & Fuel Injection

3.6.1 Features of the combustion process

The combustion in diesel engines occurs through a different sequence compared to the spark-ignited engine. The most essential can be summarized as follows. The fuel system injects the liquid fuel through a fuel injector at the end of the compression stroke. The injection begins just before the desired start of the combustion.

The liquid fuel is injected at high velocity, normally by several jets, through small nozzles in the injector tip. This atomizes/vaporizes the fuel, that allows it to penetrate and mix with the high-pressure temperature air in the combustion chamber. The hot mix of air and fuel then starts to ignite spontaneously thus creating the downward pressure on the piston. While this happens cylinder pressure rises while the mix of air and fuel burns.

The consequent compression raises the pressure and temperature which will ignite the remaining unburned fuel. The fuel injection continues until the desired amount of fuel has entered the cylinder. All the steps continue until all the injected fuel has gone through each process. The fuel-burning rate can be difficult to control but depends on the rate the air mixes with the fuel. (Heywood, 2018).

3.6.2 Fuel-Injection System

The fuel-injection systems task is to meter the appropriate fuel quantity for each cycle and cylinder for a given engine speed and load. It must also inject the fuel at the right time in the cycle to achieve a successful combustion. The injections must be exact so that no unnecessary injections occur.

To accomplish this fuel is drawn from the tank by a supply pump. From there the fuel goes further on to the injection pump from where fuel is distributed to the nozzle pipes in the injectors. Excess fuel goes back to the tank.

The common way of achieving this at present is by using a high-pressure fuel pump integrated with the supply pump. This is called a common-rail fuel-injection system which can deliver rail pressures up to 2000 bar and more. An electronic control system is needed to give the right injection and the right amount of fuel. (Heywood, 2018)

3.7 Components

This section will explain the larger main components of an internal combustion engine (ICE). The engine consists of many different parts for it to run properly, this chapter will briefly explain the role of the main components.

3.7.1 Crankshaft

The crankshaft in an internal combustion engine is used to convert reciprocating motion from the pistons into rotational motion. For example, a propeller shaft can be connected to the crankshaft in marine vessels. (Heywood, 2018).

3.7.2 Main Bearings

The main bearings, also known as crankshaft bearings, are what support the crankshaft in the crankcase. The number of main bearings depends on the engine's maximum speed and load. The surface between the crankshaft and the main bearings must stay lubricated, therefore the crankcase is usually sealed at the bottom with an oil pan to act as an oil reservoir for the lubricating system. (Heywood, 2018).

3.7.3 Connecting rod

The connecting rod is the component that connects the crankshaft to the piston. It transfers the piston motion to the crankshaft while also functioning as a lever arm. The connecting rod's big end is fastened on the crankshaft with a rod cap. Bearings like main bearings can be found between the surface of the big end, rod cap, and crankshaft. These bearings are called big-end bearings. The connecting rod's small end is connected to the piston with a steel piston pin. (Heywood, 2018).

3.7.4 Piston and Piston Rings

The piston acts as a seal in the cylinder and transfers the combustion-generated gas pressure to the crankshaft via the connecting rod. The piston rings are mounted around the piston. The upper ring called compression ring, helps with keeping the seal between the piston and cylinder to avoid gas leakage and the lower ring's function is scraping excess oil from the cylinder walls so that the oil does not reach the combustion chamber. (Heywood, 2018).

3.7.5 Cylinder

The cylinder is contained in the engine block and guides the piston's motion. The cylinders can be directly cast into the engine block but for larger diesel engines it is more common with the use of a liner. The liner is a removable sleeve that’s pressed or lowered into the engine block. One major advantage of using a liner is that it’s easily replaceable in the event of a breakdown. If a breakdown occurs without a liner, the cylinder integrated with the engine block requires much more repair work. (Heywood, 2018).

3.7.6 Cylinder Head

The cylinder head seals the cylinder and is one of the more robust parts of the engine. It must withstand the immense gas pressure that is built up during compression and combustion and must distribute the gas flow as evenly as possible in the combustion chamber. The cylinder head contains the vital parts for the combustion process. The inlet and exhaust valves, spark plug for spark ignition (SI) engines, or a fuel injector for compression ignition (CI) engines. (Heywood, 2018).

3.7.7 Camshaft

The camshaft is used to open and close the inlet and exhaust valves. The camshaft has one cam per valve or a pair of valves for four valves per cylinder. For four-stroke engines, the camshafts turn at half the crankshaft speed. In smaller diesel four-stroke engines the camshafts can be one solid shaft but for larger diesel four-stroke engines the camshaft is usually split up in sections that are connected during assembly. The camshafts can be driven by chain, belt, or gear. Gears are most common in larger four-stroke diesel engines due to larger loads. (Heywood, 2018).

