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"ORGANIZATION AND MANAGEMENT OF TWO STROKE SLOW SPEED DIESEL ENGINE OVERHAUL"

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Summary

The subject of this thesis concerns the examination of the mechanical maintenance carried out on the equipment of one of the three electricity generating stations of the Cyprus Electricity Authority, in that of Dekelia. Specifically, the maintenance perform on the station's internal combustion engines, and in particular on the two stroke internal combustion engines, is being studied.

First, a general approach to the definition of maintenance is made, with a presentation of the widespread maintenance methods and their organization. This is followed by a report on the operation of the Decelia power plant as well as an explanation of the general operation of internal combustion engines. The description of the operation of the station was made in the simplest possible way. Then, based on the collection of data from the station, a description was given of the methodology and maintenance planning carried out in the part of the station related to the two stroke internal combustion engines.

Key words

Maintenance, precicion, inspection

Contents

Schemes and photos Contents

Introduction

1.1 General

In the modern era, rapid technological development plays a primary role in shaping, sustaining, competing and consolidating various businesses that either take up space in the global market or are employed locally. The main goal of modern businesses is to provide services to satisfy customer requirements while producing high quality products at the lowest possible cost and with the highest possible profitability and efficiency. All this makes the maintenance and selection management of equipment, a process of optimal importance. With the rational use of an appropriate organizational maintenance program, timely treatment and reduction of any equipment failures and failures is achieved, reducing costs and increasing the efficiency of a business [1].

1.2 Definition of maintenance

Maintenance is defined as the set of actions that can detect the onset of damage to the equipment and generally ensure the quality and continuous operation of the technological equipment of an industrial enterprise, during its lifetime.

Maintenance procedures are directly linked to production, so the main goal is to produce products with the lowest possible cost and the best possible quality. More specifically, the maintenance must ensure [1-3]:

- Unhindered operation of equipment and ensuring the required level its reliability
- Reduction of lost time waiting and performing tasks
- Extending the life of equipment
- Optimizing the quality of results
- Cost minimization with the most economical operation and the maximum equipment productivity
- Continuous information to improve the equipment
- Increasing the availability of equipment

- Increase production availability
- Protection of the health and safety of employees from the risks of facilities and the equipment they handle
- Environmental Protection

1.3 Maintenance evolution history

According to John Moubray in his book Reliability Centered Maintenance, the evolution of maintenance is divided into three periods [1-5]:

The first period covers the period up to the second world war. Until then, industries relied more on human resources and less on machines, and thus on their maintenance. Industrial equipment was usually of little complexity since the industry was in its early stages of development and designed with a high degree of safety, which gave it continued reliability and easy repairability. Therefore there was no systematic maintenance program, other than replacing the equipment when needed. This was also the first approach to maintenance, which was called “Operation until Failure” [1-5].

The second period dates back to the end of the second world war, where a greater use of machines and a reduction in human resources began to be observed, which led industries to look at maintenance issues more closely. The complexity of machines increased rapidly, resulting in higher downtime costs. This development led to the development of the concept of preventive maintenance, a more planned system of maintenance at set intervals.

From the 1960s onwards, the demands and needs of the aviation industry and then of other sectors made it necessary to systematically monitorand inspection of equipment to reduce the occurrence of failures. Thus, in combination with the search for a multitude of new maintenance techniques, from the mid 80s the Predictive Maintenance approach, based on the current state of an industry, began to prevail. More emphasis is now placed on equipment reliability, the lifetime of machines is increased, better quality products are produced and there is a more adequate relationship between cost effectiveness [1-5].

In recent years, a new approach to maintenance has started to be applied in some cases, Precision Maintenance, which, in addition to checking the condition of the equipment, gives more importance to the control and monitoring of the quality of the produced products. However, this method is still not widespread and is the future of maintenance [1-5].

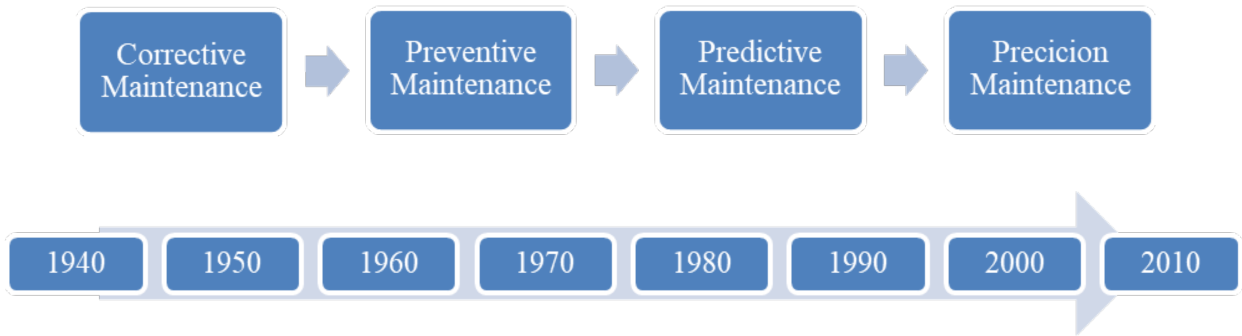

Figure 1.1: Historical evolution of Maintenance [1]

1.4 Maintenance Methods

Based on the historical review, the main types of maintenance are divided into:

i. In fault recovery maintenance or corrective maintenance

ii. In corrective maintenance,

iii. In preventive maintenance and

iv. In predictive maintenance

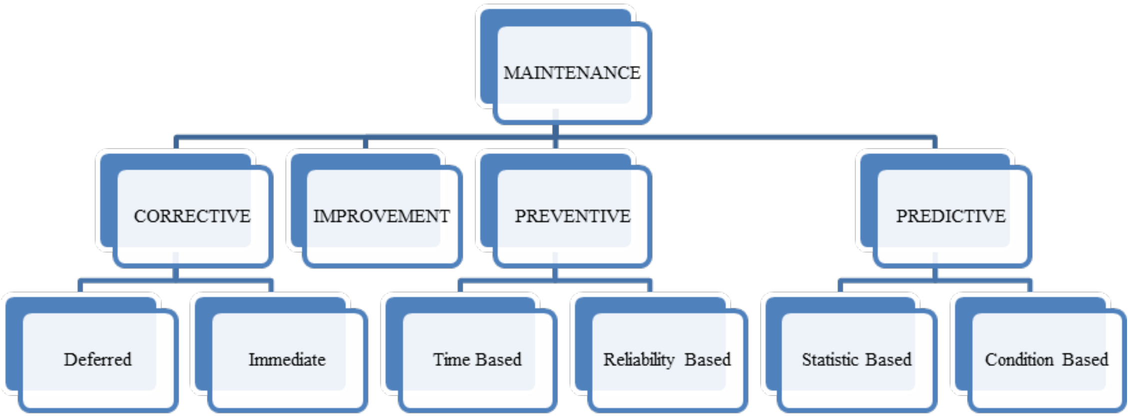

Figure 1.2: Basic maintenance methods [1]

1.4.1 Breakdown Maintenance or Corrective Maintenance (Breakdown maintenance)

It refers to the maintenance that is done in the event of a sudden breakdown of the equipment and its restoration. It is essentially characterized by the absence of any action to prevent any damage to the equipment until failure occurs, so it is not a continuous process. The appearance of damages can be due to errors that arise in the equipment during its operation, from unsuitable construction materials, due to incomplete design or from mistakes made during construction [1,6-14].

Breakdown Maintenance is divided into two main categories. The first category concerns damage to parts of the equipment that directly affect the process of the production system and therefore need immediate repair (Immediate). The second category has to do with repairs and restoration of unwanted damage that does not affect other useful functions and is somehow of secondary importance (Deferred). These fixes are basically for routine situations.

In general, a key advantage of this maintenance method is that it is usually applied to low power equipment, which is not vital to the production operation of a company. However, maintenance costs in this case may be very high. The increased cost of rehabilitation is due to the overtime work, the extraordinary arrival of personnel in non working hours and the addressing to external factors, phenomena that are common in industries that follow the specific way of approaching maintenance. Also, the absence of systematic control of the machine, leads to long times to find and restore faults, therefore to increased dead times. In addition, since the fact that it is not known exactly when the equipment will present a mulfunction, forces the company to maintain a fairly large stock of spare parts [1,6-14].

1.4.2 Improvement Maintenance

It refers to the modification and upgrading of the equipment without, however, changing its required function. Sometimes it also includes the total replacement of a company's equipment. It aims to minimize equipment downtime, design and unhindered supply of spare parts to equipment, and upgrade machine features with appropriate conversions for better production quality and cost reduction [1,6-14].

A necessary condition for the effective implementation of the Improvement Maintenance is the archiving of the history of failures concerning the equipment as well as the creation of a list by the company with the most suitable suppliers. In this way, the maintenance staff is given the possibility to modify and upgrade the equipment either by the company itself, or to turn to third parties, assuming that there will be continuous communication and good cooperation between the company and the suppliers. In addition, the existing maintenance staff must be aware of the new technological trends appearing in the market, always keeping in mind the age of the respective equipment [1,6-14].

1.4.3 Preventive Maintenance

Preventive Maintenance is the evolution of Corrective and Repair Maintenance. From the middle and later of the last century, the automation and greater complexity of industrial equipment combined with the increase of competitiveness in the context of the globalized market, issues related to the maintenance and reliability of the equipment and plant components, gained more importance, which led to the adoption of a new maintenance policy.

Definition of Preventive Maintenance is the application of maintenance that is carried out at predetermined time intervals (time based) or that meets specific criteria concerning the production unit (reliability based). The aim is to reduce the probability of failure, to prevent a future failure of the equipment and to promptly replace the failure should it occur.

Preventive Maintenance is divided into two levels: The first concerns lubrication actions and cleaning of the individual components of the machines for the smooth operation of the equipment as well as some standard upgrades that must be done. Lubrication processes require proper planning, since they are processes that largely determine the long term reliability and service life of the equipment. In cases where a large number of machines are lubricated, special emphasis must be placed on proper planning to avoid poor inventory control as well as equipment being out of service for a long period of time [1,6-14].

The second level, which essentially constitutes the main stage of preventive maintenance, includes the processes of lubrication but at the same time seeks to avoid any future damage to the equipment as well as the disclosure of significant damage to the various components that may lead to equipment failure. This is achieved by continuous inspections of all the components of each machine and many times their replacement to avoid damage in the future. In addition, a detailed network is required for equipment study, maintenance inspection and precise instructions for each maintenance action, depending on the operating hours of each machine. With this strategy, situations that can lead to damage are prevented in time, which proves to be more economical than the sudden occurrence of an equipment failure which can cause major damage to the production system [1,6-14].

This maintenance policy may have high operating costs because it requires maintaining an adequate safety stock of spare parts, having a maintenance program in place in the event of a production stoppage, and categorizing machines according to when a maintenance inspection is needed.

On the other hand, it leads to a reduction in the total maintenance costs of the business, due to the planned maintenance and use of personnel that will be allocated for this purpose. Compared to the Breakdown Maintenance method, there is a reduced cost resulting from the downtime when the unit remains out of service, but also from the ability to schedule repair times and spare parts supply in advance. It could therefore be characterized as a method with an increased quality of maintenance. Nevertheless, in order for Preventive Maintenance to be considered efficient and economical for an industry, the presence of appropriately trained personnel, the existence of a properly structured system of recording and information circulation as well as regularly scheduled checks of the machines is necessary [1,6-14].

1.4.4 Predictive Maintenance

The specific maintenance strategy is achieved by using data based on statistica methods (statistical based) or based on data recorded and concerning the current state of the business (condition based). It aims to determine the life time of various materials and components to calculate the time until their replacement, more accurately and to diagnose the actual condition of the equipment. This technique involves systematic monitoring of the equipment to identify the causes that cause a breakdown and then taking the necessary actions to prevent them. Essentially it contains elements of Preventive Maintenance (prevention procedures) and elements of the Damage Restoration method (when the damage is now unavoidable) [1,6-14].

The control of the condition of the various components is carried out using special instruments for monitoring the operation of the equipment and information gathering systems. Specifically, a comparison is made of the various equipment operating parameters, such as lubrication, temperature, pressure and voltage, in relation to the mechanical safety limits of the equipment operation for each parameter, which were set either by the manufacturer or by the the business. The machine enters a duty cycle (Figure 1.3). Thus any problems can be surfaced through frequent inspections and measurements and the remaining useful life of the components is determined. When the readings are close to the set safety limits, extensive analysis of component operation is done to draw safe conclusions [1,6-14].

The most common measuring techniques of Predictive Maintenance for fault diagnosis are the measurement and analysis of vibrations which is carried out mainly in bearings and bearings, the impact pulse method which is also used for prognosis of bearing faults, ultrasonic measurement to detect cracks in equipment, tribology methods for analysis of lubricating oils and the method of thermography [1,6-14].

