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Industrialization of V12W32E Turbocharger Module

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Tämä opinnäytetyö on tehty Wärtsilä Oyj:n Vaasan toimitusyksikön moduulitehtaalle. Opinnäytetyön aiheena oli uuden W12V32E – turboahdinmoduulin tuotannollistaminen. Työn tarkoituksena oli varmistaa tuotannon edellytykset sekä kokoonpanon sujuvuus. Lisäksi tarkoituksena oli laatia kokoonpano-ohje asentajille.

Työ aloitettiin tutustumalla moduulin rakenteeseen tarkastelemalla teknisiä piirustuksia. Työn alussa tutustuttiin myös työn teoreettisiin taustoihin perehtymällä teoksiin tuotannosta, tuotannon ohjauksesta, laadunhallinnasta, dieselmoottoreista sekä Lean – ajattelumallista. Tuotannon edellytykset pyrittiin varmistamaan ottamalla huomioon materiaalit, työkalut sekä työmenetelmät. Kokoonpano-ohjetta varten jokaisesta työvaiheesta otettiin myös kuvia.

Turboahdinmoduulille tehtiin työohjeen lisäksi myös uusi vaiheistus, jonka seurauksena piti tehdä muutoksia materiaalivirtoihin. Ennen ensimmäisen moduulin tuomista kokoonpanolinjalle, asentajille järjestettiin koulutustilaisuus, jossa kokoonpano-ohje käytiin läpi.

Työn tuloksia hyödynnetään turboahdinmoduulien kokoonpanossa sekä kokoonpanolinjan kehitystyössä. Tämän työn aikana tehtyjä havaintoja hyödynnetään myös tulevaisuudessa toteutettavissa projekteissa.

Avainsanat tuotannollistaminen, turboahdin, Lean, laatu, laadunhallinta

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ABSTRACT

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This thesis was made for the module factory of Wärtsilä Finland Oyj, Delivery Center Vaasa. The topic of thesis was the industrialization of W12V32E – turbocharger module. The purpose was to ensure the feasibility of the assembly in an assembly line. Also the making of assembly instructions was within the scope of this thesis.

The work was started with examining the technical drawings of the module. Theoretical background was researched by examining literature on production, production planning, Lean, diesel engines and quality management. The feasibility of the assembly was ensured by taking into account the materials, tools and working techniques used. Every phase was also photographed.

In addition to the assembly instructions, a list of the order of the assembly and tasks was also made. Based on the new order of assembly, changes were made to the material flows. Prior to the introduction of the turbocharger modules to the assembly line, the assemblers received training on how to do the assembly.

The results of this thesis will be made use of in the assembly work as well as in further development of the assembly line. The observations made during this project will benefit future projects also.

Keywords Industrialization, turbocharger, Lean, quality, quality management

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1 INTRODUCTION

The topic of this thesis was the industrialization of a new turbocharger module for a new engine type W32V12E. The production of this new engine type will start in the spring of 2013. The assembly of the first engine started in week 5. This thesis is based on the observations made during the assembly work of the TC-module. The first TC-module was assembled in a specialized assembly station independent of the assembly line where the regular models are assembled. This was done to ensure that the normal assembly work could continue uninterrupted.

Industrialization in this case means ensuring that the assembly of the new module in the assembly line will be feasible. By nature, line assembly is vulnerable to stoppages caused by unforeseen factors. In order for an assembly line to work properly and smoothly, it is essential to have a well-planned flow of materials as well as functioning logistics. Another crucial aspect is the level of effort required to complete the actual manual labor. The required effort is influenced by the tools used, the design of the parts, i.e. how easy they are to install, as well as the walking distances between the parts and the assembly stations.

The objective of this thesis was to observe and analyze the challenges encountered in the assembly of the new model. Once the problems were identified, change requests were made. Also, the documentation of the assembly work and the making of assembly instructions, were within the scope of this thesis.

2 WÄRTSILÄ

Wärtsilä is a Finnish corporation specialized in the manufacturing of large engines and other equipment for marine and energy industries. Wärtsilä also provides services and maintenance to medium and low speed engines and other related installations. Wärtsilä emphasizes technological innovations and total efficiency of their power solutions in order to maximize the environmental and economical performance of vessels and power plants of its customers. /13/.

Wärtsilä's net sales in the year 2012 were 4 725million. At the end of the year 2012 Wärtsilä employed a total of 18900 people. Wärtsilä operates in 70 countries and in 170 locations all over the world. Figure 1 shows the net sales by business area. /11/.

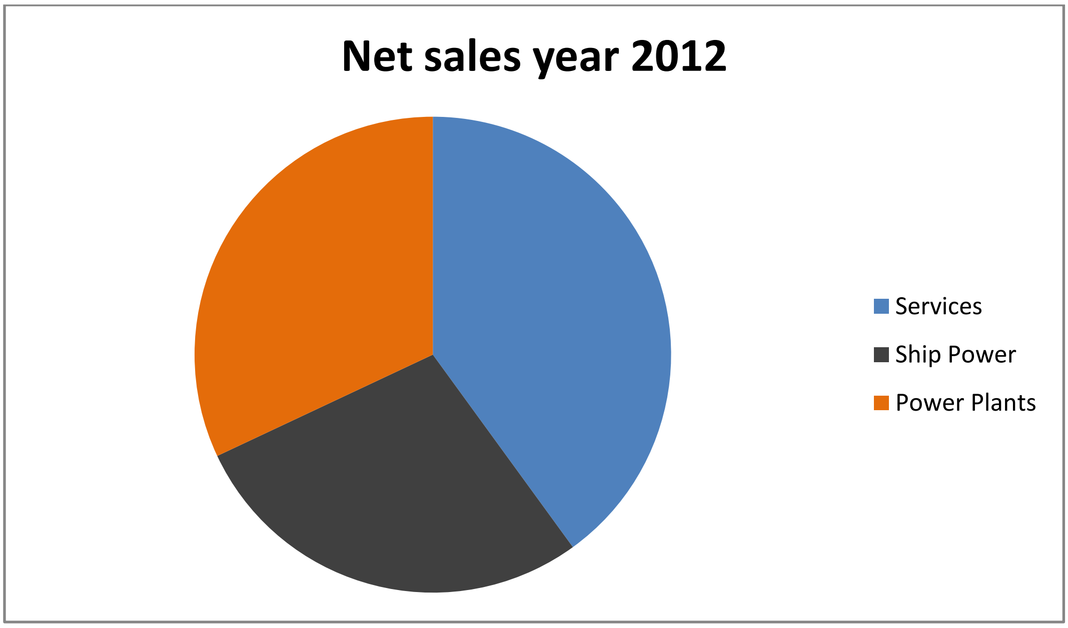

Figure 1. Net sales in the year 2012 by business area./11/

19 % of Wärtsilä's personnel are located in Finland and 35% in other European countries. Outside Europe, 32% of employees are located in Asia and 13% in the rest of the world. /11/.