3.7.8 Manifolds & Turbocharger

The four-stroke diesel engine is equipped with an intake manifold and exhaust manifold to complete the engine assembly. The intake manifold transfers air that goes into the combustion chamber via the intake valves. The exhaust valves release hot burned gases into the exhaust manifold.

A turbocharger is commonly used in four-stroke diesel engines to compress and increase the amount of air that enters the cylinder each cycle. By doing this the engine produces more power. The turbocharger is powered by the energy of exhaust gases. The turbocharger consists of a centrifugal compressor, which compresses the air. The centrifugal compressor is placed and driven by the same shaft as the exhaust-gas-driven turbine. (Heywood, 2018).

3.8 Cam Timing and Top Dead Center

This section will explain the importance of the timing and top dead center for an engine to run properly. The correlation between these two will also briefly be explained.

3.8.1 Top Dead Center

Top Dead Center (TDC) is found where the head of the piston is farthest away from the crankshaft. In the internal combustion engine, it is crucial to determine TDC correctly, because many other processes such as fuel injection, fuel ignition, and valve opening and closing time rely on that TDC being set correctly in correlation to the crankshaft angle. (Lion Precision, 2024).

3.8.2 Cam timing in general

The cam timing directly affects the engine’s performance. If the timing is not correctly set the inlet and exhaust valves may open or close too soon or too late. This affects the gas exchange in the combustion chamber and leads to loss of power output. The engine’s fuel consumption may rise, the engine may overheat, and the fuel-air mixture may not ignite and burn correctly during the power stroke.

Both the inlet and exhaust valves must open and close at the right time for the engine to run properly. In the worst case either of the valves can be fully open when the piston reaches TDC which will lead to breakdown. The gas exchange is a crucial part of the engine's efficiency.

It is the camshaft that determines when the valves open and close. The camshaft is run by the crankshaft. The cam timing setting begins when the piston is at a TDC zero-degree angle. The timing for both the inlet and exhaust valve is relative to the crankshaft. (compcams, 2024).

3.8.3 Fixed Valve Timing

An engine without variable valve timing cannot alter the opening and closing of the inlet and exhaust valves while the engine is running. This is called fixed valve timing, and the valve timing is restricted to the type of camshaft used. The cams lift determines for how long the inlet and exhaust valves are going to stay open. (Heywood, 2018).

3.8.4 Variable Valve Timing

Variable Valve timing (VVT) or Variable Valve Control (VVC) is a method designed to properly adjust the opening and closing of the inlet and exhaust valves based on the operating parameters (load and speed) for the engine. The advantages of altering the opening and closing of the inlet and exhaust valves are many. (Howie, 2023).

For example, if an engine is running at low speeds the valves can be set to open and close sooner, which leads to increased fuel economy without sacrificing power output. If the engine is running at higher speeds both valves can be adjusted to stay open for longer and close later and the power output can be increased. Other important advantages of variable valve timing are reduced emissions and smoother idling. (Howie, 2023).

Almost every engine manufacturer has their own VVT system. The methods may differ and look different from each other, but the working principle is the same. Currently, almost every manufacturer equips their engines with their own developed system, and the manufacturers are constantly improving and optimizing the system. (Heywood, 2018).

A few examples are listed of different names on VVT from different engine manufacturers from the automotive industry, industrial industry, and marine and energy industry.

- **BMW**: Variable Nockenwellensteuerung (VANOS). (Internet Arcive, 2018)

- **Nissan:** Continuous Variable Valve Timing Control System (CVVTCS). (Automotive Tech Info, 2013)
- **Ford**: Variable Camshaft Timing (VCT). (Wayback Machine, 2010)
- **Honda**: Valve Timing Electronically Controlled (VTEC) (Honda global, 2017)
- **Man**: Variable Valve Timing (VVT). (Man Energy Solutions, 2020)
- **Wärtsilä**: Variable Inlet Valve Closing (VIC) and Variable Exhaust Valve Closing (VEC). Interview with Dennis Högberg, Senior test engineer at Wärtsilä.

4 Methodology

This chapter will explain the approach and the factors that had to be taken into consideration before the modeling and design process of the brackets. The software used for the modeling was the CAD program Siemens NX.

4.1 Requirements and Functionalities

Meetings with the mechanics and visits to the production line were of importance to understand the timing process more thoroughly. Assembly guides had to be followed so that the bracket with the attached sensor would fit. Generally, it is only the crankshaft, camshaft, flywheel, and gears attached to the block when the timing process begins, but in some cases, there may be some extra pipes, flanges, or other parts already attached.