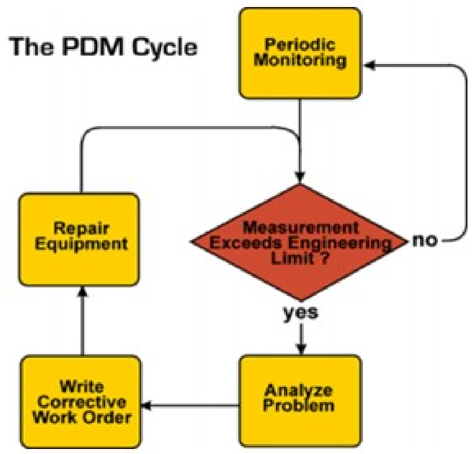

***Figure 1.3:* Preventive maintenance duty cycle [1,6-14].**

The main advantage of implementing Predictive Maintenance is the significant reduction of the time during which the equipment is out of operation, the minimization of cases where failures can prove to be destructive to production as well as the reduction of unscheduled repairs and maintenance. In addition, overall maintenance costs are reduced compared to the aforementioned methods, since control activities are carried out when they are justified and have already been foreseen by the maintenance department. Direct cost savings result from reducing costs from insurance premiums or from reducing the frequency of Preventive Maintenance processes. Thus a greater profit is calculated for the production unit. Besides, this method helps to establish the JIT (Just In Time) policy as far as spare parts are concerned. All this contributes to increasing the efficiency of the production system.

On the other hand, the implementation of Predictive Maintenance requires proper training of the staff in the use of the appropriate machines to fulfill each maintenance process separately, which is a disadvantage of the method. In addition, the costs for the necessary equipment and supplies required for the various measurements are included [1,6-14].

1.4.5 Precision Maintenance

As already mentioned, in recent years a modern method of maintenance has been developed, which is not yet widespread, Precision Maintenance. This particular method aims to correct any defects in the design of the machines that were caused by incorrect handling during their installation or due to a wrong choice of construction materials. Therefore, the direct cooperation of the maintenance department with the design engineer is essential. Precision maintenance is not only aimed at eliminating equipment failures, like previous methods, but at eliminating the causes that lead to the need for maintenance.

A necessary condition for the implementation of Security Maintenance is the existence of a dynamic management unit, which constantly monitors the evolution of the market so as to be able to promote innovative products to meet customer demands. In addition to the correct application of this method, specialized and skilled craftsmen are needed who can identify and solve the mechanical problems related to the design [1,6-14].

1.5 Organization – Maintenance management

Maintenance Organization and Management is a particularly important activity of a maintenance system. Its main objective is the most efficient operation of the system, through the optimization of the planning and organization of the maintenance works, always within a consistent financial framework for the company [1-14].

In general, the Organization Maintenance Management manages elements related to the requirements of the maintenance processes, the spare parts and their continuous control, as well as the equipment in use. She is also responsible for the control and supervision of the maintenance work, with the various workers they employ. All these elements take place at the start of the operation of the equipment. In addition, he has responsibility for overseeing external actors, such as manufacturers, who are directly related to maintenance [1-14].

Based on the results obtained by the Maintenance Organization and Management, new requirements in the maintenance process are assessed as well as continuous designs that will lead to an increase in the efficiency of the system [1-14].

1.6 Planning system organization

Maintenance organization includes work planning, work measurement and project management.

Work planning essentially includes the content of each task and specifies the maintenance method to be followed, the required number of workers, the scheduling of maintenance resources and the appropriate tools needed to perform the tasks.

The next stage that follows is that of work measurement, where the time required to complete each work is calculated.

Finally, project management, which exists mainly in the largest production units, deals with the development of activity networks by applying appropriate techniques (CPM, PERT) through appropriate computer software [1-14].

1.7 Organization systems using CMMS software

The primary objective of a company's maintenance managers is to best apply the information available to them, to achieve the greatest possible efficiency and effectiveness in production. At the same time, maintenance engineers have to manage and process a wealth of data for the planning and scheduling of maintenance processes and when planning the available spare parts of the production unit. Taking into account the iterative nature of most maintenance processes, the use of computer programs in Maintenance Organization Management becomes essential [1-14].

One of the most widespread maintenance organization and management systems using a computer is the CMMS (Computerized Maintenance Management System) and it mainly concerns preventive maintenance methods. This computer system helps to structure maintenance organization more easily and to record and process maintenance information. The CMMS is a continuous database for the maintenance department and contains the characteristics of the maintenance organization design discussed earlier. This makes it easier for maintenance engineers to make decisions and better inform the executives who make up the department [1-14].

2. Description of the Decelia power plant

2.1 Brief description

The Dekelia power station is one of the 3 power stations in Cyprus, together with the Vassilikos and Moni stations, and is the second largest installed station on the island. It is located east of the province of Larnaca in a coastal area controlled by the British bases. It has a total of six gas turbines with a generated power of 60 MW each and six internal combustion engines with a total power of 100 MW [1-14].

***Photo 2.1**: Aerial photo of Dekelia Powerplant [1-14].*

2.2 Powerplant history

The electricity supply of Cyprus until the middle of the last century was done by local electricity production companies in local municipalities, until the English authorities raised the issue of subordinating the island's electricity supply under the public regime. Thus, within the framework of the study that was carried out, the construction of the first power plant in the area of Dekelia began, with the parallel establishment of the state organization of the Cyprus Electricity Authority (ECA). The station was put into operation for the first time in 1953 with fuel oil as the main imported fuel and gradually reached a total capacity of 84 MW. With the operation of the station, the until then private electric companies were expropriated and at the same time, transmission lines were built from the station to all the cities of the island to supply electricity [1-14].

With the independence of Cyprus, another power generating station was established, that of Moni, while the Vassilikos station was created much later, with its first phase operating in 2000.

However, due to the painful events of the Turkish invasion in 1974, the installation of a new power station was deemed imperative (there was no station in Vassiliko until then). It was finally decided in 1980 to build a new power station, again in the area of Dekelia, next to the old station that existed before. The new station was named "Dekelia B". The first phase of the new plant was put into operation in 1982, initially having a unit with a capacity of 60 MW. Gradually, over a period of eleven years, a total of six gas turbine units with a total capacity of 360 MW were installed which are still in operation today. The old station at Dekelia, ("Dekelia A"), was finally demolished in 2002, having been in operation for over thirty years [1-14].

Additionally in the late 2000s, work began on the installation of two internal combustion engines. Specifically, in 2008, a 2 stroke engine manufactured by the Japanese group of companies MITSUI MAN B&W was installed. Finally, in 2010, the construction of a machine with a four stroke cycle engine (4 stroke) was completed with the support of the production company electricity and WARTSILA offshore platforms. The total capacity of the two machines amounts to 100 MW [1-14].

2.3 Organizational structure of the station

The Dekelia station is subdivided into six main departments with a uniform distribution, the Processing and Control Department, the Electrical Department, the Mechanical Department, the Automation and Control Department, the Chemistry and the Statistical Office of the station. The field of maintenance concerns the Electrical, Mechanical Department and the Automation and Control Department [1-14].

The Processing and Control Department is responsible for monitoring and controlling the smooth operation of the plant's machinery, both the steam power unit and the internal combustion engines, as well as for the correct starting or shutting down of the engines when required, under the supervision of the respective shift engineer. The appropriate manipulations are carried out by the department officials in special control rooms. For any failure that occurs, the Processing and Control department is informed by the display of warning signals on computers attached to each machine and notifies the respective department concerned by the failure (electrical, mechanical) [1-14].

The station's Electrical Department deals with the station's electronic applications. In other words, it has as its basic responsibility the continuous supervision and repair of all devices related to electricity. Also, the department is responsible for controlling the flow of electricity in the station, so that the distribution of electricity is done without problems and reaches the consumers without interruption.

The Mechanical Department, which is the largest of the station, is responsible for the proper operation of all the station's machines and is entirely concerned with any mechanical problem that occurs. Essentially, it is the department responsible for the mechanical maintenance of the various mechanical components and the repair of malfunctions that are observed and affect the correct operation of the machines. It consists by the shift engineers, who are responsible for the continuous supervision of the machines, the foremen and various technicians.

Subsequently, the Automation and Control Department is also responsible for matters of installation, maintenance and repair of the technological equipment, as well as for the isolation of electrical networks and the placement of groundings. At the same time, the specific department deals entirely with the installation and calibration of various sensors and measuring instruments [1-14].

There is also a Chemistry Department at the station. The main responsibility of the department is the systematic control of fuel, water in the various parts of the steam generators, lubricating oils and exhaust gases, as well as the chemical cleaning of the equipment. Also the department is responsible for carrying out checks and concentration of hydrazine and ammonia, substances responsible for avoiding oxidation by the remaining oxygen during water transport in the condenser and in the various pipelines. In addition, Chemistry Depatent is responsible for keeping urea CO(NH2)2in a special tank, a substance used to clean the catalysts installed in internal combustion engines [1-14].

Finally, the accounting and statistical office of the station receives all the data of the station and after recording it, processes it and exports it to the various departments of the station. In addition, the accounting office is responsible for recording the quantities of fuel oil supplied to the station as well as measurements related to pollutants, amounts of money available from the station and other statistical data [1-14].

2.4 Operation of the station

2.4.1 Operation of a steam electric unit

The operation of the steam power plant is based on the import of fuel oil, which is supplied by a tanker and through an underground submarine pipeline ends up in six tanks with a capacity of 12000 tons each. The fuel oil is transferred to the pumping station and from there it is transferred to the boilers through the pumps. There are also three pumps that they end up from the tanks to the internal combustion engines. The fuel oil is burned in the boiler through burners (one burner for each boiler) so as to achieve the vaporization of the water. The necessary air for burning the fuel oil in the boiler is supplied by a compression fan, after it has been preheated by the exhaust gases produced during the burning of the fuel oil in a special space called a water preheater. The steam produced in the boiler is then pumped through ducts to the rotor blades of the steam turbine at high speed and high pressure causing the steam turbine to rotate at 3000 revolutions per minute. The steam, after giving all its energy, enters the steam condenser, where it is cooled with large quantities of sea water, to keep its temperature as low as possible, and liquefies. Via a feed pump, the liquefied steam is fed back to the boiler to be vaporized. Thus the cycle of electricity generation repeats itself [1-14].

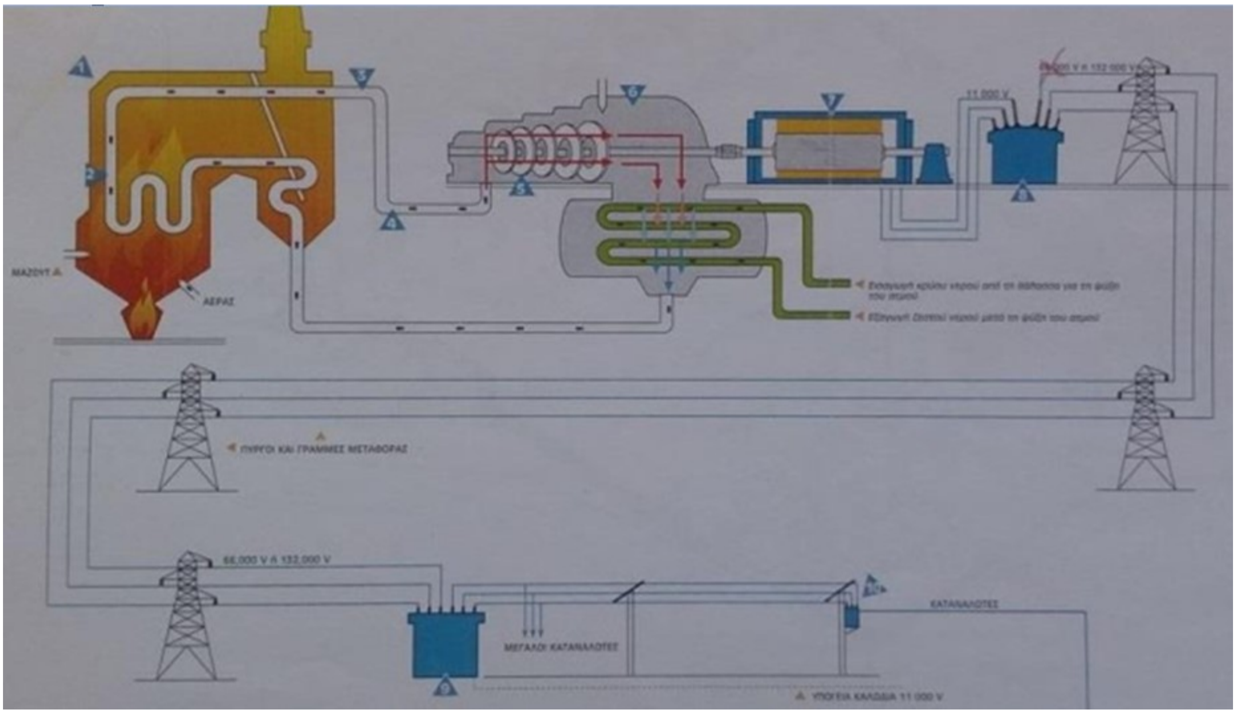

***Figure 2.1*: Explanatory diagram of electricity production in the steam plant until consumption: 1. Hot water 2. Boiler 3. High pressure steam 4. Piping 5. Turbine blades 6. Turbine 7. Generator 8. Step up transformers 9. Step down transformers 10. Step down transformers for consumption [1].**

In turn the turbine transmits the motion to the electric generator which is coupled on the same axis with it. The rapid rotating motion of the generator produces rotating magnetic field resulting in a voltage of 11,000 Volts which is raised with the help of transformers to 132,000 Volts. With the help of other transformers the voltage is reduced to 240 Volts so that the electricity is distributed for consumption purposes [1-14].