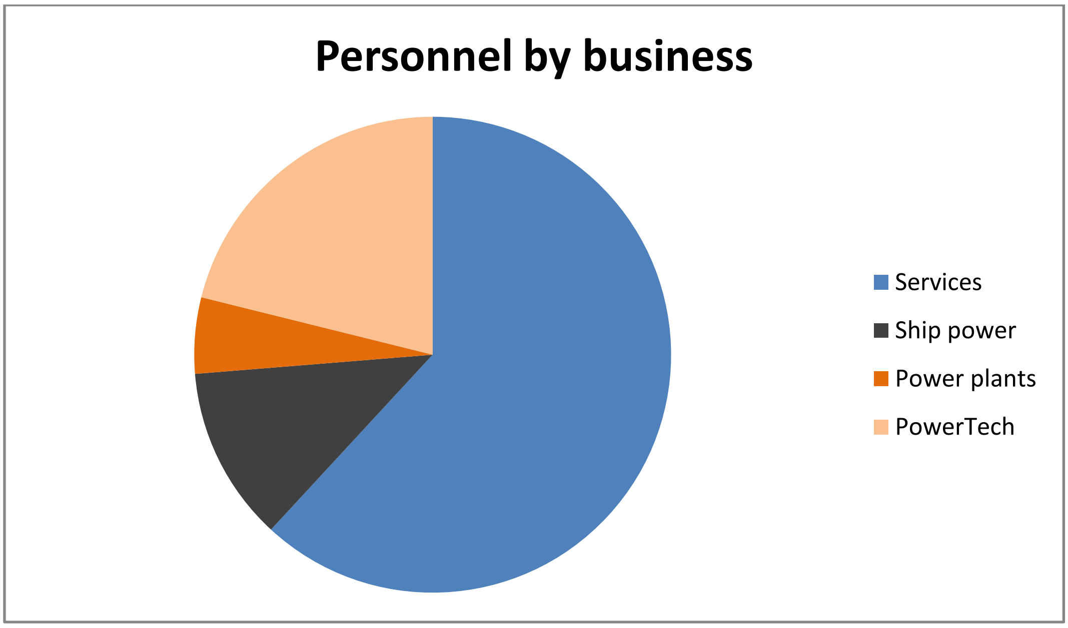

Figure 2. Personnel by business in 2012. /11/.

2.1 Ship Power

The purpose of Ship Power is to produce solutions that are environmentally sustainable, efficient, flexible, and economically sound for its customers in the marine industry. Wärtsilä is a technology leader in this field and through the experience and the know-how of its personnel; Wärtsilä can provide customized solutions for its clients around the world. /11/.

2.2 Power Plants

Wärtsilä is a leading supplier of modern, environmentally advanced and highly efficient power plants. Wärtsilä offers multi-fuel solutions for power generation markets, from base load generation to peaking and load following. The company specializes in fast track deliveries of entire power plants. The fast deliveries accompanied by long term operation and service agreements, offers flexible capacity to customers in both urban areas and remote environments. /11/.

2.3 Services

Wärtsilä supports its customer throughout the whole life cycle of their installations. Wärtsilä has the broadest service network in the industry, including both the energy and marine markets. The company provides high quality, expert support and good availability of services regardless of the location of the installation. /11/.

2.4 Products

The main products of Wärtsilä are engines. Wärtsilä manufactures both 2-stroke and 4-stroke engines. The 2-stroke engines are usually much larger and they are also called low speed engines while the smaller 4-stroke engines are called medium speed engines. This is the usual way of distinguishing engines. The cylinder bores in the 2-stroke engines ranges from 350mm to 960mm. The smallest cylinder bore in the 4-stroke engine family is 200mm and the largest 640mm. /12/.

The engines can also be categorized by the fuel they are using. Wärtsilä produces engines that run on oil, gas or both. Engine models that can handle both liquid and gas fuels are called dual fuel engines. /12/.

3 ON PRODUCTION

Production can be defined as including every function needed to provide a customer with a product or a service. This means that the word production includes the whole supply chain and every function in it. /4, 351/.

3.1 Targets of Production

The targets of production depend on the company's strategy. The most common targets of production are usually seen to be cost efficiency, quality, time and flexibility. Cost efficiency is one of the most important targets of production. It deals with minimizing costs by using the available resource effectively and keeping the needed working capital as low as possible. A large portion of cost efficiency is dependent on material purchases. Material costs can even be higher than labor costs and capital costs. High cost efficiency leads to lower costs per unit produced, thus making the company more profitable and its prices more competitive. /4, 357/.

Quality means how well the product or service meets the customer's expectations. From the productional point of view quality can be seen as the ability to produce flawless products in a flawless production process. The product has to correspond with its specifications as well as meet the expectations and demands the customer has placed for it. Any sources of error in the production process have to be removed in order to cut down costs and to prevent deviations from planned operations. /4, 357/

Fast delivery times are also one of the main targets of production. Fast deliveries demand a lot from the whole supply chain and they are vital especially in customer oriented production where the product is made according to orders received. Companies also try to cut down their lead times. Reducing the lead times of products leads to more efficient processes, improved quality and lower costs. /4, 357/.

When talking about flexibility in the context of production, the general definition is how fast and how cost efficiently, the production process can be altered. Volume flexibility means the ability to adapt to fluctuations in demand quantity. Flexibility with multiple products means the time needed to reallocate resources from the production of one product to the production of another. In some businesses it is important to be able to introduce new products to the production process fast. Yet another form of flexibility is the ability to implement new technologies, be they machines, other equipment or systems. /4, 358/.

The main targets of production can be summarized as being fulfilled when the product is produced at the right time, in right quantities, with sufficiently high quality all the while keeping the costs at a minimum. /4, 359/.

3.2 Production Strategy

Production strategy means the long term objectives that have been set for production processes and the means by which these objectives can be accomplished. Production strategy is a part of the overall strategy of the company and it has to be compatible with marketing and competition strategies. Decisions made regarding a company's production strategy are important because investments for new facilities or production systems are usually high. Also the decisions tend to be long term and they can affect the company for decades. /4, 365/.

There are several key issues to be considered when planning a production strategy. A company has to define its production methods and processes. The production methods chosen are heavily influenced by the properties of the product, production quantities and the supply chain the company has chosen. Because of this the company's ability to influence its production methods are limited. /4, 365/.

Another aspect is the scope and the implementation principles of the company's processes. It is not usual for a company to handle all the manufacturing processes by themselves. A company usually has a lot of partners, suppliers and subcontractors. Decisions have to be made on what functions and processes the company wants to take care of and what it transfers to its subcontractors. Generally the most important functions are kept within the company and those that are less crucial are handled by the supplier network. /4, 365/.

Decisions concerning the locations of production facilities and warehouses become exceedingly important in fields where transportation and distribution costs are high. Usually the location is chosen with minimizing transportation costs in mind. This means that facilities are located near the customers or in the vicinity of raw materials. Also the availability of qualified work force and other special properties of a location affect the decisions. Companies operating in the global market usually make their decisions based on the costs of the production factors in a location. /4, 365-366/.

Production capacities have to be scaled according to demand of the products. The capacity can be higher than demand, corresponding with the average demand or it can be lower than the actual demand. Companies scale their capacities depending on the cost of the capacity, the availability and the cost of subcontractors, how easy the products are to keep in storages and the demand the customers have set for the supply chain. /4, 366/.