Preferably the brackets with attached sensors were to be placed in such places that would be of easy access for the mechanics for a better working position. The installation process had to be as easy as possible with no need for further centering of the sensors, so the machined engine blocks tapped holes and parallel pins were preferred for the fastening of the measuring construction.

5 Result

The results will be presented as figures from CAD program NX with explanations. Consider that these are only the current designs that may or may not need further modifications and they are only early-stage concept designs. The designs have not been approved for further development since more meetings with all departments are needed. This will be explained in section 6.1. All Parts colored yellow are meant to be made by additive manufacturing. As a material, a polymer will be used.

As mentioned in section 4.1, meetings were of great importance to get a design that the mechanics in the production could use. Three meetings were held regarding the subject, though only two where people from the three different departments could participate.

The first meeting was more of an introduction to the thesis subject while the other two were more of a follow-up and brainstorming different solutions. Some designs were developed further while some designs had to be rejected. In the third and final meeting, one month before the thesis had to be finished, some major changes appeared in the production. Preferably no screws for the fastening of the mounts and brackets were to be used since this was very time-consuming from the production line's view.

The sensors and encoders chosen for this task also changed and the brackets/mounts had to be further modified.

Since this only covers the design, these changes were not a problem other than that the thesis work had to be finished before 14.4 2024 and the final meeting was held in the middle of March 2024.

Tools that are currently used for the timing process were allowed to be modified to attach the sensors in case no other reasonable design solution was found. The tool that measures TDC was modified to fit a laser. For the three other measurements, no reasonable design solution was found by modifying tools that are currently in use.

5.1 Crankshaft

The mounting for the crankshaft encoder is the largest and most challenging design because of the flywheel. This measurement will measure rotational movement. A reasonable design was difficult to produce since it must go around the flywheel, and the flywheel's thickness may differ from the W31 engine type. Below screenshots of the assemblies will be presented and explained.

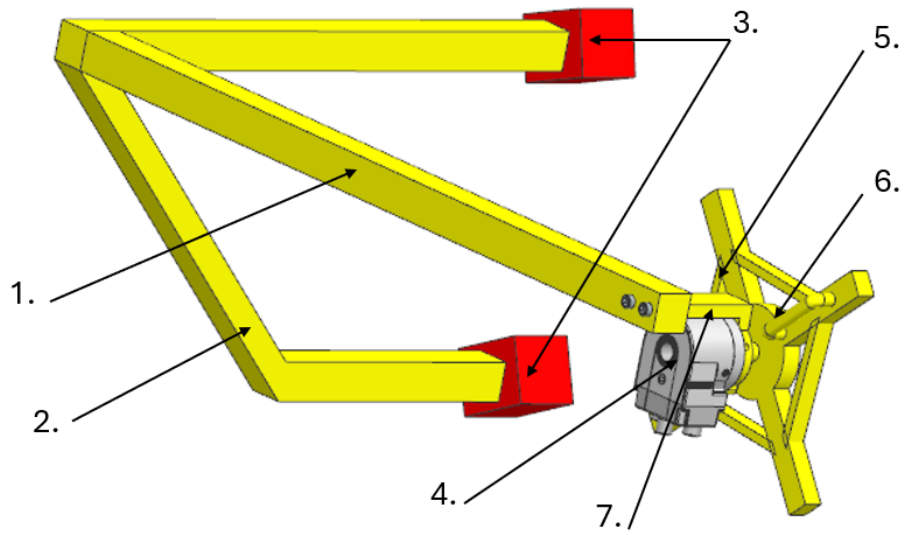

Figure 6: Concept of crankshaft measuring tool from NX with parts numbered.

Part one (1) is what connects part two (2) to the measuring mount. Part two (2) is fastened to the engine block by two magnetic bases (3). The encoder (4) is of hollow shaft type and is fastened to the shaft part eight (8) on part five (5). Part five (5) is meant to be dropped into the flywheel and is fastened by magnets. Part six (6) are handles for removing part five (5) when the measurement is done. Part seven (7) is what connects the encoder to part one (1). The different parts are illustrated in Figure 6, figure 7, figure 8 and figure 9.