2.4.2 Description of a steam electric unit

For the needs of the steam power plant, the station has six boilers manufactured by the Austrian company Waagner Biro. It is of the monotympanic type and has natural water circulation. They produce up to 260 tons of steam per hour at a temperature of 515 °C and a pressure of 88 bar, while the thermal efficiency of each boiler is calculated at 88.7%.

The steam turbines used are single cylinder type with a maximum power of 60 MW and a thermal efficiency of 38.5% and are of Japanese origin.

In addition, to protect the boiler and the various pipes, the station has a water treatment system, so that the water used is of high purity. This system includes stills which are responsible for cleaning the water from microorganisms and harmful salts. Further treatment of the distilled water from salts of magnesium, iron and other salts is done by the station's chemistry [1-14].

There are also three water sieves at the station. The sieves are turned slowly with the help of electric motors, to trap algae and other solid objects and remove them from the seawater intended for cooling the steam in the condenser.

Also as mentioned, fuel oil is stored in six capacity tanks 12,000 tons for each. The tanks have a heating system (coils) to preheat the fuel oil with the help of steam, so that it achieves the required fluidity and is pumped more easily to the pumping station [1-14].

***Photo 2.2*: Fuel oil storage tanks [1-14].**

In addition, the station has a special unit for industrial wastewater treatment. The unit has the ability to process a large amount of liquid waste per hour, with its volume mainly coming from the washing of steam boilers. At the same time, the existence of a special slurry after the fuel oil storage tanks helps to separate and clean the water from the fuel. The use of this water produced by the treatment plant is for irrigation purposes only. In addition, there is also a special outlet channel with a bow which ends in the sea, so as to keep the water at a desired level in case of low tide and also to help maintain the ecology of marine waters [1-14].

To control the various processes for the proper operation of the boiler and steam turbine, there is a special unit control room. This is where the required amount of fuel oil, air and water entering the boiler for combustion is controlled, the temperature and pressure of the produced steam are controlled, as well as meter readings of the unit's main operating parameters are recorded. The above adjustments are made with the help of modern automated machines.

On the other hand, in the control room of the station, the amount of electricity produced and exported from the station is regulated. Appropriate checking and adjustment is done so that the production voltage remains constant at 11,000 Volts and the system frequency corresponding to the consumption demand, at 50Hz. A decrease in this frequency is equivalent to an increase in demand and vice versa, as a result of which the appropriate adjustments are made for a greater loading of the machines and an increase in their load. Outages are handled in the same room, by channeling the generated energy through the balances on the transmission lines [1-14].

Finally, there are the power transformers that step up the generated current to the voltage of 132,000 Volts, to reduce losses during the transfer of current throughout Cyprus. From the power transformers the current is transferred throug busbars and switches to the transmission lines, to be channeled to the consumers. In addition, there are also auxiliary transformers for each sub unit, to lower the production voltage to 3,300 Volts for the use of the station's auxiliaries and in general the station's internal energy needs [1-14].

2.4.3 Operation of internal combustion engines

As already mentioned, a sub unit (ICE 1 – Internal Combustion Engine) with three twot stroke internal combustion engines manufactured by the MITSUI company and a sub unit (ICE 2) with three four stroke internal combustion engines by the WARTSILA company have been installed at the station. Each sub unit has a total generated power of approximately

50 MW (17 MW for each machine). The total thermal efficiency of the two internal combustion units is around 41% [1-14].

Each four stroke engine (ICE 2) consists of eighteen cylinders and is of V type configuration. The operation of the four stroke engine of the engine is based on the thermodynamic cycle of Diesel where the fuel self ignites in the combustion chamber without the existence of a spark. The four stroke engine of the machine follows four phases of operation or times that is a stroke of the piston from the top dead center to the bottom dead center of the crank and they are as follows [1-14]:

• Suction stroke where the fuel mixture (fuel oil or crude oil) enters the combustion chamber through the open intake valve.

• Compression stroke, where the piston moves to top dead center with closed valves raising the air temperature above that of fuel ignition. At the end of the compression time, the fuel is ignited with the help of an injector.

• Power stroke as a result of the combustion of the air mixture fuel and project production. The valves remain closed while the pressure due to combustion pushes against the piston head.

• Exhaust stroke, where the piston has reached bottom dead center and rises to upwards, pushing the exhaust gases and forcing them out of the cylinder through the open exhaust valve [1-14].

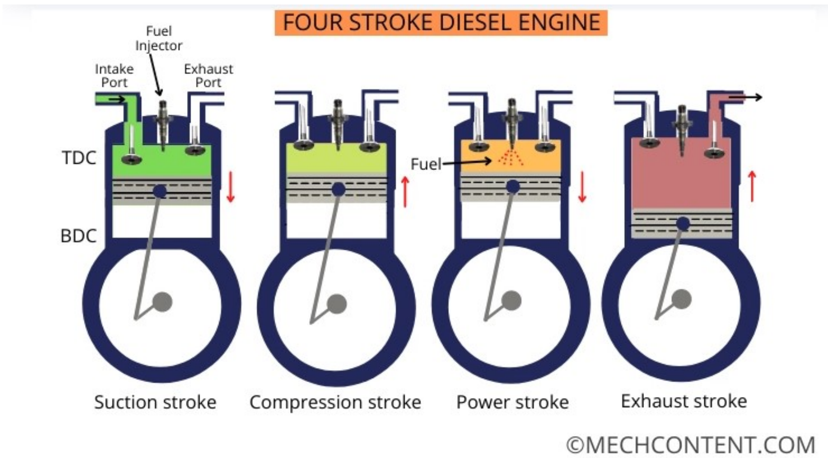

Figure 2.2: Operation of four stroke engines [1-14]

In contrast, the engines of the ICE 1 subunit are based on the operation of the two stroke cycle. They are designedfor starting, running and stopping in the use of heavy fuel oil. Each machine ait consists of twelve cylinders which are arranged in a row. Their operation relies on a single rotation of the crankshaft to complete of the cycle, i.e. in two piston times. Two stroke engines are mechanically simpler than four stroke engines, but they take up much more space [1-14].

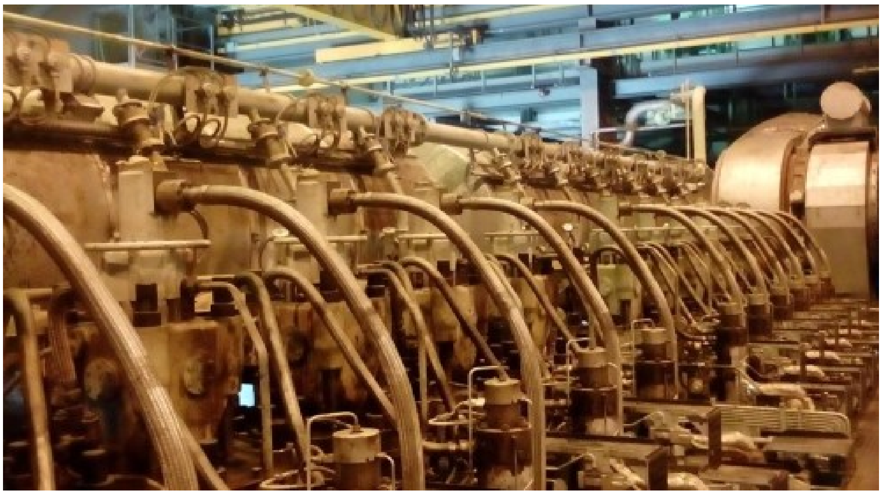

Photo 2.3: Two stroke engine cylinders arranged in series with intake pumps [1]

During compression the engine turns with external assistance and the piston rises. During compression, a vacuum is created in the combustion chamber. The pressure drop results in the opening of the intake valve through which air is introduced into the combustion chamber which is drawn in. When the piston changes its direction of motion and begins to descend, the valve closes and then the expansion in the combustion chamber begins and the mixture is compressed at the base. The piston continues to move revealing the two doors, the bypass and the exhaust, causing a small portion of the mixture to escape. The crank continues its idle rotation, the piston rises closing the two doors, thus compressing the mixture, repeating the first phase of the cycle. The gases are released by pushing the piston down. The engine is now started and can repeat the next cycle on its own without the help of external factors. Again the same process follows, where the piston moves down, the exhaust door opens and immediately after the transfer door, the pressure on the piston decreases and the compressed air enters the cylinder, pushing the rest of the exhaust gases out.

2.4.4 Structure of internal combustion engines

Apart from the operation mode of the two stroke engine which is simpler than that of the four stroke, their structure is very similar and their main difference lies mainly in the volume and arrangement of their cylinders and the accessory machines that make them up.

In both the two stroke and the four stroke engine, its main body consists of the cylinder body and its cylinder head. The cylinder body is made of cast iron and in its lower part forms the crankcase and the oil sump, a reservoir where the lubricating oil is pumped. In the two stroke engine, this tank is not attached to the cylinder but is an independent body. Along the cylinder body is the camshaft, which helps to open and close the valves, depending on the stage of the cycle the engine is in. Through a suitable device the camshaft is connected to the crankshaft. The valves are located in the cylinder head [1-14].

Next, in the cylinder body is the combustion chamber. The ratio of combustion chamber volume to piston displacement volume, which is swept on each piston stroke, determines the compression ratio. The compression ratio plays a large role in the theoretical cycle efficiency of the engine.

Next comes the Main Cinematic Mechanism (Piston, Conn Rod, Crank) and consists of the ~~piston,~~ piston and crankshaft. The piston has the form of an inverted cup, is made of steel and receives the force of the exhaust gases. The piston or connecting rod connects the piston to the crankshaft and converts the piston's reciprocating motion into rotary motion. Finally, the crankshaft is connected to the piston by a pin and its position is proportional to the firing order of the cylinders [1-14].

 

Photo 2.4: ***a)Piston system and b)Piston [1]***

The third system concerning the operation of two stroke and four stroke engines concerns the mixture creation system and consists of the carburettor and the injection pump. A carburetor is a device that introduces fuel into a stream of air as it enters the engine. The air stream enters through a scavenging air receiver pump from the turbocharger. By means of a float, the fuel level is maintained at a desired level. Once the air is forced into the cylinders, it begins to accelerate creating a vacuum which causes the fuel to be injected from the injector.

In addition to the three main structural operating systems, the station's two stroke and four stroke engines are also made up of auxiliary devices. The first of these has to do with the fuel ignition system. This system consists of pumps with the corresponding distribution system and ends at the fuel injection injectors (injectors). The injectors are electromagnetic and are exposed to the high temperatures and pressures that take part in the combustion chamber. They have properly shaped nozzles to inject and disperse the fuel in the combustion chamber [1-14].

As in the case of the operation of the steam electric unit, there is also a flexible coupling that connects the engine to the generator. Each generator produces a voltage of 11,000 Volts at a frequency of 50 Hz [1-14].


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Photo 2.5: ***Injector to Maintenance Department for cleaning [1-14]***

The auxiliary equipment also includes the turbocharger. As the engine speed continues to increase, the power reaches a maximum value, resulting in a reduction in the intake of air into the engine. Thus, at speeds above the limit, the air supply is reduced in each engine cycle, resulting in a limitation of the system's performance. To overcome this disadvantage at high engine speeds, the turbocharger is introduced which helps to increase the pressure and amount of air entering the cylinder. Its operation is based on the movement of a centrifugal blower through a gas turbine. Six turbochargers are available at the station, one for each sub unit of ICE 1 and ICE 2 respectively [1-14].

On the contrary, during the operation of the engine at low revolutions, during its start a special air blower (motor air blower) is used until the engine reaches 177 revolutions and coordination is achieved. It should be mentioned that compressed air is used as an energy means for starting the machines with a function based on a pneumatic system [1-14].

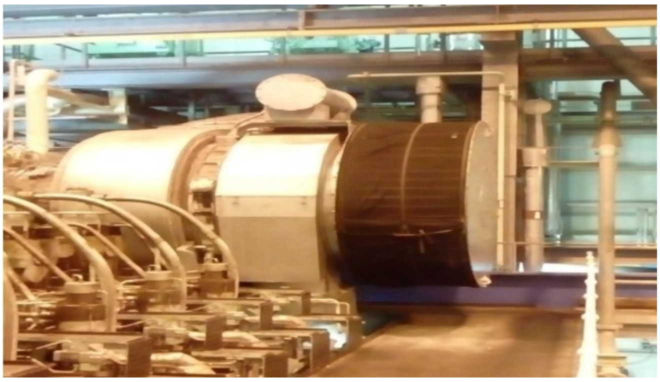


***Photo 2.6*: Turbocharger in ICE 1 [1-14]**

Necessary for the smooth operation of engines is the existence of a cooling system. The water, after first passing through the sieves of the station for cleaning and then through a system of filters with ultraviolet radiation (UV) for further microbial disinfection of the water, ends up in special coolers which are located around the engine. Because the engines are liquid cooled, they release heat with the help of water and transfer it to the radiators, while a thermostat in the cylinder liners keeps the temperature constant [1-14].