Production technologies are also a part of the production strategy of a company. Newer technologies are usually more efficient and have higher quality than old technologies. Robots and other automation equipment are versatile and can be used to develop production processes flexibly. Investing in new production systems is expensive. This makes it crucial that all the risks and benefits are thoroughly analyzed before making decisions. Adding new technologies to production and staying up to date is a vital part in improving the competitiveness of a company. When improving product technologies, production technologies have to be usually developed, too. /4, 366-367/.

One of the main factors affecting the long term success of a company is its personnel. The overall competence, skills and motivation of the people working in the company are what determine the efficiency and development potential of it.

Developing the personal skills and motivation of the personnel is important for the success of the company. /4, 366-367/.

3.3 Production Planning

The planning of production processes is a challenging task that includes designing factory layouts and working practices. When a company is planning its production processes it has to take into account the targets it has set for its production. Decisions made when designing layouts and working practices, greatly affect the company's ability to achieve said targets. /4, 475/.

3.3.1 Layout Planning

The term layout refers to the way in which the physical parts of the production process are stationed in the factory they have been installed in. It includes machines and equipment used, as well as warehouses and routes used to move material. /4, 475/.

Different types of layouts have different attributes and unique characteristics. In an assembly line all machines and equipment needed in the production are sequenced according to the working of the product manufactured. An assembly line is specialized in producing a specific product. The manufacturing process and the handling of material are efficient. The prerequisites for building an assembly line are a high production volume and a high operating rate. Even though the initial investment of building an assembly line is high, with high enough volume, the cost per unit is low. The downside of assembly line layout is that it highly susceptible to disruptions. These disruptions, however small they may be, can easily and quickly affect negatively the productivity of the whole assembly line. The role of quality control is highlighted due to the fact that the costs caused by disturbances in the production process are high, and an assembly lines ability to produce even faulty products very efficiently. /4, 475-476/.

Another layout type is a called functional layout. In this type of solution machines and work stations are arranged according to their function. For example, all milling machines are located in the same place and all lathes are stationed in the same place or area. In this type of layout, production quantities and types of products manufactured can vary a lot. The production control process is based on allocating work tasks to individual machines, i.e. each machine has its own work queue. This makes lead times long. Material handling and moving costs are high due to long distances between working stations. As a result, the costs per unit are high. The advantages of having a functional layout are that it is easy to set up with low investment costs. Additionally, capacity can be increased flexibly and the layout allows the manufacturing of different kinds of products. /4, 476/.

A cellular layout consists of production cells that are independent of each other. Each cell is specialized in producing a single product or task. The cellular layout model could be perceived as being an intermediate model between the line layout and functional layout. A cell can flexibly manufacture the products it was meant for. Material flows are clear, preventing any intermediate storage from forming. Cellular layout is more flexible than the line model and more efficient than the functional model. However, it is more vulnerable to strong fluctuations in the product range than the functional model and the operating level of machines is lower than in the line model. /4, 477/.

4 QUALITY

Quality is a broad and complex topic. It can cover everything from company practices to the application of specific statistical tools. Quality consists of two mutually dependent perspectives: the value perspective and the conformance perspective. The value perspective deals with the products ability to satisfy needs that have been stated for it. The approach taken in the conformance perspective means ensuring that the product or service is free of deficiencies. /1, 82-83/.

4.1 Value Perspective

The value perspective deals with how the customer feels that the product or service fulfills their needs. Eight key dimensions by which customers evaluate quality have been identified. /1, 83/.

Performance dimension deals with the basic operating characteristics of the products. In addition to the basic characteristics, customers are also interested in the extra features the product or service might have. This is called the feature dimension. The reliability dimension of the product is also important. Basically this means how long a product can go between failures or the need of maintenance. The useful life of the product comes up when thinking the durability dimension of the product. /1, 83/.

The conformance dimension means how well the product or service meets its specifications. How well the products or services appeal to the senses is also identified as one factor by which quality is evaluated, this is called the aesthetics dimension. Serviceability means how easy it is to do repair or maintenance work on the product or service. How the customers perceive the quality is also one factor. This deals with the reputation of the product or service. /1, 83/.

4.2 Conformance Perspective

The difference between the value perspective and the conformance perspective is that while the former focuses on accurately fulfilling the needs of the end user, the latter focuses on whether a product was made or a service performed as was originally intended. Conformance quality is usually measured by comparing the finished product or service to standards that have been pre-established for it. /1, 84/.

4.3 Quality as a Competitive Factor

Quality was first seen as major competitive factor in the 1960s. The level of quality was generally low in many products. The demand for high quality products rose and when companies began to improve the quality of their products and processes, they discovered that improving the quality leads to better cost efficiency. /4, 374/.

Improved performance and reliability leads to a better reputation. A company with a good reputation generally has a higher market share and can keep its prices higher. When the market share increases so do the production volumes. The increased volumes in turn lower the costs per unit as the fixed costs affect a bigger quantity of products manufactured. These factors lead to improvements in profitability. /4, 374/.

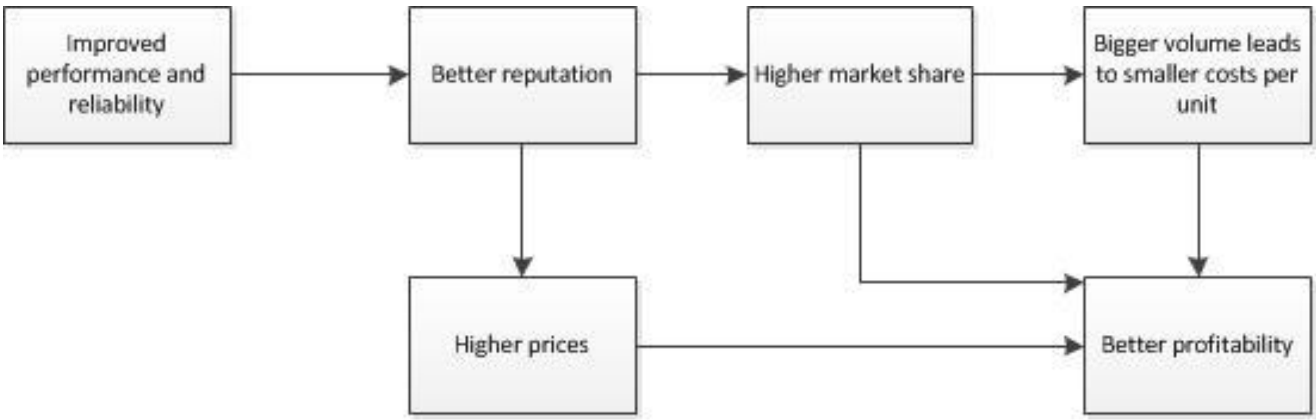

Figure 3. Impact of improved quality on profitability. /4, 374/.

4.4 Cost of Quality

There are four types of cost types usually associated with quality. Internal failure costs are caused by defects that occur before the delivery of the products to the customer. They include the repair or scrapping costs and the time wasted on these activities. These costs tend to be big as the time used for repair work is time when nothing new is produced. If the defective products go unnoticed until they reach the customer, the organization incurs an external failure cost. These costs are also large as they include the long term consequences of losing future business and litigation procedures. /1, 86/.