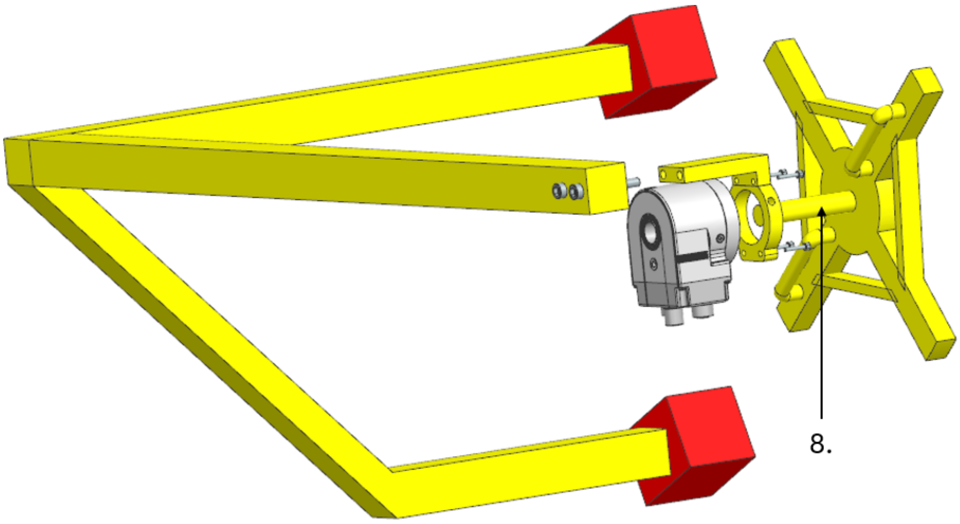

Figure 7: Concept of crankshaft measuring tool from NX right angle.

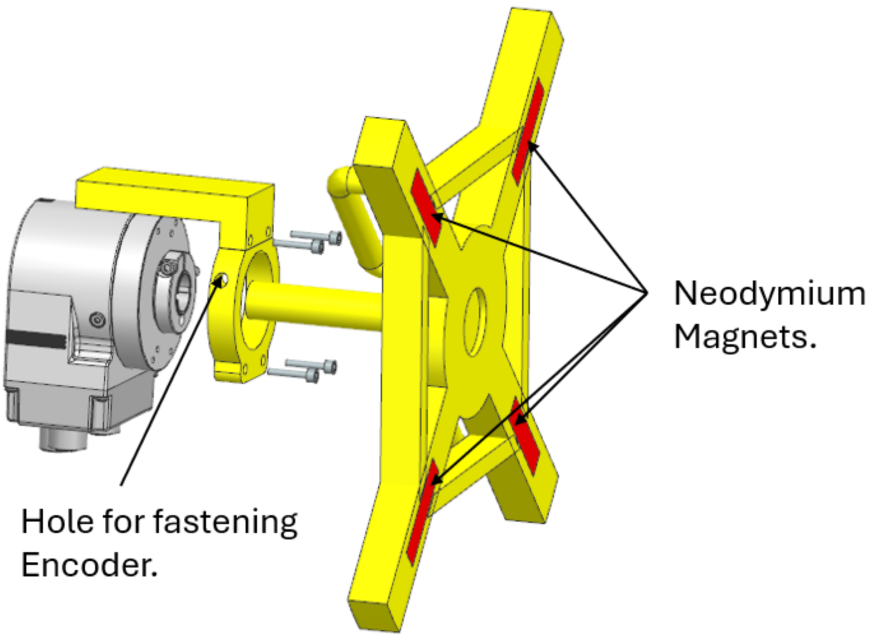

Figure 8: Concept of crankshaft measuring tool from NX left angle.

The magnetic bases will be fastened by pin bolts to part two (2) and all other magnets can be attached by screws, glued, or integrated with the additive manufacturing process, the choice of fastening for these has not been decided yet. Part one (1), part four (4), and part seven (7) always stay attached.

The assembly idea is that part five (5) is placed inside the flywheel, position does not matter since the shaft will always be centered. The shaft's length is to be made long enough to fit different thicknesses on the flywheel, as well as part two (2). The encoder together with part one (1) and part two (2) is then placed on the shaft and fastened. The assembled parts can hang loose while fastening part two (2), with magnetic bases attached to it, to the engine block, and part one (1) is then connected to part two (2) by a magnet can be seen in Figure 9. Assembly to the engine block in NX can be seen in Appendix 1 and Figure 10.

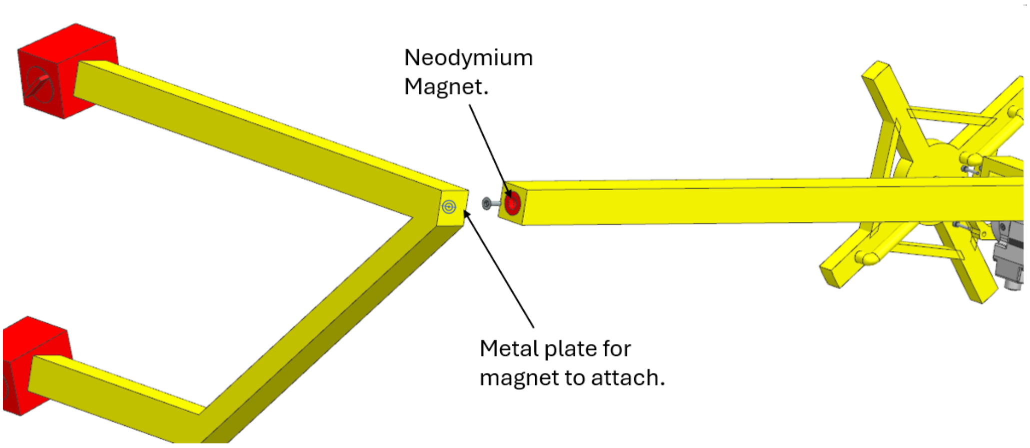

Figure 9: Connection explanation of parts one and two for crankshaft measuring tool.