***Photo 2.7*: Cooling water heat exchanger (plate type) [1-14]**

There is also the lubrication system (lub oil system) which serves to reduce friction. The lubrication system is fed from the oil tank and by means of a pump it is pushed into a pipeline system and from there it reaches the crankshaft under pressure. Through special holes in the crankshaft, the oil is ejected and wets the walls of the cylinders, the cams and the pistons and even the piston pins. Mandatory lubrication ensures the safe lubrication of all moving parts of the engine while also providing a means of cooling for the engine. In the two stroke engines there is also a special lubrication system in the cylinders (cylinder oil) [1-14].

The auxiliary equipment also includes the fuel treatment system, which includes special separators and feed pumps. Separators are responsible for cleaning fuel oil and removing various impurities from it. The fuel is channeled from the fuel storage tanks through the feed pumps. Special separators are also available for cleaning the cooling water [1-14].

Photo 2.8: a. Fuel oil and b. Water separators [1]

The exhaust system is located on top of the cylinders, which consists of a silencer to dampen vibrations, exhaust the exhaust gases more smoothly and reduce the noise produced. Special catalysts have been installed in the muffler to control exhaust emissions and reduce unburned hydrocarbons and nitrogen oxide, substances that are harmful to the environment. The produced ash, after being processed by the catalysts, ends up in the station's chimneys where it exits into the environment. In fact, special German made catalysts have recently been installed in the engines of the ICE 1 substation, in order to treat the produced exhaust gases and reduce pollutant emissions within the framework of the relevant legislation of the European Union [1-14].

***Photo 2.9*: Arrangement of the catalyst with a resistance structure at the ICE 1 substation [1]**

3. Maintenance procedures in internal combustion units

3.1 Station'smaintenance methodology

Based on the current situation in the two internal combustion units at the station, the maintenance methodology applied is a form of preventive maintenance, due to the planned organizational chart set by the station, with elements of preventive maintenance on certain components of the engines that require appropriate measurements and comparisons with fixed standards. In particular, a total general maintenance (overhaul) is carried out for the three engines of the ICE 1 substation every 36,000 hours of their operation, based on a maintenance statute that has guidelines from the manufacturers of the engines, specifically from BWSC (Burmeister & Wain Scandinavian Contractor), a company that cooperates with MITSUI MAN B&W. At ICE 1 substation in addition to the general maintenance carried out on each twot stroke engine, it is not considered necessary to carry out any maintenance action concerning the engine until it completes 14,000 hours of operation, except for some standard checks that are carried out. In contrast, at the four stroke engine substation, in addition to the general maintenance that is carried out every 12,000 hours of operation, based on a statute issued by the WARTSILA company, maintenance procedures concerning the engine and its individual components are carried out at specific time intervals regardless of the planned their general maintenance. This is due to the fact that two stroke engines are simpler and more efficient than four stroke engines, so no maintenance other than general scheduled maintenance is required [1-14].

As regards the auxiliaries that make up the machines, scheduled maintenance procedures are carried out at regular intervals, with each element requiring a separate maintenance management statute, unless an unexpected breakdown occurs, in which case immediate maintenance is carried out. Scheduled general maintenance is carried out for all six steam turbine units separately, under the supervision of their respective manufacturing companies.

In addition to general maintenance, for any action that mainly concerns some planned or unexpected repair, the shift engineer in charge, after first assessing the given situation, issues the relevant work permit certificate. Essentially, it is an official document used to control specific types of activities that involve risks and to assess those risks. Specifically, the work to be done, the necessary precautions to be taken and above all to ensure that the work system will be completely safe and that the machines on which the repair and maintenance activities will be carried out have been shut down or isolated. Also, the authorized personnel must be aware of the risks and the safety measures required for the execution of the work. Each certificate has a license number, the location of the activity and a description of it. Upon signing the certificate, the responsible engineer keeps the copy until the work is completed, where he removes the isolation [1-14].

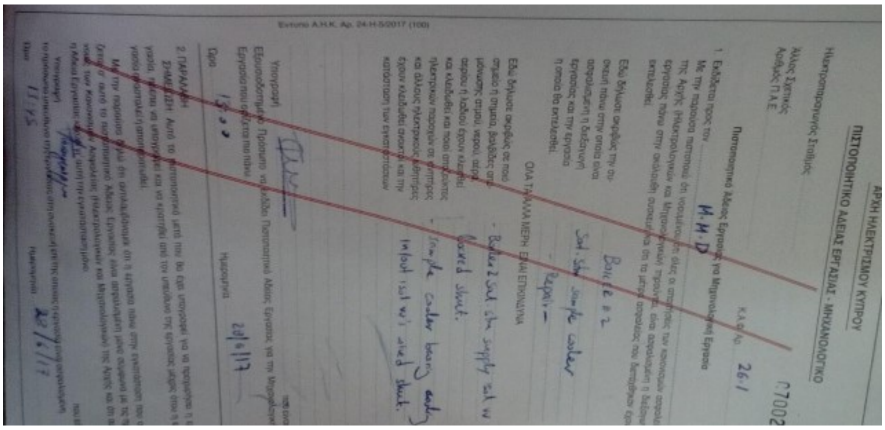


Photo 3.1: Example of work permit certificate [1]

3.2 General maintenance on the ICE 1 subunit

3.2.1 General reference

ICE 1 general maintenance was scheduled after 14000 hours of operation unit from the moment it was installed and put into operation. The supervision of the maintenance was entirely undertaken by the BWSC company, due to the inexperience of the station staff in this type of engine maintenance. The next scheduled maintenance of ICE 1 will again be supervised by BWSC officials, but with station personnel taking on more responsibilities than the first general maintenance performed. The long interval between the second and the first general maintenance is due to the fact that the entire ICE 1 subunit was taken out of service for quite a long time, almost the whole of 2013, due to the processes carried out to install modern and more compatible catalysts with environment. The operation of each two stroke engine is estimated to average around 6500 operating hours per year, which corresponds to 18 operating hours per day [1-14].

BWSC issued a detailed report on the progress of the maintenance, the personnel deployed and the results obtained. Initially a brief report was made by BWSC with general elements of the maintenance. The duration of the maintenance of the three two stroke engines was recorded, the maintenance equipment was recorded, the tasks were distributed and some general observations made at the end of the maintenance were recorded. In the main part of the report, the division of tasks was recorded and a detailed description of each maintenance process was made for each piece of engine equipment. At the final stage of the report, suggestions were recorded from BWSC to the managers of the power plant on maintenance issues concerning the three two stroke engines [1-14].

The maintenance concerned only the ICE 1 sub unit of the Dekelia station. The total time allotted for general maintenance of the engines was twelve days and an additional two days for checking the operation of the engines and painstaking correction. The exact time and date maintenance was started and completed was recorded, as well as the exact time each engine was restarted.

During the maintenance, a daily report was sent to the station management to inform them about the progress and progress of the maintenance. Communication with EAC management was done through the responsible technician and the day shift assistant engineer of the station.

Upon completion of maintenance, a full report of all work carried out, including all measurements, as well as engine load performance before and after general maintenance was recorded. Also attached was a program to reduce cylinder and ring lubrication for their operation on the new piston.

According to BWSC, the components removed from the engine were found to be in very good condition, with minimal wear on some cylinder liners, which will be detailed below. All components removed from the engine were cleaned, measured to owner's manual guidelines, and inspected so that they would be able to last until the next overhaul. Any parts of the engine found to be worn beyond the recommended limits were replaced with the corresponding spare parts. Also, all measurements ang calibrations taken were recorded both electronically and in hard copy [1-14].

3.2.2 Equipment description

The data regarding the manufacturers, type and codes regarding the two stroke engines along with some auxiliary data for their operation are given below [1-14]:

- Diesel Engine Manufacturer:Mitsui- MAN B&W
- Diesel engine type:12K50MC S
- Serial number:5501

- Date of installation:2008
- Turbocharger Manufacturer:MAN B&W
- Type of turbocharger:TCA88 20048
- Serial number:4061
- Roll Lubrication System Manufacturer:Hans Jensen
- Type of roller lubrication system:MARK 7
- Generator manufacturer:Maiden
- Generator type:TICB AF
- Serial number:IC7071RJ1
- Unit opening hours:14001

3.2.3 Personnel and labor division

In total, for the needs of maintenance, BWSC provided two supervisors, a responsible engineer and a mechanical engineer as well as ten installation engineers technicians from two of its subsidiary companies, BWSC Lanka and APOM. On the other hand, the EAC's Dekelia station provided significant assistance to technicians and assistant technicians to fulfill the required tasks. In addition to,the on site shift engineer of the power plant had supervisory duties.However, due to the large number of technicians present during the general maintenance and due to their constant rotation, it was difficult to record the exact number of technicians available. The main objective was to acquire, if possible, all workers experience in matters of general maintenance and repairs, because such a general maintenance procedure on internal combustion engines was carried out for the first time at the station. The station also allocated five cleaners for each shift under the supervision of BWSC.

The work was divided into two shifts with a duration of ten hours for each. The first shift (shift A) started from 06:00 until 14:00 while the second shift (shift B) from 14:00 until 24:00. An overlap of two hours between shifts was often made for the purposes of easier flow and delivery of work. All in all there was one day φree for each worker during the week so that there is time to rest while general maintenance is being carried out.

As mentioned, due to the inexperience of the staff at the station, the general supervision of the execution of the maintenance procedures was taken over by the BWSC. However some work was left entirely to station staff always under the supervision of BWSC engineers in charge, such as general maintenance of fuel pumps, grinding of cylinder liners and machining of exhaust valve seats [1-14].

In particular, the provision of three technicians and three assistants from the power station was arranged for the general maintenance of the 12 fuel pumps of each engine separately, under the close supervision of a BWSC staff member.The total duration of the works lasted eight working days, as can be seen in the relevant table and they were completed during the day. The immediate objective was to enable station employees to be trained in maintenance issues related to general fuel pumps. For this reason, the station management took the opportunity to train almost all the craftsmen at its disposal for this work. However, the station managers felt that some technicians should be busy with other repair work on the engine and its adjacent components, for this reason an order was given to speed up the procedures for repairing the fuel pumps. Thus five more technicians and assistants were rushed at regular intervals to complete the repairs of the fuel pumps.

Also, EAC authorized technicians undertook the general maintenance of the fuel valves that had been removed from the engine, cleaning their individual components checking and adjusting their correct operation and opening pressure.

As for liner grinding, two engineers were made available from the station during the morning shift to carry out the engraving, grinding and grinding of the cylinder liners under the supervision of BWSC. He took over the night shift to complete the grinding work on the cylindrical sleeves BWSC staff member.

Depending on their availability, one or two mechanics were used to machine and repair the exhaust valve seats and their stems during the morning shift under the supervision of the BWSC. There were times when workers worked extra hoursto cover work that involved machining the rear of the exhaust valve seats. By periods ehelper was provided by BWSC during the night shift to repair exhaust valve seats and stems.

It should be noted that the provision of all consumable parts required for the repair of the engine and its individual components was the sole responsibility of the Dekelia station.

According togeneral organizational chart issued by BWSC all processes of general maintenance took fourteen working days not including weekend days. Next, detailed data are given of the maintenance processes that took place according to the appropriate sequence and succession of these tasks and their distribution to the technicians of the morning shift, the technicians of the night shift and the assistants cleaners, so as to study the case of saving time of general maintenance (See Table 3.1)

In the program, 20 working hours were considered for each day with the collapse of the two shifts and a start date of 13/2/2012. Listed are a description of the tasks, the duration of the working hours of each task (work), the execution hours of each task (duration), the day the work began (start), the day it ended (finish) and the specialty with the number of workers required for the execution of each task (resource names). The program was divided into **seven** main projects with their sub projects [1-14].

Based on the data for the description and duration of the maintenance tasks, the table 3.1 was constructed, showing the exact number of days required to complete the maintenance tasks and their allocation to the relevant department [1-14].