Costs arising from inspections and assessing quality levels are called appraisal costs. Appraising quality is not the same as preventing defects. Costs that stem from preventing quality defects from happening in the first place are called prevention costs. They include employee training, supplier certification efforts and investments in new processes as well as equipment maintenance. /1, 86/.

4.5 Total Quality Management

Quality management is more than just optimizing the defect level of the company. In order to meet customer expectations and produce products and services matching the specifications driven by user requirements, all individuals within an organization must address quality within the organization's business processes. /1, 88/.

This managerial approach is called total quality management. It is the management of an entire organization so that it excels in every quality dimension that customers deem important. Total quality management is a broad concept that can be divided into seven core ideas: /1, 88/.

- Customer focus
- Leadership involvement
- Continuous improvement
- Quality assurance
- Supplier partnership
- Strategic quality plan

Customer focus is the basis of total quality management. Employees must be aware of customer expectations and how they really feel about the product. If the employees do not know the customer, they risk alienating customers. Not all employees have external customers but everyone has someone whose expectations they have to meet within an organization. /1, 90/.

When trying to implement a total quality management system to an organization, the change must begin at the top. The management should make it clear all throughout the organization that quality is important for everyone. W. Edwards Deming presented a set of guidelines for managers to follow: /1, 90/.

- Demonstrate consistency of purpose toward product improvement
- Adopt the new philosophy of continuous improvement
- Cease dependence on mass inspection; use statistical methods instead
- End the practice of awarding business on the basis of price tag
- Find and work continually on problems
- Institute modern methods of training
- Institute modern methods of supervision
- Drive out fear–promote a company oriented attitude
- Break down barriers between departments
- Eliminate numerical goals asking for new levels of productivity without providing methods
- Eliminate standards prescribing numerical quotas
- Remove barriers that stand between the hourly worker and his right to pride of workmanship
- Institute a program of education and retraining
- Create a corporate and management structure that will promote the above 13 points.

Managers bear the responsibility for quality problems. In order to succeed they must focus on the entire organization. /1, 90/.

Continuous improvement means taking steps to continually improve processes. The basic philosophy is that there is always room for improvement and being content with the status quo is not an option. /1, 90/.

Employee empowerment means giving employees the responsibility, authority, training and tools to manage quality. Quality is everybody's job and it is up to every employee to improve think of ways to improve working methods, processes and other quality related issues.

Quality assurance refers to action taken to ensure that the products, processes and services meet the requirements of customers. The activities take place on every level of the organization. In the design phase, a technique called quality function development is often used. Its purpose is to translate customer requirements into technical requirements for every stage of product development and production. Another technique is called statistical quality control. It uses statistics in order to help organizations assess quality levels. Quality auditing is also one widely used tool when evaluating quality levels in an organization. /1, 90/.

Companies must extend their quality management systems to their supply chain partners. Members of the supply chain must also implement total quality management systems as their products and services will ultimately become a part of the product or service offered to end users. If the quality of the suppliers is low, quality of the end product suffers. The supplier partners must be monitored and their performance evaluated in order to ensure that they are willing to meet the expectations. /1, 91/.

The implementation of total quality management takes a significant amount of time and effort. A well-made strategic quality plan is necessary. They define the objectives of the organization in the long term and also establish goals for the short term. Quarterly evaluation on how well the performance matches the goals must be made by the executives. /1, 92/.

5 LEAN

Lean is a production practice that focuses on eliminating waste from all production processes. In lean thinking waste is specified as meaning any human activities which use resources but do not create any value. These include mistakes that require rectifying actions to be made, unnecessary movement of goods and employees and groups of people waiting in a downstream organization for other activities to be finished. /10, 15/.

Lean has expanded beyond manufacturing processes to include services and all aspects of supply chain management. Companies following the lean principles usually see substantial improvements in their productivity, inventory levels and quality. /1, 527/.

5.1 Lean Principles

There are eight widely recognized sources of waste in the lean philosophy. The first one is overproduction. Overproduction means that the organization is producing goods before they are needed. This is caused by inflexible or generally unreliable processes. Waiting is another source of waste and it is usually caused by inefficient layouts or the inability to match demand with output levels. /1, 528/.

Transportation of goods increases costs but does not necessarily add any value to the final customer. Unnecessary transportation should be avoided. Also all processes should be kept as simple as possible. There is no point in using overly complex processes, if there are simpler ones available. Unnecessarily high inventory levels are also a major source of waste. Poorly designed processes cause people and equipment to move more than what would be necessary had the processes been designed properly. Defects create uncertainty in the processes and they use up production capacity because they create sub-standard products that need to be reworked or scrapped. The eighth source of waste is underutilization of employees. Companies often do not fully take advantage of their employees’ skills and decision making capabilities and this creates waste in the process. /1, 528/.

5.2 Inventory

Excessive inventory is seen as one of the sources of waste. In addition to being a form of waste, high inventory levels can hide other wasteful business practices. By lowering inventory levels, companies force themselves to address these poor practices and revise their production process. /1, 530/.

In a supply chain where there are high inventory levels at every stage of the chain, problems do not become immediately visible. If a machine or some other equipment breaks down in the middle of the supply chain, in the short run only the facility in which the breakdown occurred, is affected. No matter what the cause of disruption in the supply chain is, inventory hides it. The problem is that inventories cost money and problems in the supply chain can go undetected and uncorrected. /1, 530/.

In a supply chain that operates under the principles of the lean philosophy, the case is different. In this case, if there is a disruption in the middle of the chain, it immediately has an effect on the whole chain. This exposes the problems for what they are. The purpose of lean is to lower the inventory levels and gradually remove the obstacles in the order in which they arise. This process continues until all sources of waste and uncertainty have been removed. /1, 531/.

5.3 Value

Lean thinking starts with specifying value. Value can only be determined by the end user, i.e. the customer, of the product. Also the definition of value only has meaning when it is expressed in terms of a specific product which fulfills the customer’s expectations and demands at a specific price at a specific time. The customer determines the value but it is the producer who creates it. /10, 16/.

Specifying value is critical in lean thinking. It should be the first thing to focus on when implementing lean principles in an organization. The goods and services produced must be what the customer wants and values. Even when produced the right way, providing the wrong good or service is waste. /10, 19/.

The value stream means all the actions taken to bring a specific product through the critical management tasks of a company. These tasks are identified as problem-solving task, which means bringing the product from concept to design and finally to production launch, the information management task meaning order taking, scheduling and delivery and the physical transformation task that entails the manufacturing process from raw materials to the finished product. /10, 19/.

The identification of the entire value stream of a product will usually expose the wasteful practices along the value stream. A value stream usually has steps that create value, steps that do not create value but are unavoidable with current technologies and steps that do not create value and are immediately avoidable. /10, 19-20/.

5.4 Wärtsilä LEAN

The purpose of Wärtsilä Lean is to apply the Lean principles to all of Wärtsilä's processes. The objective is to satisfy customer needs by using less of everything i.e. capital, time, inventories and human effort. The focus is to eliminate waste from all processes so that every one of them adds value to the end user.