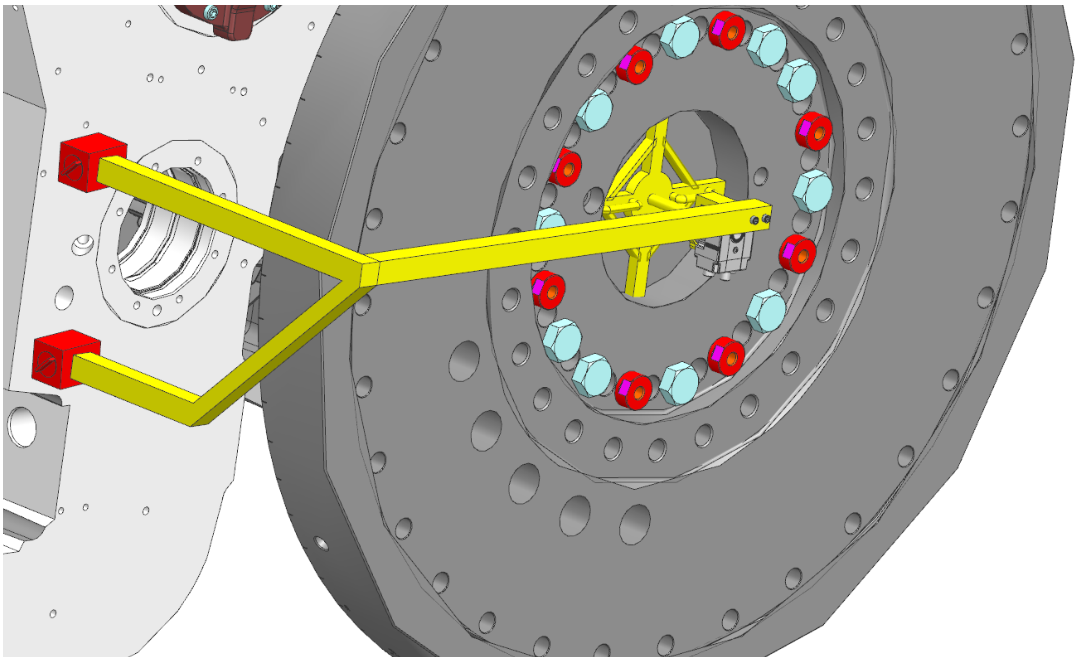

Figure 10: Concept of crankshaft measuring tool assembled to the engine.

5.2 Camshaft

The mount and measurement for the camshaft follow the same principles as the crankshaft. The cap is to be placed onto the pin bolt for the camshaft, the cap is held in place by magnets. The encoder and the mount are the same ones used for the crankshaft. An illustration of this can be seen in Figure 10.

The encoder together with the arm, mount, and magnetic base is put on the cap's shaft and fastened, finally, the magnetic base is attached to the engine block. Assembly to the engine block can be seen in Appendix 1.

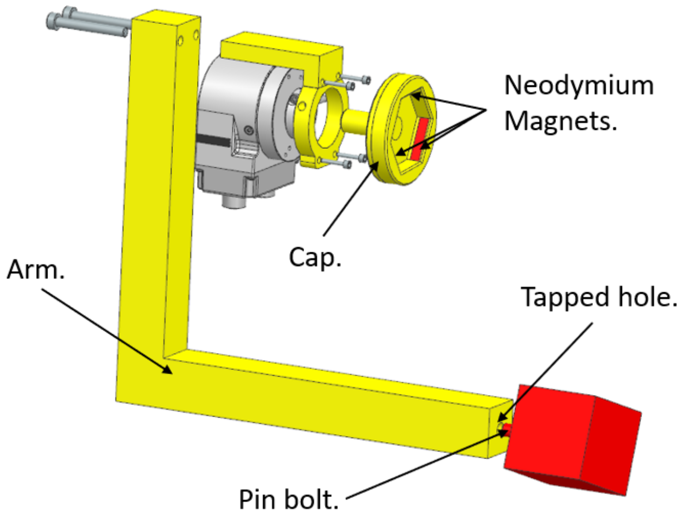

Figure 11: Concept of Cam Tool assembly in NX.