Task Name	**Work**	**Duration**	**Start**	**Finish**	**Resource Names**
START	0 hrs	0 hrs	Mon 13/2/12	Mon 13/2/12	

Disassembly parts	**320 hrs**	**26 hrs**	**Mon 13/2/12**	**Thu 16/2/12**	
Pipe Disassembly 1-12	20 hrs	5 hrs	Mon 13/2/12	Mon 13/2/12	Morning Shift Technitians (4)
Storage and Air Receiver Cover Removal	5 hrs	5 hrs	Mon 13/2/12	Mon 13/2/12	Morning Shift Technitians
Removal of cylinders covers 1-12	25 hrs	5 hrs	Mon 13/2/12	Tue 14/2/12	Morning Shift Technitians (5)
Cleaning storage area and air receiver	100 hrs	10 hrs	Mon 13/2/12	Tue 14/2/12	Assistants-cleaners (10)
Removing pistons	24 hrs	6 hrs	Tue 14/2/12	Tue 14/2/12	Night Shift Technitians (4)
Disassembly of pipes from fins	10 hrs	10 hrs	Wed 15/2/12	Thu 16/2/12	Night Shift Technitians
Pulling out the liners	16 hrs	4 hrs	Tue 14/2/12	Tue 14/2/12	Assistants-cleaners
Engine block and fuel pump base cleaning	50 hrs	10 hrs	Wed 15/2/12	Thu 16/2/12	Night Shift Technitians (5)
Fuel pump removal	40 hrs	10 hrs	Mon 13/2/12	Tue 14/2/12	Morning Shift Technitians (4)
Cleaning fuel pump base and perimeter	30 hrs	10 hrs	Tue 14/2/12	Thu 16/2/12	Assistants-cleaners (3)
General liner maintenance	**270 hrs**	**50 hrs**	**Tue 14/2/12**	**Wed 22/2/12**	
Removal of lining sleeves	10 hrs	10 hrs	Tue 14/2/12	Wed 15/2/12	Morning Shift Technitians
Cleaning liners	70 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Assistants-cleaners (7)
Measurement of liner diameters	20 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Night Shift Technitians-Morning Shift Technitians

Grinding of liners	120 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Morning Shift Technitians (6) Night Shift Technitians (6),
Assembly of liners and fins	10 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Night Shift Technitians
Painting cylinders and cooling liners	10 hrs	10 hrs	Tue 21/2/12	Wed 22/2/12	Assistants-cleaners (4)
General maintenance of cylinder heads	**140 hrs**	**46 hrs**	**Tue 14/2/12**	**Tue 21/2/12**	
Disassembly of cylinder heads	40 hrs	10 hrs	Tue 14/2/12	Wed 15/2/12	Night Shift Technitians (4)
Cleaning of cylinders heads	40 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Assistants-cleaners (4)
Grinding pockets in cylinder head valve seats	40 hrs	10 hrs	Wed 15/2/12	Thu 16/2/12	Night Shift Technitians (4)
Installation of cylinder cooling covers	20 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Night Shift Technitians (2)
Maintenance of exhaust valves	**380 hrs**	**64 hrs**	**Wed 15/2/12**	**Mon 27/2/12**	
Disassembly of exhaust	20 hrs	10 hrs	Wed 15/2/12	Thu 16/2/12	Night Shift Technitians (2)
Exhaust valve cleaning	80 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Assistants-cleaners (8)
Exhaust valve stem grinding	20 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Night Shift Technitians (2)
Exhaust valve seat grinding	20 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Night Shift Technitians (2)
Measurement of shaft and bearing diameters	10 hrs	10 hrs	Tue 21/2/12	Wed 22/2/12	Night Shift Technitians
Cylinder air	5 hrs	5 hrs	Thu	Fri	Night Shift Technitians

measurement			16/2/12	17/2/12	
Hydraulic measurement cylinder	5 hrs	5 hrs	Fri 17/2/12	Fri 17/2/12	Night Shift Technitians
Replacement of seals	20 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Night Shift Technitians (2)
Maintenance of safety valves	10 hrs	10 hrs	Wed 15/2/12	Thu 16/2/12	Night Shift Technitians
Exhaust Valve extraction	40 hrs	10 hrs	Thu 23/2/12	Fri 24/2/12	Night Shift Technitians (4)
Maintenance of air starter valves	40 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Night Shift Technitians (4)
Valve maintenance indication/relief	40 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Night Shift Technitians (4)
Installation of starting and indicator valves	10 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Night Shift Technitians
Installation of exhaust valves on the cylinder heads	20 hrs	10 hrs	Fri 24/2/12	Mon 27/2/12	Night Shift Technitians (2)
Paint exhaust valve housings	40 hrs	10 hrs	Fri 24/2/12	Mon 27/2/12	Assistants-cleaners (4)
Maintenance of fuel pumps	**285 hrs**	**51 hrs**	**Tue 14/2/12**	**Thu 23/2/12**	
Disassembly of fuel pumps	20 hrs	10 hrs	Tue 14/2/12	Thu 16/2/12	Morning Shift Technitians (2)
Cleaning fuel pumps	120 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Assistants-cleaners (12)
Valve maintenance suction	20 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Morning Shift Technitians (2)
Maintenance of drilling valves	20 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Morning Shift Technitians (2)

Damper maintenance vibrations	5 hrs	5 hrs	Thu 16/2/12	Thu 16/2/12	Morning Shift Technitians
Valve assembly suction/drilling	20 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Morning Shift Technitians (2)
Assembling fuel pumps	40 hrs	10 hrs	Wed 22/2/12	Thu 23/2/12	Morning Shift Technitians (4)
Inspection of guide rollers- Change of seals in holes	40 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Morning Shift Technitians (4)
Piston Maintenance stuffing boxes	**380 hrs**	**30 hrs**	**Wed 15/2/12**	**Mon 20/2/12**	
Disassembly of pistons and stuffing boxes	40 hrs	10 hrs	Wed 15/2/12	Thu 16/2/12	Morning Shift Technitians (4)
Cleaning pistons and stuffing boxes	220 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Assistants-cleaners (22)
Piston diameter measurement	20 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Morning Shift Technitians (2)
Assembling pistons	40 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Morning Shift Technitians (4)
Stuffing box ring diameter measurement	20 hrs	10 hrs	Thu 16/2/12	Fri 17/2/12	Morning Shift Technitians (2)
Assembly of stuffing box rings	40 hrs	10 hrs	Fri 17/2/12	Mon 20/2/12	Morning Shift Technitians (4)
Install items	**675 hrs**	**73 hrs**	**Mon 20/2/12**	**Fri 2/3/12**	
Placement of liners	20 hrs	10 hrs	Tue 21/2/12	Wed 22/2/12	Night Shift Technitians (2)
Connection and control of oil	20 hrs	10 hrs	Thu 23/2/12	Fri 24/2/12	Morning Shift Technitians (2)

vanes					
Installing pistons	20 hrs	10 hrs	Thu 23/2/12	Fri 24/2/12	Morning Shift Technitians (2)
Piston rod tightening telescopic tube installation	20 hrs	10 hrs	Fri 24/2/12	Mon 27/2/12	Night Shift Technitians (2)
Stuffing box tightening	20 hrs	10 hrs	Mon 27/2/12	Tue 28/2/12	Morning Shift Technitians
Placement of cylinders heads	40 hrs	10 hrs	Tue 28/2/12	Wed 29/2/12	Night Shift Technitians (3) Morning Shift Technitians
Assembling pumps connections	50 hrs	10 hrs	Wed 29/2/12	Thu 1/3/12	Night Shift Technitians (5)
Check cooling water lubricating oil and fuel for leaks	40 hrs	10 hrs	Thu 1/3/12	Fri 2/3/12	Morning Shift Technitians (4)
Upper part cleaning machine	220 hrs	10 hrs	Mon 20/2/12	Tue 21/2/12	Assistants-cleaners (22)
Crank cleaning	100 hrs	10 hrs	Wed 29/2/12	Thu 1/3/12	Assistants-cleaners (10)
Safety device check	10 hrs	5 hrs	Thu 1/3/12	Fri 2/3/12	Morning Shift Technitians (2)
Final inspection before starting	10 hrs	5 hrs	Thu 1/3/12	Fri 2/3/12	Morning Shift Technitians (2)
General cleaning of engine and accessories	120 hrs	10 hrs	Wed 22/2/12	Thu 23/2/12	Assistants-cleaners (12)
End	**0 hrs**	**0 hrs**	**Fri 2/3/12**	**Fri 2/3/12**	

Table 3.1: Detailed descriptionof Tasks, specialties and duration [1]

According to the table 3.1, the maintenance processes had a total duration of 15 days, since they ended on 2/3/2012. This result is in line with the organizational chart provided to the station by BWSC which had a duration of 14 days. This reduction is due to the collapse of some processes and the employment of more workers than the planned number to complete certain tasks, for reasons of specialization and gaining further experience.

3.2.4 Description of general maintenance work

In this section will be described the maintenance procedures performed on the engines and their individual components, in the order in which they must be performed, according to the specific manual of the ICE 1 unit. As aforementioned, overhaul of each component includes its disassembly, cleaning, continuous inspection, measurements and replacement of seals and worn elements when deemed necessary [1-14].

Maintenance on cylinder heads and valves [1]

- Remove the cylinder heads from the engine and transport loading them in the space
- Cleaning and inspection of the water cooling area after removing the cooling jackets.
- Inspection and crack control of all cylinder heads (non destructive testing color testing)
- Inspection and grinding of all sealing surfaces on the covers of cylinders for all valves.
- Disassembly and general maintenance of fuel valves.
- Disassembly and overhaul of all starter valves.
- Disassembly and overhaul of all indicator valves and valves security
- Inspect the combustion chamber for burning or damage.
- Installation of a cooling system with new O rings.
- Reinstall the repaired valves in the cylinder heads
- Installation of cylinder heads on the engine

Overhaul of exhaust valves [1]

- Disassembly of all valves from the cylinder covers and cleaning all parts.• Inspection of valves and seats, checking the passage of exhaust gases from the valves extraction and checking of the fins for wear and correct placement.

- Grinding of all exhaust valve seats and spindles.
- Measurements of all axles and seats after grinding.
- Check seats and spindles for cracks using the color check method.
- Replacement of defective/worn valve seats or stems.
- Exhaust Valve Hydraulic Actuator Overhaul Measurement wear of the cylinder ring and piston rings.
- Replacement of all seals and overhaul of the pneumatic piston.
- Measure the bore of the pneumatic piston and spindle guide ring.
- Overhaul of high pressure exhaust valves.

General maintenance of pistons [1]

- Remove pistons from the engine and transfer them to the loading area.
- Inspect the pistons and rings before removing the rings from the pistons.
- Cleaning and pressure control of the crowns on the top of the pistons and replace the piston crown if required.
- Cleaning, inspection and measurement of piston crown burnout, height of the ring groove and the thickness of the chromium layer.
- Cleaning, inspection and measurement of piston rods.
- Overhaul of piston stuffing boxes, replacement of rings scraper, sealing rings and sheets on scraper rings when necessary.
- Inspection of the housing ring mounting area on the gearbox filling and replacement of casings where wear has been observed with spares when required
- Checking the springs in each stuffing box and measuring the length under load based on the instructions in the manual.
- Measure the distances between the sealing rings and the bushings scraper with the casings of the stuffing boxes.
- Introduction of identification numbers on crowns, filling boxes and piston rods for component identification purposes.

• Installing pistons in the engine.

Overhaul of cylinder liners [1]

• Removing the cylinder liners (sleeves) from the engine and transporting them in the loading area.

• Inspection of the running surfaces (walls) of the sleeves before cleaning their.

• Measuring and recording the cylindrical bore of the sleeves before and after grinding.

• Regular control of the sleeves during their grinding. Inspection and measurement of roughness of the sleeve surfaces after grinding.

• Cleaning the cooling water space of both the linings and the cooling jackets.

• Extensive cleaning of the sleeves after grinding.

• Replacement of sealing rings for the water cooling jackets and their installation.

•Measuring the piston rings after their extensive cleaning.

•Identification of the identification number of the sleeves with the identification numbers of crown rings for grouping and proper reinstallation.

•Cleaning the scroll oiler fins by blowing with air and fitting the in the cylindrical sleeves.

•Installation of sleeves on engines.

***Photo 3.2**: Removal of cylinder liners from the initial engine to be transferred to the loading area [1]*

Replace fuel pumps [1]

- Removing the fuel pumps from each engine and transporting them to the site loading.
- Dismantling the cylinder covers, cleaning and repairing them.
- Overhaul of all suction and drill valves and reassembling them with new seals.
- Overhaul of all suspensions.
- Grinding of high pressure pump seats, when necessary.
- Overhaul of all pistons, barrels and VIT.
- Inspect the piston and barrel branches for signs of corrosion / cavitation.
- Inspect plug screws for slot markings.
- Overhaul of sealing caps and assembly of all pumps fuel.
- Inspection of the pump guide cylinder #1 for training purposes.
- Install all fuel pumps on the engine.
- Setting the index VIT and the fuel pump indicator to achieve engine balance.

Crankshaft check [1]

- Recording of crankshaft distortion, before and after repair.
- Inspection of all component locking devices after maintenance.
- Cleaning and inspection of the crankcase.

Air receivers [1]

- Clean and inspect the air receiver.
- Cleaning and checking of temporary storage areas.
- Inspection of air receiver check valves.

Water cooler [1]

- Replace the supply air cooler with the no4 after installing the spacers and longer screws according to the maintenance manual.

Adjustment of oil cylinders [1]

- Check and adjust the lubricants to achieve the correct feed rate during operation.

Cleaning the engine and electrical installations [1]

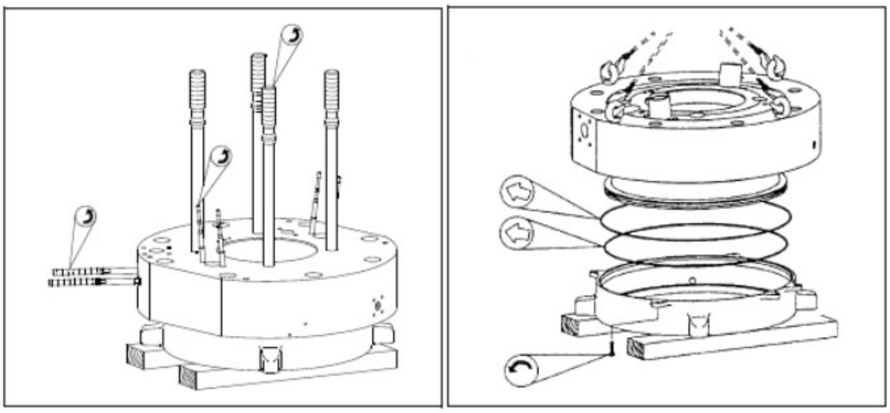
- Cleaning the motor and electrical current flow facilities for presentation of the installation in a clean condition after the completion of the maintenance work.