The Wärtsilä Lean –program has been piloted in WIO and from there it has been expanded to other divisions. The employees within WIO receive training on the Lean Principles and are thus enabled to use them to identify and eliminate waste in all global processes. /12/.

Wärtsilä Lean framework consists of five areas. These areas are: people, strategy development, way of working, extended enterprise and tools & techniques. This means that the responsibilities and accountabilities should be clear for everyone in the organization. The vision, goals and strategy have to be clearly communicated through the organization and key measures and targets appropriately deployed. Improvements should be made and managed in order to improve customer value with minimum bureaucracy and waste. The organization should develop strategies for identifying and eliminating waste throughout the supply chain, including external partners. Continuous improvement should be a part of the organization's daily routine and the tools and techniques used should be simple and visual. /12/.

Figure 4. Wärtsilä lean. /12/.

6 DIESEL ENGINES

A diesel engine is an internal combustion engine that uses compression to produce enough heat to ignite a fuel charge. The ignition does not require any separate ignition components, such as spark plugs. The temperature of the compressed air is enough to ignite the fuel as it is injected in to the cylinder. /8, 11/.

6.1 History

In the 19th century the steam engine was the main power source behind the industrial revolution in the United States. Towards the end of the century it had become clear that the steam engine could not meet the needs of certain industries. Problems stemmed from the fact that steam engines were very large and they required an external firebox, a boiler and a condenser. Also the efficiency of steam engines was very low. The need for small and efficient power sources was filled by internal combustion engines. /8, 14/.

Rudolf Diesel was a German engineer credited for creating the diesel engine. In 1892 Diesel made his first patent draft for an internal combustion engine. Diesel proposed that the engine could run on coal dust. During the years between 1892 and 1897 Diesel tried different fuels and configurations. After almost five years of testing, the first diesel engines were ready to be sold. The first commercial diesel engine was installed in a Bavarian match factory. It had two cylinders and a power output of 60 horsepower. In 1898 the diesel engine was officially presented to the public for the first time. /8, 17/.

Production started out slow. Because of its size and weight, applications for diesel engines were limited. These issues lead to the automobile industry choosing the gasoline engine as its power source. The main interest came from the marine industry and the first diesel powered ocean-going ship made its maiden voyage in 1912. Rudolf Diesel died in 1913 and never got to see the full potential of the diesel engine unleashed. The World War I sped the technological development up dramatically. In 1936 the Daimler-Benz Company launched the first production model diesel automobile. /8, 18/.

Modern applications for diesel engines are plentiful. They are used in mobile applications, such as cars and ships, as well as stationary applications, such as power generators and cranes. /8, 18-19/.

6.2 Main Components

A diesel engine is comprised of several components.

6.2.1 Cylinder Block

The cylinder block is the largest of the components found in a diesel engine. It supports the other components and contains openings for cylinders, internal passages for coolant and lubricating oil and bores and passages for other engine components. /8, 55/.

6.2.2 Pistons and Connecting Rods

Pistons move up and down inside the cylinders. As the pistons move downward, their movement is transferred to the crankshaft through the connecting rods. On the side surfaces of the pistons there are grooves where the piston rings are fitted. The piston rings seal in the compression and combustion pressures as well as the lubricating oil film on the wall of the cylinder liner. /8, 57-58/.

The connecting rods connect the pistons to the crankshaft. The connecting rods are attached to the pistons with piston pins. The purpose of the connecting rods is to transfer the pistons’ reciprocating motion into the rotational motion of the crankshaft. /8, 59/.

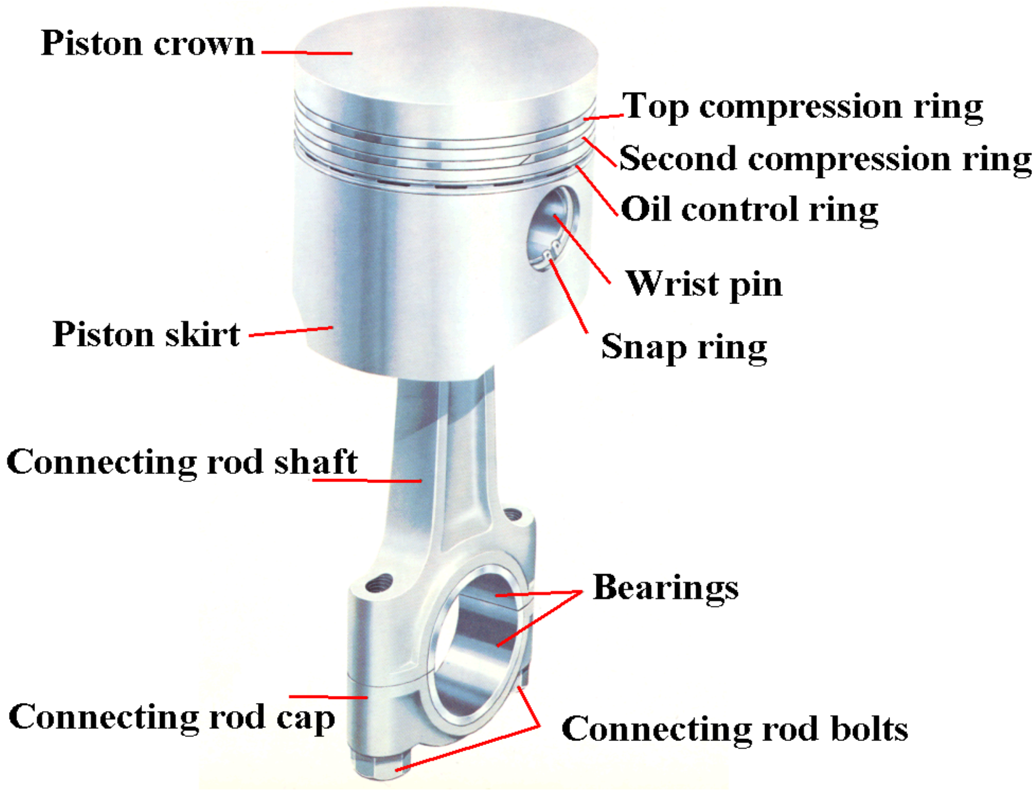

Figure 5. Piston and connecting rod. /5/.

6.2.3 Crankshaft

The purpose of the crankshaft is to convert the reciprocal motion of the pistons into rotary motion that can be used to turn shafts in a transmission or driveline. The crankshaft transmits all of the power that the engine produces. /8, 58/.

The crankshaft has several key components. Journals are the parts of the crankshaft that ride in the cylinder block saddles. The main bearing journals support the crankshaft as it turns during the run of the engine. The connecting rod journals are located at the ends of the throws of the crankshaft. The connecting rods are connected to the crankshaft through the connecting rod journals. /8, 58/.

There are also oil galleries along the length of the crankshaft. The purpose of the oil galleries is to feed lubricating oil to the connecting rod journals and their bearings. /8, 58/.