5.3 Valve Lift

The valve lift measurement measures a distance, and a laser is meant to be used for this purpose. The valve lift mount is meant to be made as one whole part by additive manufacturing. The mount is fastened to the guide block by thumbscrews and the laser is always attached to the mount. The inlet valve is usually the only lift that is measured but if the exhaust valve also needs measuring the mount can be dismounted and turned 180 degrees. The concept of the valve lift mount can be seen in Figure 11 and the Illustration in Figure 12.

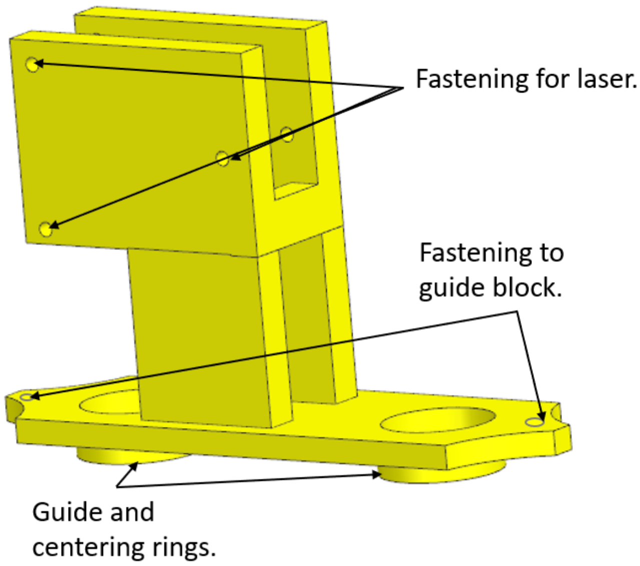

Figure 12: Concept of Valve lift mount in NX.

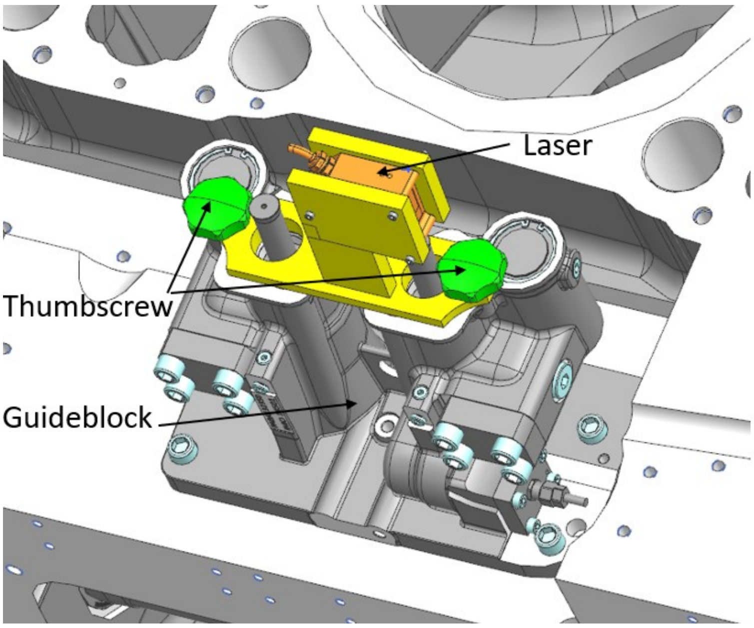

Figure 13: Illustration of the valve lift mount with attached sensor fastened to guide block.

5.4 Top Dead Center

The TDC measurement measures a distance and follows the same principles as the valve lift. For this measurement, an already finished timing device was preferred since no reasonable or simpler solution was found and it would be difficult to design. The mechanics also preferred a modification of the tool currently in use. All parts colored green belong to the existing timing tool. The laser mount is meant to be made as one whole part by additive manufacturing. The laser mount is the only thing that is modified and is fastened to the upper plate by screws.

When turning the engine, the shaft moves up when going towards TDC and down when going towards BDC. The shaft is connected to the connecting rod's lower part where the connecting rod is attached after measurements have been made. It is the moment when up and down movement begins to change that is measured so that an absolute TDC can be determined.

The timing device for this measurement takes the longest time to assemble according to the mechanics, if needed the laser mount can be removed and the original dial gauge mount can be assembled to the upper plate in case the laser does not work. An illustration of the laser mount with the existing timing device can be seen in Figure 13 and in Figure 14 the shaft mounting is explained.