3.2.5 Detailed description and observations during miscellaneous maintenance parts

The sequence and procedures for performing the work were carried out in accordance with the instructions of the maintenance manual for the unit of ICE 1, as described in the previous section. The following is a breakdown of the maintenance procedures performed for each individual component of the three engines [1-14].

3.2.5.1Cylinder Heads

Firstly, the maintenance procedures began for the Cylinder Heads of the twelve cylinders corresponding to each engine. All the cylinder heads were disassembled from the engines after first removing all the valves from them by performing a thorough cleaning and inspection. The four screws securing the water cooling jacket to the cylinder caps were then removed to release the water cooling cases so they could be cleaned. The cylinder caps were lifted with a hook to make a quick inspection of their combustion chambers, where no abnormality was observed. They were then taken to the maintenance area for closer examination and correction [1-14].



<u>Figure 3.1</u>: a. Valve disassembly from cylinder head , and b.Water cooling jacket removal [1]

An NDT test was then performed, with dye penetration into the cooling shroud sealing area of all cylinder heads, with no cracks detected. The fuel valve mounting holes were cleaned and small pieces of metal were observed near the holes on some of the cylinder heads. These were smoothed by grinding, using a carbon cutter. They were then checkedvalve bearing surfaces and restored by lapping. There were no signs of damage or failure to any of the valve seats. Also cleaned the cooling paths from the holes in the exhaust valve locations. The combustion chamber was inspected for any burns due to fuel spray on the cylinder metal surfaces. All the cooling water housings were put back with new O rings and the cylinder heads were reinstalled with new soft iron gasket [1-14].

3.2.5.2 Fuel injectors

All fuel injectors were taken to the power plant workshop for careful examination and correction. BWSC staff took responsibility for the maintenance of the fuel valves because station staff were busy preparing for the overhaul of ICE 2 (separate from the ICE 1 overhaul) and they were extensively pressure tested. According to the BWSC report, the No. 3 regulated fuel valve that has been repaired and kept in standby condition was installed in the cylinder heads with new O rings. The No. 1 fuel valve that had been removed from the first diesel engine was maintained fully and kept as a spare after checking the pressures when it was opened HIP compound type and can run up to 16000 hours of operation before withdrawal [1].

3.5.2.3 Starting air valves

After being removed from the cylinder heads, the air starter valves were disassembled, cleaned and inspected. To disassemble them, first the top cover fastening screws with nuts were unscrewed, and then the cooling jacket. Then the piston, spacer tube, valve spring, protective sleeve and O ring were removed to leave the requested starting air valve and cleaned. No blowout damage was observed [1-14].

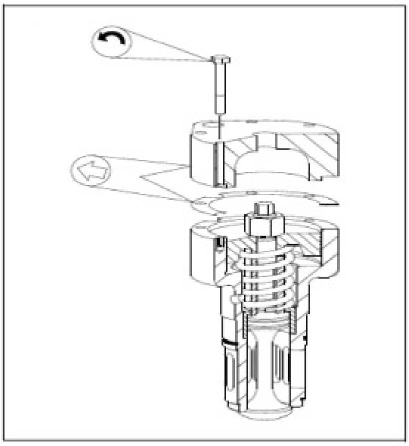


***Figure 3.2**: Starting air valve disassembly [1]*

The valve bearings were then sanded using a sanding ring, after first being coated with sanding paste. All internal parts of the bearings (sliding surfaces) were also lubricated. The sealing surfaces were welded together to restore a good overall sealing surface. The valves were assembled with new gaskets (specifically O rings) and seals as needed and fitted to the cylinder heads. All valves were stamped with identification numbers. Finally all the previously removed pieces were reinstalled along with new o rings and a new gasket [1-14].

3.2.5.4 Indicator valves

After removing them from the cylinder heads, the indicator taps (valves) were disassembled, cleaned and inspected without any blow by or other damage being observed. The surface seals were welded together to achieve a good sealing surface. The faucets were assembled with new gaskets and seals, depending on their needs and were assembled on the cylinder heads [1-14].

3.2.5.5 Safety valves

After removing them from the cylinder heads, the safety valves were disassembled, cleaned and inspected. In this case too, there was no damage due to blowing. The sealed surfaces were wrapped together for a better seal. The valves were then fitted with new gaskets and seals where necessary and the opening pressure on the valves was adjusted to 200 +/- 5 bar. Previously safety valves were fitted to a pressure control device which was connected to a high pressure pump to control the opening pressure. Finally, they were reassembled ready to be connected to the indicator valves [1-14].

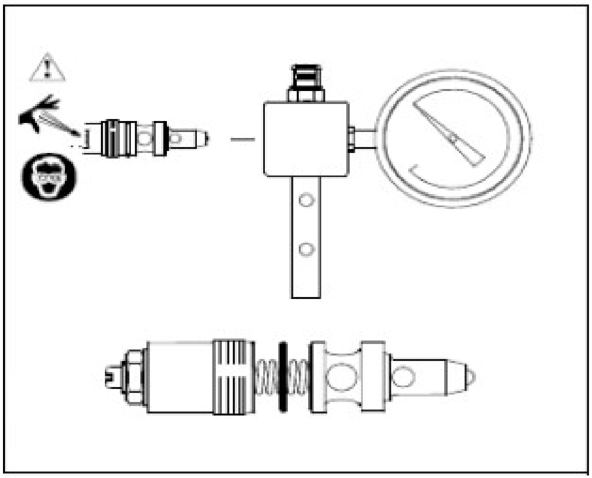


Figure 3.3: Safety valve and opening pressure control device [1]

3.2.5.6 Exhaust valves

To remove the exhaust valves from the cylinder heads, the cooling water inlet and outlet had to be shut off first to get the exhaust valves out. Then the high pressure pipe responsible for actuating the hydraulic valve, the cooling water outlet pipe and the oil pipe were disconnected. Also removed all the screws of the cooling water inlet to the side of the exhaust valves and the insulated plate housing. Then the protective caps were removed from the valves and four hydraulic plugs were installed so that the high pressure pumps were connected to the sockets via a distributor block.In this way it was achieved ebleed the hydraulic system. Finally, after removing the nuts first, the valve was placed on a lifting hook so that the exhaust valves could be easily removed [1-14].

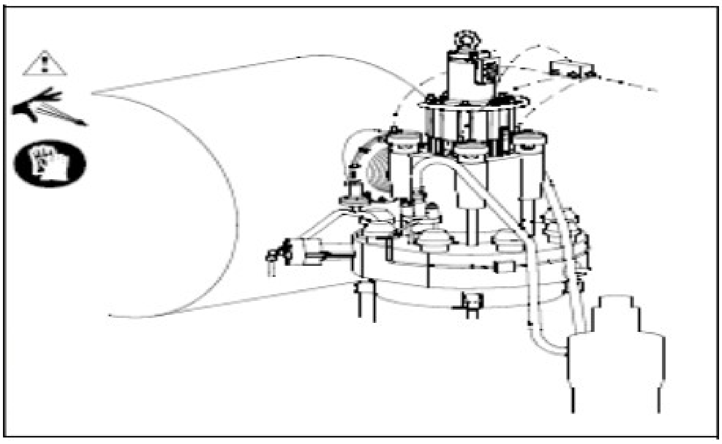


***Figure 3.4**: Bleed hydraulic system for disassembling exhaust valves [1]*

After disassembly, the exhaust valves were placed on a special platform for thorough cleaning and inspection for any damage. Initially a removal of the the oil cylinder was done and placing it on a wooden stand so that the orifice plug holes can be accessed for cleaning. Then the O rings, hydraulic hoses and high pressure hoses were removed in order. There was no damage to them, so replacing them was not considered appropriate. The sealing rings, gasket and piston of each valve were then removed to check and inspect the bore diameter of the oil cylinder.

The valve stems and bearings were checked for damage, and nothing untoward was noted, except for some slight pitting in some areas of the valve seats. These marks were removed by grinding using a special shaft provided in the special tool set.also some small marks were found on all of them valve shafts, which were however considered acceptable and therefore the valve shafts were used for further use without machining. However, it was decided to clean only the fine machined seat areas [1-14].

The shafts were checked for burn surface marks with nothing observed on any of the valve stems. Measurements were taken on the sealing surface and stem, through which the shaft seal passes. In seven of the valve stems, all in the first engine, stem wear was found to be beyond acceptable limits. These valves were replaced with available spare parts and necessary arrangements were made to send them for rebuilding [1-14].

***Photo 3.3*: Exhaust valve shaft for grinding [1]**

As for the exhaust valve bearings, the same procedure as the axles was followed. The bearing seats were found to be in good condition, except for a few small dents noted on all valve bearings. The bearings were machined to have a good shock sealing surface. Both the machining of the bearings and that of the spindles was done by BWSC personnel in cooperation with the station engineers, since it was the first time for the station personnel to deal with this type of work. The bearings were checked for burning on their surface, but nothing untoward was observed. In addition, the necessary measurements were made in the area where the bearings are located, as well as new measurements after the mechanical treatment carried out [1-14].

Photo 3.4: Exhaust valve bearing machining [1]

Inspection was carried out on the exhaust valve housings after they were cleaned, with the help of a lifting tool. The bore in the axle necks was found to be within limits after proper measurement, so no replacements were made.

Finally, regarding the exhaust valve actuators, they were all visually inspected without disassembly and found to be in good condition. All exhaust valve high pressure pipes (hydraulic pipes) were also found without the slightest wear on their sealing surfaces, after first being cleaned and inspected for damage. New O rings were installed on their thrust pads.

The following table refers to the necessary tools to be used for exhaust valve machining:

No. Item	Description
046	Cutting machining machine
M1	Exhaust valve housing lifting tool
M2	Bracket for exhaust valve
M3	Advance angle measuring tool
M4	Wrench for hydraulic hose thrust pad

Table 3.2 : Description of tools for exhaust valve maintenance [1]

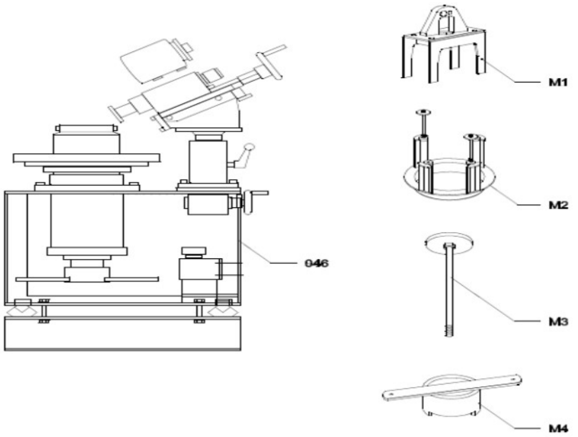


Figure 3.5: Tools used to service exhaust valves [1]

3.2.5.7 Pistons

Initially, all the pistons were disassembled from the cylinders, with the cylinder caps already removed beforehand. To disassemble them, it was first necessary to remove the telescopic tube from the cylinder head using a special tool. It was then released from the cylinder liners with a stud setter and with the aid of a lifting hook, each piston was placed on a platform for transport to the loading area for careful examination and correction.

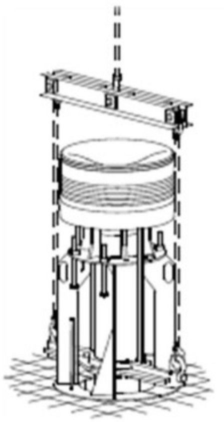


Figure 3.6: Placing disassembled piston on platform using lifting hook [1]

After the pistons were inspected, they were immersed in water for more carbon deposition, so that they could be cleaned more easily. When the pistons were submerged in water, the oil cooler chamber was pressure tested to check for leaks, where none of the pistons were found to leak through the O rings. The piston crowns and ring grooves were also extensively cleaned. Ring groove height and chromium layer thickness were measured on all piston rings. High ring groove wear was observed on four piston crowns (ID 3, 8, 9 and 12).

Specifically for each piston, it was checked theamount of carbon deposits noted on the top of the piston and whether the rings were stuck in the grooves and in good condition. The calibration data for each groove was also checked to see if it was within tolerance so that the piston crown could be reused.

On the twelve pistons of each engine tested, a moderate amount of carbon deposit was found on the top of the pistons as well as carbon deposits on the back of the ring grooves. With the exception of the second piston ring ID number 1 of the first engine checked, which was found stuck in the groove, all the other piston rings (four for each piston) were found free in their grooves but moving slowly, especially the third ring. This is due to the carbon deposits observed, combined with the cylinder oil remaining sticky at low temperatures when the piston is out of the engine [1].