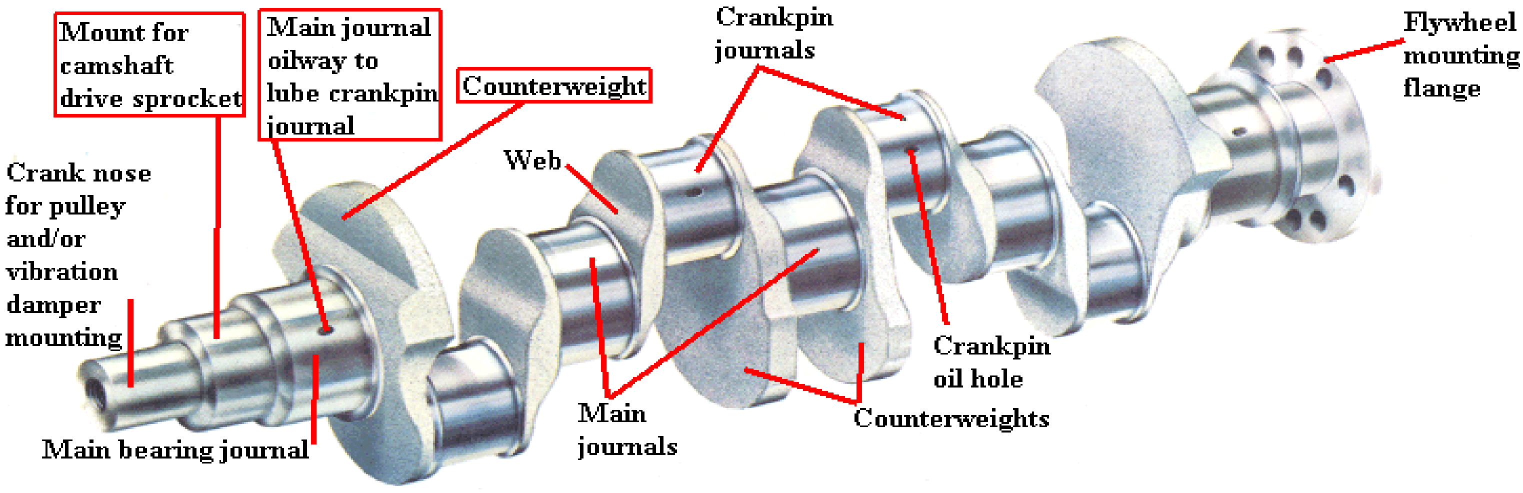

Figure 6. A typical crankshaft. /9/.

6.2.4 Camshaft

The purpose of the camshaft is to coordinate the opening and closing of the intake and exhaust valves with the operation of the piston. The camshaft has several lobes that control the movement of the valves. The camshaft can have multiple lobes per cylinder. One lobe operates the intake valve and the second lobe operates the exhaust valve. Some engines might have a third lobe between the intake and exhaust lobes that controls the fuel injector of the cylinder. /8, 60/.

Figure 7. Camshaft. /3/.

6.2.5 Cylinder Head and Valves

While a piston forms the bottom of the combustion chamber, the cylinder head forms the top. The cylinder head is bolted to the cylinder block. It contains passageways for coolant circulation, intake ports that allow air to enter the cylinder and exhaust ports which allow the exhaust gases to flow out from the cylinder. /8, 61/.

The cylinder head also supports the valve seats, valve guides, valve springs, fuel injectors, push rods and rocker arms. The valves are used to seal the air passages. The intake valve is open only during the intake stroke and the exhaust valve is open only during the exhaust stroke. /8, 61-62/.

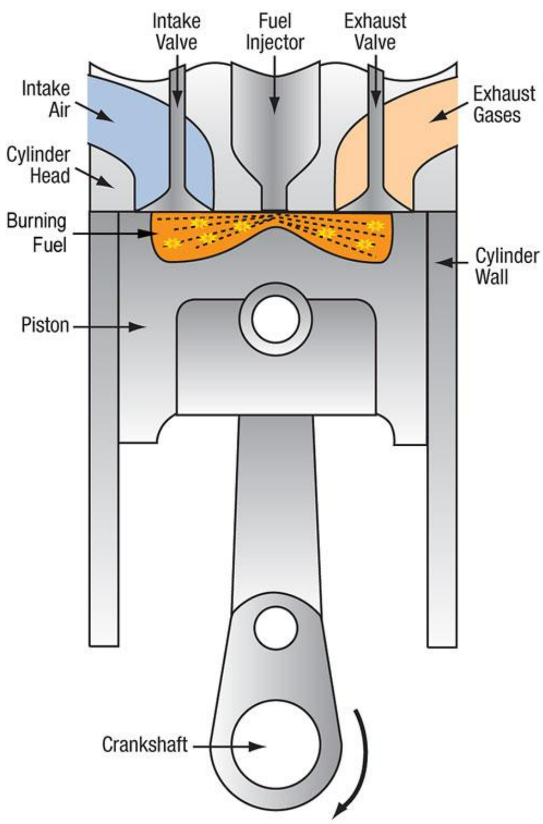

Figure 8. Diesel engine cylinder configuration. Arrows do not reflect flow directions. /2/.

6.2.6 Turbochargers

A turbocharger is a device with the purpose of supplying more air into the combustion chambers. Turbochargers are operated by the exhaust gases that are produced in the combustion processes inside the cylinders. A turbocharger allows small diesel engines to produce 40% more power compared to engines the same size that are naturally aspirated. /8, 64/.

The turbocharger improves the combustion process and this leads to smaller exhaust emissions, smoke and noise. The turbocharger also improves efficiency as the extra air it provides increases the power output without increasing fuel consumption. The main components of a turbocharger are compressor wheel, shaft and a turbine wheel. The turbine wheel is rotated by the exhaust gases exiting the engine. The rotary motion of the turbine wheel is transferred to the compressor wheel by a shaft that connects the wheels. When the compressor wheel rotates it draws in fresh air and delivers high pressure air to the engine cylinders. /8, 287-289/.

6.3 Operating Principle

A 4-stroke diesel engine uses four piston strokes to complete one operating cycle. These strokes are called intake, compression, power and exhaust strokes. 2-stroke engines accomplish the entire cycle using only two piston strokes. /8, 11/.

6.3.1 Intake Stroke

During the intake stroke the air intake valves are open and the exhaust valves closed. At the start of this stroke the piston is near its top dead center, i.e. the uppermost point that the piston reaches inside the cylinder. The piston begins to move downward and air is drawn into the combustion chamber. /8, 64-65/

6.3.2 Compression Stroke

During the compression stroke both the intake and exhaust valves are closed. The piston moves upward and compresses the air, which has been drawn into the cylinder during the intake stroke. As the air gets compressed, it begins to heat up. When the piston is near the top dead center, fuel is injected into the cylinder. The high temperature of the air causes the fuel to ignite. /8, 65/.

6.3.3 Power Stroke

When the fuel-air mixture ignites, they begin to expand. As the combustion gases expand they force the piston down. The movement of the piston is transferred to the crankshaft through the connecting rod. This is the only stroke that delivers power. /8, 65/.

6.3.4 Exhaust Stroke

After the power stroke, the exhaust stroke begins. During this stroke the intake valves are closed and the exhaust valves open. The upward moving piston forces the exhaust gases caused by the combustion process out from the cylinder. After the exhaust stroke has been completed, the cycle begins again. /8, 65/.