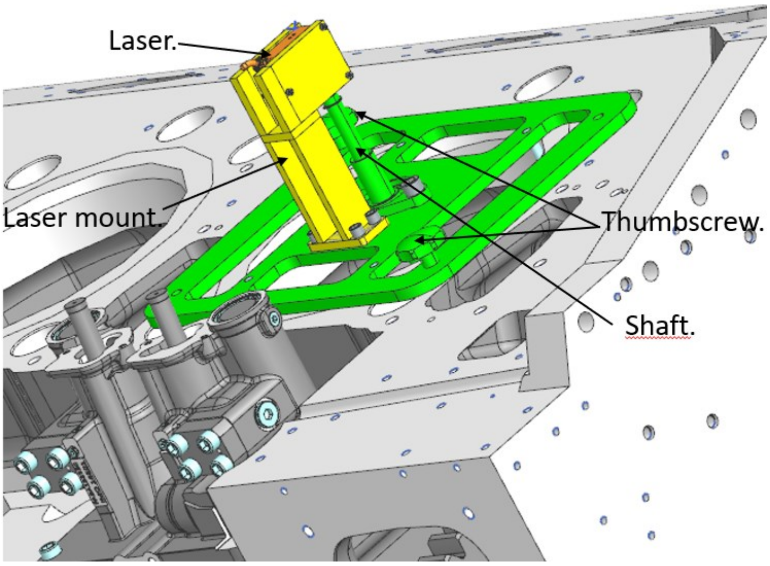

Figure 14: Illustration of TDC measurement device mounted to the engine block.

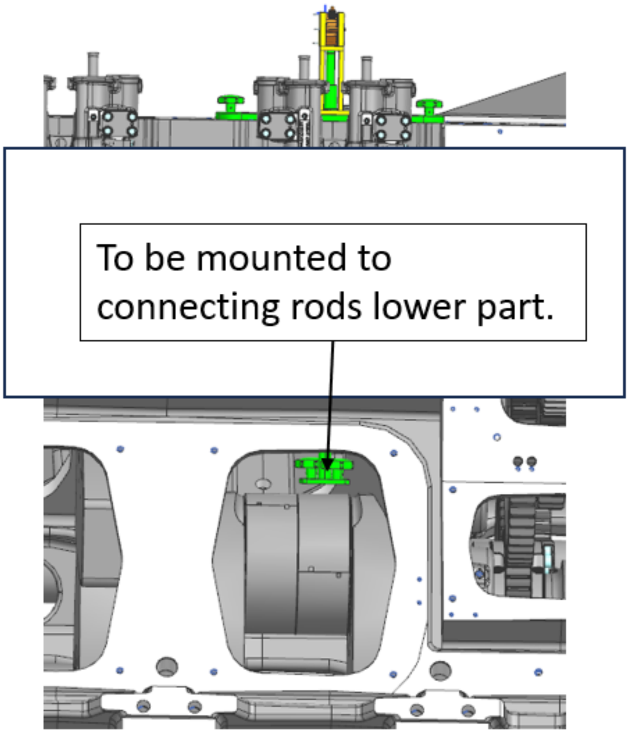

Figure 15: Shaft mounting explanation.

6 Conclusions

The original goal for this thesis work was to design and develop the brackets for the seven different engine types mentioned in Chapter 2 but was limited to only the W31 engine. For the W31, designs and concepts for the different mounts and brackets were meant to be made, and after approval some prototypes as well. The original task was to design and make the parts and drawings necessary. This was not achieved due to the vast program needed and the rights to use it.

According to the design team it takes between two to three months to fully master the program, so it was not achievable to learn within the timeframe. Better communication and planning should have been done by both parties before the thesis work commenced.

The concepts presented in Chapter 5 are the latest version. Previous designs turned out to be unsuitable for this purpose because a change in sensors and encoders was made at a late stage. The design process for this thesis work followed the basic engineering design process according to Pahl and Beitz, which can be seen in Figure 3. This thesis work is in the concept and preliminary design stage so with the delimitations in section 2.2 considered, a concept was generated for this thesis work.

It is difficult to evaluate if the requirements mentioned in section 4.1 and section 4.2 were fulfilled since no prototypes were made in this stage or if the magnet concept for the crankshaft and camshaft measurement even works.

The brackets do not need to support any loads other than their weight, so the concepts presented in Chapter 5 stay very light and should be easy to handle for one person. Since the brackets do not need to support any loads, a polymer should be enough to support the encoders and lasers chosen. Manufacturing of the brackets and mounts will be done internally at Wärtsilä’s additive manufacturing (AM) department. The magnet concept should allow for easy and quick installation of the brackets/mounts.

It is to be noted that that the results presented in Chapter 5 are only early-stage concept designs that await approval for further development.