Figure 3.7: Check piston with ID 1 on top and in its grooves [1]

Regarding the groove calibrations, some calibration data on pistons with ID numbers 3, 8, 9, and 12 for the first engine were found to be outside the specified tolerances, thus exhibiting high groove wear. More specifically, on pistons with ID numbers 3 and 8, the limits of the second ring on the forward, exhaust and aft sides were found to be above the calibration limits. On the ID 9 piston the limits on the second ring on the cam side, front side and exhaust side were out of tolerance, while on the ID 12 piston the cam and exhaust side limits were outside the maximum limit. The crowns of the aforementioned pistons were set aside for review. On all other pistons, the measurements were below the maximum limit, so the crows were ready for reapplication [1-14].

Below are tables of the four ring groove ratings of ID 3,8,9 and 12 pistons and the maximum values they can have, according to statute of manufacture of pistons in the particular engines. Values in yellow refer to values found outside the specified tolerance limits.

# ID 3	Groove Height "H" (mm)						
	Norm. Ring Height		Max	Cam	Fore	Exhaust	Aft
Ring 1	12.5		13.05	13.01	12.82	12.85	12.92
Ring 2		+ 0.265		9.99	10.07	10.08	10.04
Ring 3	9.5	+0.240	10.05	9.85	9.80	9.81	9.81
Ring 4				9.82	9.81	9.86	9.82

# ID 8	Groove Height "H" (mm)						
	Norm. Ring Height		Max	Cam	Fore	Exhaust	Aft
Ring 1	12.5		13.05	13.01	12.87	12.83	12.86
Ring 2		+ 0.265		9.99	10.02	10.05	10.12
Ring 3	9.5	+0.240	10.05	9.85	9.80	9.86	9.82
Ring 4				9.82	9.90	9.85	9.82

# ID 9	Groove Height "H" (mm)						
	Norm. Ring Height		Max	Cam	Fore	Exhaust	Aft
Ring 1	12.5		13.05	12.99	12.94	12.92	12.92
Ring 2		+ 0.265		10.02	10.12	10.14	9.94
Ring 3	9.5	+0.240	10.05	9.89	9.83	9.79	9.81

Ring 4				9.84	9.83	9.84	9.91

# ID 12	Groove Height "H" (mm)						
	Norm. Ring Height		Max	Cam	Fore	Exhaust	Aft
Ring 1	12.5	+ 0.265 +0.240	13.05	13.10	12.97	13.01	12.96
Ring 2	9.5		10.05	9.94	9.87	9.98	9.95
Ring 3				9.81	9.79	9.83	9.79
Ring 4				9.79	9.80	9.82	9.80

Table 3.3 : Ring groove calibrations for pistons 3,8,9 and 12 and values out off the specified limits [1]

This process of measuring bushing calibrations and comparing them to some predetermined tolerances falls under the policy of preventive maintenance after replacing the rings with groove wear exceeding the allowable limits and confirming operation without major groove wear for all other rings, at least until the next general maintenance.

As for the PC (Piston Cleaning) piston cleaning rings, their measurements were found within acceptable tolerances and were reused in the corresponding liners. All of the PC bushings were stamped with the same bushing ID number so that they would go together when installed and in the correct position.

3.2.5.8 Cylinder liners

The cylinder liners, which had already been disassembled to check the cylinder heads, were checked and assessed for their condition. A careful check was made on the O ring grooves, the wall surfaces, and the oil ducts linings of the sleeves. In general, the appearance of their surfaces was found to be good on all cylinder liners. There were no hard contact marks caused by either polishing holes or insufficient lubrication between the bushings and sleeve walls. The wear rate of each sleeve was much lower than the average wear rate of 0.01 mm / 1000 hours, in all locations except at point 2 of the sleeve (59mm from its top), where the highest wear was recorded. The appearance of the running surfaces of the line was at normal levels and the marks from the wave cutting machine were gone on the upper part of the sleeve The liners were ground and the surface roughness was maintained at about Ra=1.5

after grinding. The liners with ID numbers 1 6 and 12 were put back on their respective cylinders, while the liners with ID numbers 7 11 were kept as spares.

Photo 3.5: Check of the surfaces of the cylindrical sleeve with ID 4 [1]

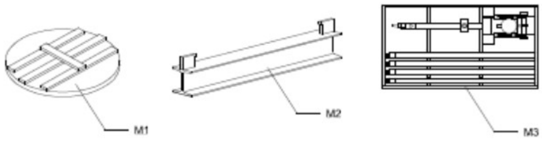


Figure 3.8: Auxiliary tools for the maintenance of cylidrical sleeves [1]

No. Item	Description
M1	Cover for cylinder liner
M2	Standard meter
M3	Measuring rod (meter) for cylinder liner

Table 3.4: Description of tools for measuring cylindrical sleeves [1]

3.2.5.9 Scavenging air receiver and piston rods

The Scavenging air receiver consist of a total of ten rings which are as follows: One top scraper ring, one top brass seal ring, two double sided brass seal rings and four steel scraper rings with replaceable blades at their bottoms. The rings are numbered from top to bottom, numbers 1 through 10. The twelve Scavenging air receivers (ID 1 12) were disassembled from the piston shafts in two pieces, removing the O rings first and then the bolts assembly. They were then taken to the loading area for continuous cleaning, inspections and measurements. Scraper rings and sealing rings (springs) were calibrated according to the instruction book and their lengths were checked. The piston rod diameters were found to be within acceptable limits and without any tendency to oval, while the areas where the rings fit into the rod were lubricated with molybdenum disulphide MoS2.

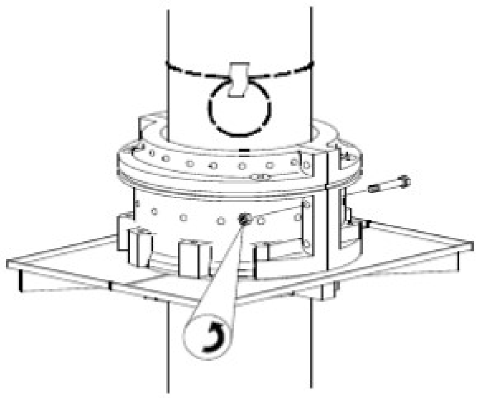


***Figure 3.9*: Disassembly of the Scavenging air receiver from the piston rod [1]**

However, several Scavenging air receivers were fitted with old sealing rings resulting in high oil leakage. In some of the boxes the position of the sealing rings 4 and 6 was found to be damaged due to waste materials, resulting in the axial distance between the stuffing box housing and the rings becoming large, sometimes above the acceptable maximum limit.

This was something that troubled BWSC quite a bit. Therefore it was decided to replace all the rings and blades with new parts. More specifically in all twelve stuffing boxes scraper ring 1, sealing rings 2, 3, 4, 5 and 6 and blades on all scraper rings (ring 7, 8, 9 and 10) were replaced with new parts. Scavenging air receivers with IDs 9 and 10 were observed to have debris in the annular ground of the top groove of the Scavenging air receivers housing. The reason for this damage was not known and BWSC ordered it to be disbanded the casing and a new part to be delivered for replacement in the aforementioned Scavenging air receivers [1-14].

<u>Photo 3.7:</u> Wear in ring grooves due to waste material for ID 9 and 10 Scavenging air receiver [1]

3.2.5.10 Fuel pumps

All fuel pumps were disassembled from the engine by first removing their protective cover, the piston of each pump and the fuel inlet pipes. Then they were taken to the workshop for processing, repair, cleaning of all disassembled parts and checking them for damage.

The pump pistons and barrels were found to be in good condition except for some light marks on the pistons (cavitation) where the helical cut was set for full operation. This was normal and acceptable so the pistons could be put to further use without hesitation.Also dno abnormal signs of wear wereobserved on the barrel leaks. Fuel regulators and VIT adjusters cleaned and inspected. Generally no abnormal wear was observed on any of the pump parts, which were carefully assembled while observing their mating points.

All intake valves were then disassembled, cleaned and inspected while their sealing surfaces were carefully coated. The valves were then reassembled with new seals. All plug screws were found to be in good condition with no signs of cavitation.

Then all the drill valves were disassembled from the fuel pump top covers, cleaned and inspected. Also the sealing surfaces were lightly welded together before being assembled with new seals. The fuel pump top covers were cleaned and checked for damage [1-14].

All mounts were disassembled from the fuel pumps, cleaned and inspected while the o rings were replaced. Slight wear was observed on the inner surface of the outer springs and the outer surface of the inner springs as they came into contact with each other during operation. However, all of the above components were in good condition for further use, so the springs were reused [1-14].

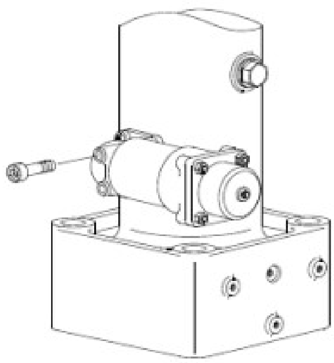


Figure 3.10: Disassembly of suspension from fuel pump [1]

The sealing cover assembly of all fuel pumps was fitted with new sealing rings. After completing their repairs, all fuel pumps were installed on the engine and the VIT (Variable Injection Timing) electronic system was reset to its previous settings. During the engine performance measurements, the VIT and fuel trim mounts were adjusted slightly to balance the engine load. The complete overhaul of the fuel pump was carried out by station personnel under the constant supervision of BWSC. Finally, all high pressure hoses were cleaned, inspected for damage, and wrapped as necessary. All O rings replaced [1-14].

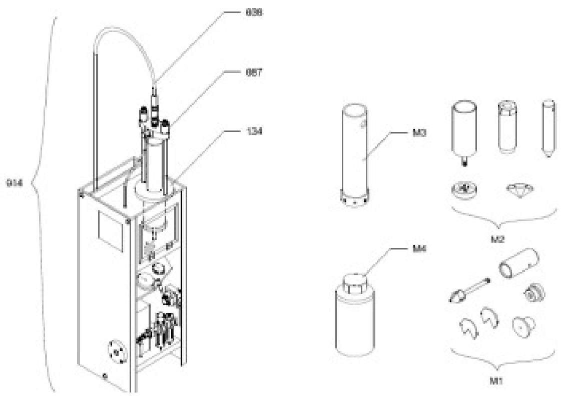


Figure 3.11: Tools for maintenance and repair of fuel pumps [1]

No. Item	Description
014	Mechanical test setup
038	High pressure hose
087	Spring housing
134	Test Setup Guide
M1	Grinding tool for oil fuel pipe bearings
M2	Grinding tool for oil fuel pipes
M3	Hook safety
M4	Socket for thrust piece

Table 3.5: Description of fuel pump maintenance tools [1]

3.2.5.11 Crankcase

The crankcase of each engine was carefully inspected for loose parts before being cleaned while the bottom area was inspected for any white metal particles, nothing untoward was found. In addition, the crankshaft was checked for deflection using a spin wheel and its position was checked with a pin gauge while turning. Crankshaft misalignment was checked before and after general maintenance with the results being within recommended tolerances. All bolts in the crankcases were also inspected, checking their locking plates and wires and performing a sound hammer test, with nothing objectionable found [1].

3.2.5.12 Air receiver and temporary storage area

Scanned the air cleaner receiver and buffer area with a full clean and inspection for damage and cracks, nothing found.

3.2.5.13 Charge cooler

Cleaning the scavenging air cooler was a task assigned to the station staff. The condition of the coolers was relatively good with the exception of the number 2 cooler which had been damaged earlier due to loosening of the cross beam bolts supporting the tube support plates. The cooler was repaired according to BWSC instructions and chemically cleaned.

3.2.6 Engine Startup Procedures

With the end of the general maintenance of the individual components of the three engines, a preparation for restarting their operation began. The preparatory work was carried out in the presence of the assistant shift engineer in charge.

Initially cooling water was refilled into the engine where minor leaks were observed through the O rings at the water connections to the cylinder heads. The leaks were immediately fixed by changing the O rings. Fuel then reached the engine under low pressure in the first stage. There was an oil leak coming from all the fuel drain pump discs. Immediately the operation of the fuel pumps was stopped and the cause of the leak was investigated. It was found that the mixing tank drain remained open excessively when the pumps were started resulting in fuel not being able to drain into the oil tank (reservoir). As a result, the pipe was filled with oil which came out of the open connections through the discscreating a problem in the already cleaned machine. So some personnel from both BWSC and the EAC station were mobilized to clean the engine.

During general maintenancedno other oil leaks were observed from the fuel pumps and associated pipes that were removed. The oil pump started and oil jets were observed from the crosshead bearings. The spaces below the piston chamber were checked for leaks from the seals between the liner and the piston rod, and between the crown rods and the piston rod without leaking. This confirmed that the rubber piston oil cooler chamber seals remained intact. All cylinder oilers were adjusted to run the piston rings and liners [1-14].

During startup, no problems occurred and all three engines were stopped after 10 minutes of no load operation in order to check their bearings and piston rings. The engines were re run at 5 MW for one hour and a crank inspection was carried out for misalignment. The rings and liners on each piston were found to be in good condition with adequate lubrication. Also, all locking devices on the piston rods, stuffing boxe and telescopic tubes were found to be intact [1-14].