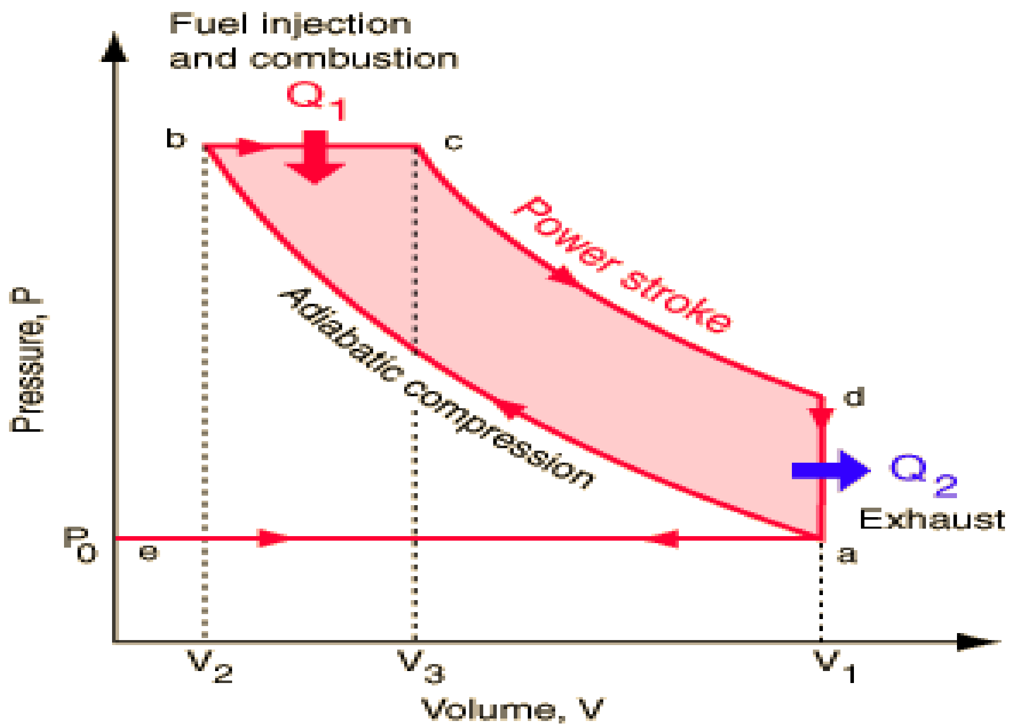

Figure 9. Ideal diesel cycle. /7/.

7 WÄRTSILÄ 32E

Wärtsilä 32E is the newest addition to the Wärtsilä 32 –engine family. It is a 4-stroke turbocharged diesel engine with direct fuel injection and charge air cooling. It is a marine engine intended to be used in ships. It was first introduced in the design stage in the year 2011 and the first in-line engines were assembled in 2012 and the assembly work of the first V-engines began in January of 2013. /12/.

Wärtsilä 32E has a cylinder bore of 320mm and a piston stroke of 400mm. The engine speed varies from 720rpm to 750rpm. The power output per cylinder ranges from 550kW to 580kW, meaning that at 750rpm, a 12-cylinder engine produces approximately 7MW of power. The engine is available in different cylinder configurations. In-line engines are available as 6, 8 or 9-cylinder versions and V-engines are available as 12, or 16-cylinder versions. /12/.

7.1 W12V32E Charge Air System

The W12V32E engine has two Napier 298 turbochargers that are mounted in --degree angle in the free end of the engine. The engine exhaust pipes are separate for each cylinder bank. There is a branch pipe connecting the exhaust pipes from both turbochargers to a common exhaust gas pipe.

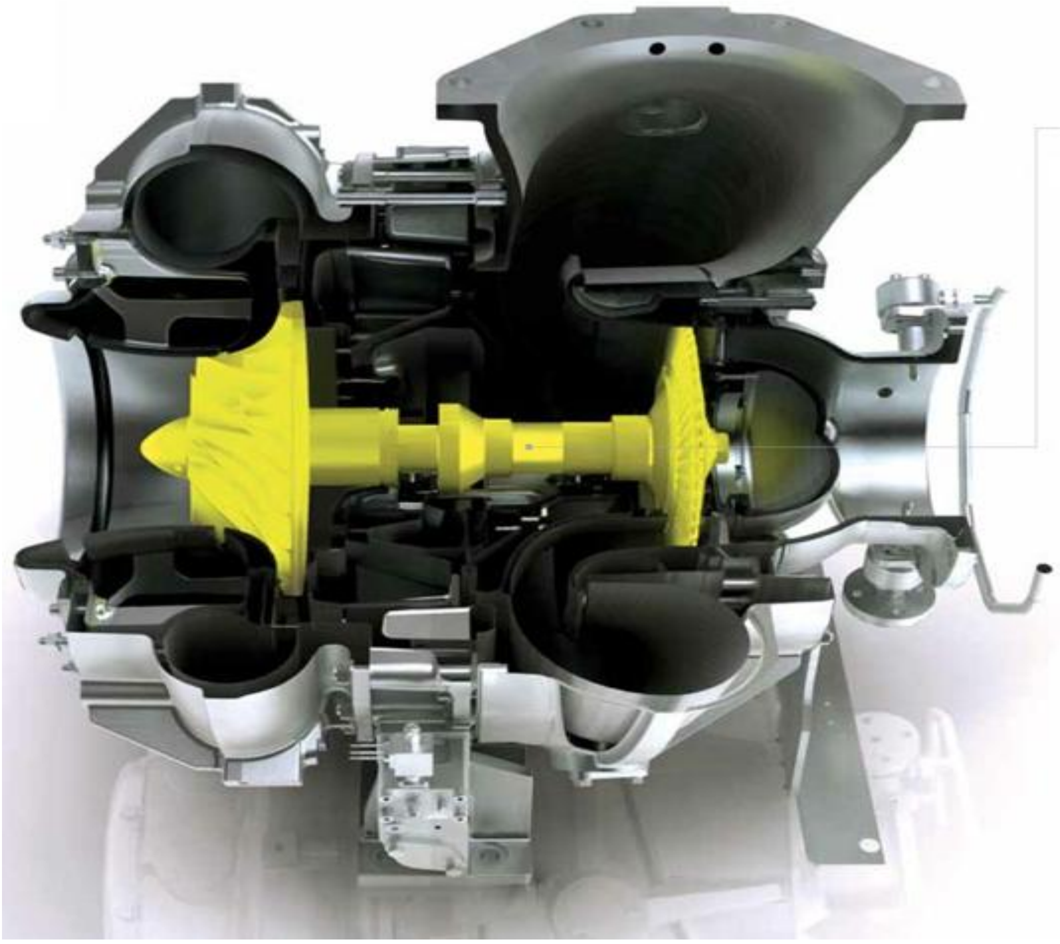

Figure 10. Cross section of a Napier 8-series turbocharger. /6/.

7.1.1 Turbine Washing System

There is a system for turbine washing installed in the engine. The purpose of this system is to wash away the soot that accumulates in the turbine during the run of the engine. The turbine must be washed at regular intervals. Depending on the quality of the fuel, washing must be done every -- hours. The dirty water should be lead to a tank specifically intended for the purpose. Turbine washing is necessary when operating on heavy fuel oil. /12/.