6.1 Further development

If the concepts are approved for further development prototypes will be made. Before the prototypes are made calculations need to be done regarding the magnets and materials strength. For the crankshaft aluminum may have to be used considering the length of what supports the encoder, and the length limits the additive manufacturing possibilities. The mounts and brackets need topology optimization. The optimization is done by the AM department, therefore the results presented in Chapter 5 are left unoptimized.

Topology optimization is the process of optimizing mechanical components or parts by reducing material while the components or parts' characteristics remain the same (Engineering Product Design, 2021).

When prototypes have been made, tested, and approved, a final product will be manufactured for the W31 engine. Modifications will be made to the final product so that it fits the other engine types mentioned in Chapter 2.

This thesis work was made possible by Tomi Riiki who is the manager of the Instrumentation and Measurements (I&M) department.

This thesis work covers the mechanical design of the sensor bracket. The sensors/encoders and automation process are another thesis work done by Egon Grönberg who is also a student at Novia University of Applied Sciences. Egon Grönberg's degree program is electrical engineering.

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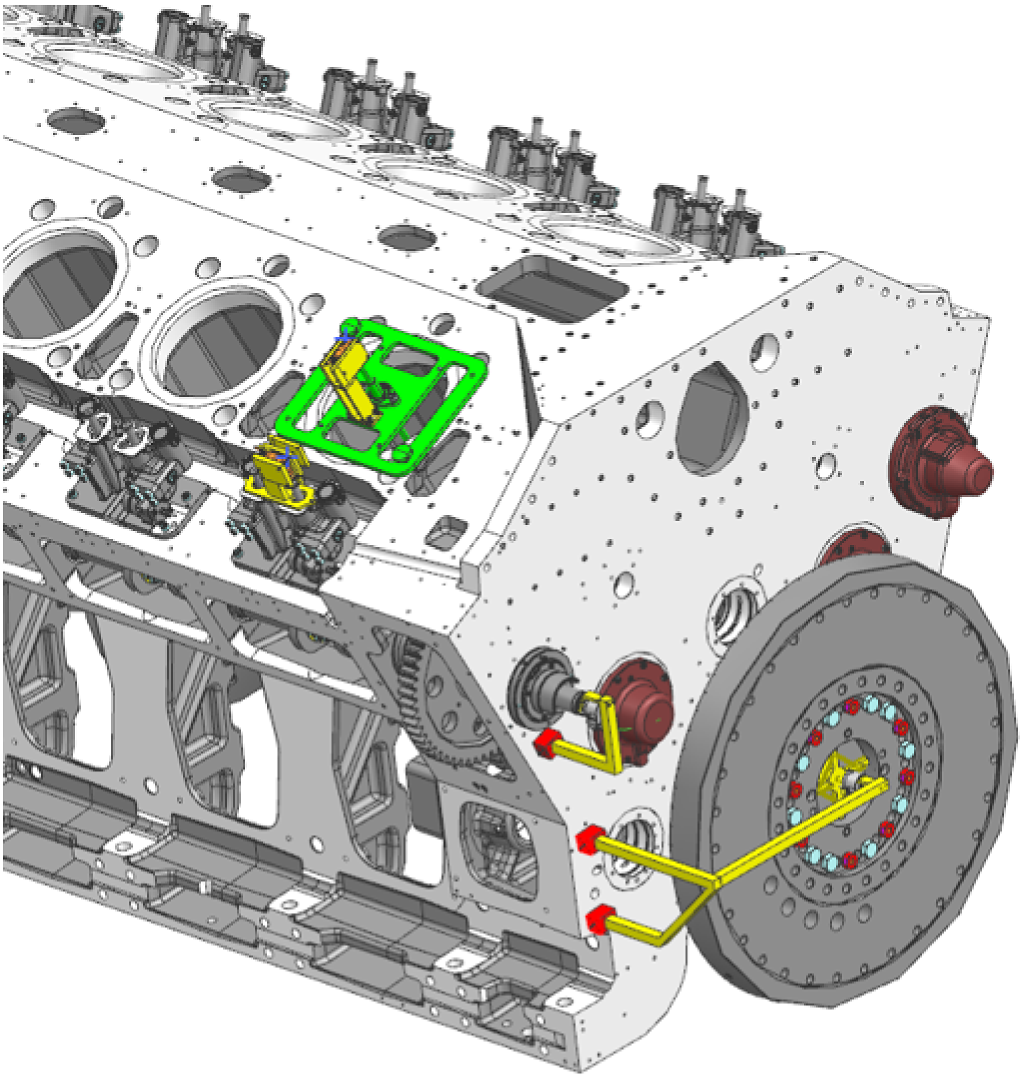
Appendix 1



Appendix 1. Assembly of the NX concept designs assembled to the engine block.