7.1.2 Wastegate and Air By-pass

A wastegate is a valve used to divert exhaust gases from the turbine of a turbocharger. The purpose is to keep charge air and cylinder pressures at an optimal level. The wastegate valve adjusts the charge air pressure to the correct value regardless of varying conditions on site, i.e. temperature and humidity. /12/.

Because the engine operates at varying speeds, an air by-pass valve is installed. This is done in order to ensure that the turbocharger is operated at the optimum point at high load while maintaining enough of a safety margin at part load. /12/.

7.1.3 Charge Air Blocking Device

In applications where there is a possibility of over-speeding of the engine because of combustible gas or vapor being present in the inlet air, a charge air blocking device is required by the authorities to be installed. /12/.

The device is located on the charge air duct after the turbocharger. In V-engines there are two shut-off devices, one for each turbocharger. They are spring loaded shut-off valves with the purpose of shutting down the engine by cutting of the charge air to the cylinders. If the engine begins to over-speed, the safety system sends a signal to a solenoid valve, which in turn shuts the shut-off valves. The solenoid valve can also be operated manually by pushing a button located on the solenoid. There is also a t-handle in every device. When pulled the handle releases the spring holding the valve and the valve closes. The handles are meant to be used in case of emergency. /12/.

8 INDUSTRIALIZATION

Industrialization of a product means ensuring the overall feasibility of the manufacturing process of the product. It includes taking into account the tools and working methods used, material flows and the order in which the assembly is carried out.

8.1 Premise

The purpose was to ensure that the new turbocharger module could be assembled in the assembly line where most of the TC-assembly is carried out in Wärtsilä's factory located in Vaasa. The goal was to minimize the effort needed in the assembly work. The assembly line consists of five mechanical assembly stations and one station meant for electrical assembly work.

The most important thing to consider during the industrialization project was safety. The lifting equipment and working techniques have to be safe so as to avoid any injuries or, worst case scenario, casualties. When doing assembly work, there is always a risk of injuries, especially when dealing with heavy machinery and products as large as Wärtsilä engines. While equipment and machinery can be safe, there is always the risk of human error. This risk can be minimized by organizing proper training on safety at work and on operating cranes and other lifting machinery. Proper instructions on how to do specific jobs requiring special attention also help to mitigate any risk of injuries.

After the safety issues have been resolved, quality must be addressed. Wärtsilä has a reputation as a manufacturer of good quality, high performance engines. Wärtsilä Finland is ISO 9001 certified and quality is taken seriously throughout the organization. Workers at Delivery Center Vaasa can make suggestions on how to improve methods, processes and products. In this project, the quality issues were resolved in cooperation with the assembly workers, inspectors and design engineers.

8.2 Start of the Project

The assembly work started in week 5. Prior to the start of the assembly, the technical drawings of the turbocharger module were taken under inspection. At this point the purpose was to detect possible problem points before they were realized during the assembly. Also the preliminary assembly order was decided. An Avix-report was made based on the assembly order and the assembly times assigned to every task. The report showed how the work load was distributed along the assembly line and changes were made to the assembly order, based on it.

As the E-model is a completely new type of turbocharger module, there were a lot of new parts not used in any other model. This presented some challenges when making the assembly order as it is easy for problems to go unnoticed, when no one had actually assembled a turbocharger of this model yet. The order of assembly was documented on an excel sheet for the assemblers to print. It is a list of tasks that is divided into five phases, according to the assembly line. Every time an assembler finishes a task, he will mark it on the list as completed.

8.3 The Assembly

Not published.

8.4 Materials

Not published.

8.5 Assembly Instructions

Not published.

9 RESULTS AND CONLUSIONS

9.1 Results

As the turbocharger module was the first of its kind, there were problems with the assembly. Some of the assembly work proved to be challenging or impossible to do without special tools. In spite of the problems, the assembly work went relatively smoothly and the only major delays were because of missing parts and some of the parts initially delivered were wrong all together. The challenges with the assembly are documented in appendix 7.

The order of assembly was sketched out before the start of the assembly and some changes had to be made when it was realized during the project that the work load for certain phases would be too high and the different stations would not be evenly balanced. Also some work turned out to be impossible to do in the intended order. The assembly order that works also as a task list is in appendix 1.

Changing the assembly order meant that changes had to be made to the material sets also. Some materials had to be moved from the end of the line to the beginning in order to balance the work load. The work load needs to be balanced in order to avoid bottle necks on the assembly line and avoid any load peaks on individual phases.

The assembly instructions were meant to be easy to use and visual. For this reason they were done in PowerPoint format. Also if any need to update the instructions should arise, the work can be done by anyone with basic knowledge of Microsoft PowerPoint.

9.2 Future Development

As this project was the first of its kind some factors might have gone unnoticed. Whether the project was successful or not can only be determined after the first modules have been assembled in the assembly line. Some working methods and techniques might be seen more efficient and better than what was decided during the project. The nature of the assembly work in the pilot assembly station is inherently different than in the main assembly line. This is due to the fact that every module affects the whole assembly line and the layout is more vulnerable to disturbances and it is not flexible. For these reasons the industrialization process should be continued in the future if it is seen necessary. The assemblers will have insights on how to further improve the assembly process of the turbocharger module and their suggestions should be duly noted.

There were a lot of V2-notifications made, based on the structure and design of the module. The notifications contain change requests to some parts of the assembly that were seen to be problematic. Also bigger structural changes need to be made in the future in order to improve quality and make the assembly work more feasible. These changes include:

- -
- -
- -
- -
- -

It is important that the changes are carried out as fast as possible. The designer and the people in charge of production will have to cooperate in order to find the best possible solutions.

Any information and experiences acquired during this project should be applied to other models as well, as far as they are considered relevant. The W12V32E – model has some unique traits but some of the observations made apply to all V-engine turbochargers. The same kind of project should be organized whenever a new model is being introduced. This will help prevent problems in the manufacturing process and improve the efficiency of the assembly line.

The overall development of the assembly line should also be continued. Layout changes and other improvements such as new assembly orders, new tools and working methods should be implemented if they are seen to be beneficial. All the future changes should be made bearing the Lean principles in mind. At the moment there is too much waste being created all through the process of assembling a turbocharger module. The implementation of the Lean principles should start from the very beginning i.e. the design phase of the modules. When new models are introduced to production, there should be no need to do any major changes to the design, only minor fixes.

9.3 Evaluation

When this project started I had been enlisted on the department's pay roll for a year and a half. My job had been to assemble turbocharger modules so the assemblies and the working methods were not new to me. The advantage I had while making this thesis compared to someone who has not been working with the modules was huge.

My experience allowed me to see the whole picture and while making the instructions and coming up with the assembly order, I pretty much knew what I was doing. That being said, the input of the assemblers, with whom I worked in this project, cannot be understated. Also my instructor from Wärtsilä, Marko Ylikoski, was of great help.

The downside of having working experience is that it may be sometimes difficult to think outside the box. If one is too used to old habits, it is hard to try to come up with something new. In my opinion we managed to avoid conforming to old ways and genuinely tried to think of new methods of improving the assembly work.

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