The engines were then restarted in sequence, loaded according to the loading schedule to reach their full load stepwise, and then stopped after 22 hours of operation with a gradual load reduction (phase one). A new inspection on each engine was carried out at the end of the first phase and all piston rings and liners were found to be in good condition with adequate lubrication. The lubricators were set to deliver 2.4 g/kwh during this initial run. The first phase of the reopening started at 11:00 am and lasted exactly 24 hours and is described in the graph below [1-14]:

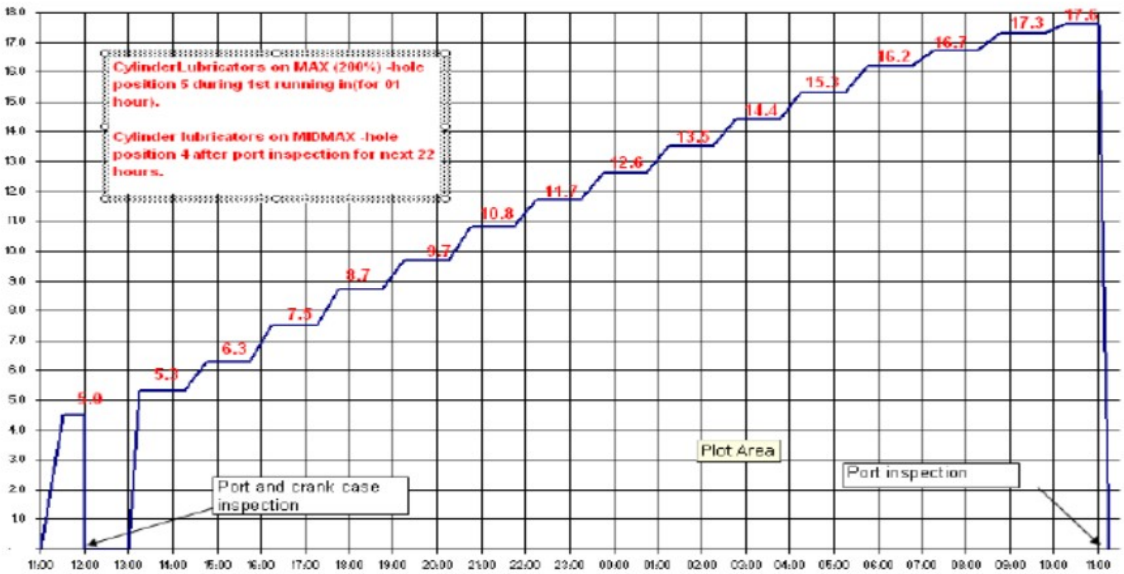


Figure 3.12: Plot during the first restart phase for each motor with gradual load recovery

(Mw) [1]

Upon completion of the first phase, each engine was put into continuous operation with a stepwise recovery of its full load (about 17.6 Mw) over a period of two hours and maintained until the next 250 hours (second phase). An inspection was then carried out again without any observations concerning the operation of the engines. The lubricators were set to deliver 1.8 g/kwh during their second restart phase.

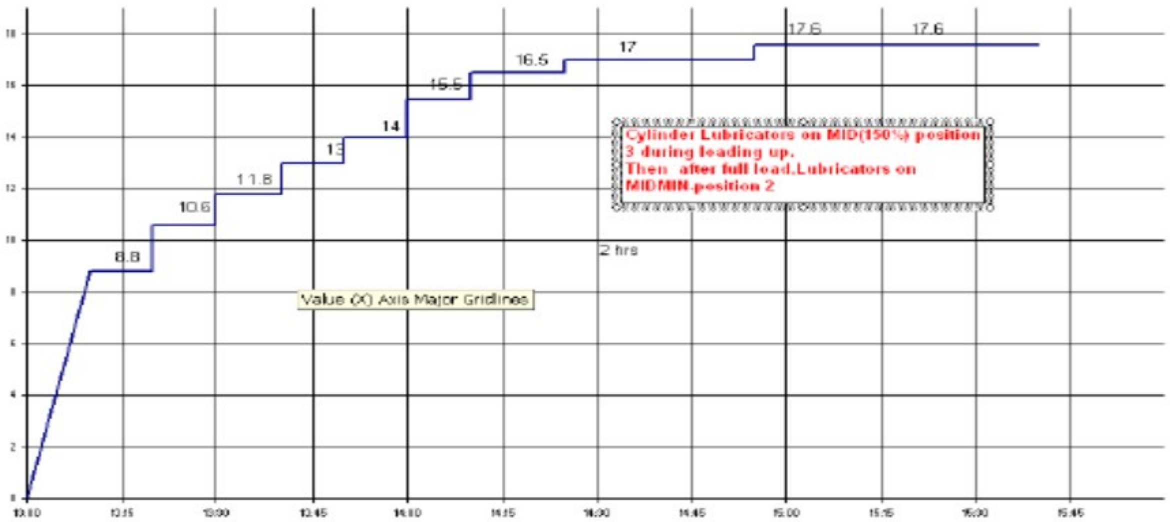


Figure 3.13: Plot during the second restart phase for each motor with full load step recovery of 17.6 Mw over two hours [1]

The above starting processes for the engines were carried out during the morning shift by the station staff. Below is a table of the workers and hours of work required to restart each engine.

No. Day	**14**		**15**	
Tasks	A	B	A	B
Engine start and check for leaks and noise	1x4			
Inspection of rings and crank after 1 hour of operation	2x2			
Inspection after 24 hours of operation			1x2	

Table 3.6 : Startup tasks for each engine [1]

3.2.7 Checks to ensure operational quality

BWSC conducted some measurements and inspections to ensure that the maintenance procedures just completed had the desired effect. In particular, the rings were inspected after running each engine for 250 hours and 500 hours, respectively without noticing anything.

The inspections at the end of the second phase of operation of the engines (250 hours of operation) concerned the general condition of the piston rings, liners and crowns. The ring packs and liners of all cylinders were found to be in very good condition with good oil supply and no signs of abnormal wear. Generally the wear rate of the ring coating thickness on each cylinder was calculated to be within acceptable limits. Fuel absorption in the cylinder storage area was minimal indicating minima combustion of the cylinder oil. The oil feed rate was also calculated with the help of the measuring cylinder. The oils were adjusted to deliver 1.8 g/kwh at 250 hours of operation and 1.5 g/kwh respectively at 500 hours.

A general performance test of each diesel engine was also carried out with the necessary adjustment of the VIT system and fuel pumps. The engines were found to be well balanced and a recommendation was made by the BWSC that a continuous check be made balancing at regular intervals to ensure their continuous optimal operation.

In conclusion, the final engine performance measurements obtained were deemed acceptable. A check was also made for the fuel drain analysis to assess the condition of the cylinder during engine operation [1-14].

Photo 3.7: Checking the rings and liners of the second cylinder on the engine after 250 hours of operation. A small amount of carbon is observed inside the upper part of the rings [1]

To ensure the quality of the overall work performed, attached by BWSC a quality assurance report with the names of the persons who reviewed each item. Also recorded for easy future reference is an overview with the part identification numbers installed and removed for each engine.

Description	Item number											
Exhaust valve stems removed	1	2	3	4	5	6	7	8	9	10	11	12
Exhaust valve stems installed	19	20	21	22	23	24	1	43	3	4	5	9
Exhaust valve bearings removed	1	2	3	4	5	6	7	8	9	10	11	12
Exhaust valve bearings installed	19	20	21	22	23	24	1	2	3	4	5	9
Exhaust valve covers removed	1	2	3	4	5	6	7	8	9	10	11	12
Exhaust valve housings installed	19	20	21	22	23	24	1	2	3	4	5	6
Piston crowns removed	1	2	3	4	5	6	7	8	9	10	11	12
Piston crowns that They settled	20	23	24	45	46	10	1	2	4	5	6	7
Linings removed	1	2	3	4	5	6	7	8	9	10	11	12
Linings installed	20	21	22	23	24	4	1	30	3	5	6	12
Stuffing boxes removed	1	2	3	4	5	6	7	8	9	10	11	12
Filling boxes that They settled	20	23	24	19	2	8	1	3	4	5	6	7

Table 3.7: Description of components removed and installed an matcing them with identification numbers [1]

3.3. Spare Parts Management

Spare parts are managed at the Dekelia station by recording and processing in a SAP database. All materials used in the station are recorded and classified in categories related to steam turbine systems or internal combustion engines, separately for each substation. After the necessary check has been done in the warehouses, the SAP database is updated by the responsible storekeeper for each component separately and the corresponding adjustments are made to the system after the use of each spare part. In this way the management is able to know the exact quantity of each spare part that the station has at any given time, the immediate consumables as well as the critical spare parts that must be available at all times.

Spare parts are listed in pieces or lots. For each material there is a pre defined minimum stock level, which requires re ordering of the material, which is given by the EAC headquarters.

To order the spare parts, the address of the station is addressed to the EAC headquarters in Nicosia. A report is drawn up by the station with the request for ordering new spare parts, specifying the type of material and the quantityorder required and then sent to head office, which has sole responsibility for ordering and timely availability of spare parts. From there, the quantity of materials to be ordered is determined by holding tenders with offers from various suppliers of spare parts, so that the choice to order the desired material is made. The tenders are evaluated based on the technical quality control of the offers and the economic evaluation that will determine the most advantageous offer and the conclusion of an agreement. In this way, the appropriate materials that meet the necessary specifications are selected. The suppliers and companies to whom tenders are awarded are made on the basis of recommendations from the manufacturers of the station [1-14].

A similar policy is followed for ordering lubricants. In particular, every night a check is carried out by the shift engineer of the station, where the quantities of the lubricating fuel for the cylinders (cylinder oil) and the lubrication system (lub oil) are recorded and a report is drawn up which is delivered to the manager of the operation of the station. When the level of lubricants in the tanks reaches 40%, the necessary processes for ordering lubricants from the head office are carried out and tenders for evaluation of offers from suppliers are carried out from there. An indicative example of the ordering of oil for the cylinders by holding tenders is the agreement of EAC in recent years with a representative of the Shell Alexia LS company for the supply of Melina S 30 type oil. In the case of choosing a different oil that has been deemed more suitable and more economical, all the previous oil must be removed from the station's tanks and replaced, which entails stopping the operation of the internal combustion engines for approximately three days to empty the tanks and cleaning the filters and pipes from amounts of old oil. The station estimates that an oil order is required every 4 5 months of engine operation. all the previous oil must be removed from the station's tanks and replaced, which entails stopping the operation of the internal combustion engines for about three days to empty the tanks and clean the filters and pipes of amounts of the old oil. The station estimates that an oil order is required every 4 5 months of engine operation. all the previous oil must be removed from the station's tanks and replaced, which entails stopping the operation of the internal combustion engines for about three days to empty the tanks and clean the filters and pipes of amounts of the old oil. The station estimates that an oil order is required every 4 5 months of engine operation [1-14].

The following is a table of the quantities of essential spare parts held by the station for the ICE 1 station and its accessories, the uses made in the last three years, the current stock held at the station and the total order quantity carried out for each material the specific time period (See Appendix Table 6.1) [1-14].

4. Conclusions

After the general repairs of the three engines of the ICE 1 unit, some highlights were noted for the better operation of the unit. Firstly, based on the checks carried out at the end of the general maintenance, a reduction of the total oil (petroleum) loss in the cylinder stuffing boxes was observed which implies a cost saving at the station. Thus, to optimize the system, the relevant recommendation of the maintenance manual was adopted to reduce the supply rate of the lubrication oil to the cylinders (cylinder oil) to 1.1 g/kwh after 1200 hours of operation.

In general terms, the general maintenance process has been considered quite successful in that no serious problem has occurred to date with the operation of the two stroke engines affecting their overall performance. This proves the better performance of two stroke engines compared to four stroke engines that require more systematic checks and intermediate maintenance procedures of some of their components, which presupposes a more immediate availability of spare parts, therefore higher costs. Of course, it should be noted that the ICE 1 station was shut down for the entire year 2013, not for reasons related to maintenance, but for the attachment of more modern catalysts for full compliance with the relevant legislation regarding the exposure of pollutants to the environment.

Also, the staff of the station who were present at the first planned general maintenance and the majority of whom continue to be employed at the station to this day, gained experience and knowledge in matters of engine maintenance as well as flexibility in dealing with any damage that may occur not only in the sub unit ICE 1 but also in that of ICE 2, where several control and maintenance procedures are very similar. In addition, he is able to carry out the next planned general maintenance by taking on more responsibilities, under the supervision again of executives of the construction company of BWSC. In addition, throughout this time, the station staff managed to adequately cope with maintenance issues related to the ICE 1 subunit and in general to the entire mechanical equipment of the station. However, it would be good to do a gradual renewal of the station's human potential, since due to the economic crisis on the island in recent years, recruitment at the station and in general in the semi state sector of the EAC has been minimal to zero. By hiring new people with appetite and key ideas, staff renewal and the transfer of knowledge from the most experienced to the existing know how will be achieved. Also, by holding special seminars and practicals at regular intervals, knowledge and perception of the personnel would be enhaced in case of any contigency.

The main problem observed recently regarding the operation of the station's internal combustion units, has to do with the maintenance of some auxiliary parts of the engines, such as the water coolers, the separators and also the ICE 1 catalysts. These auxiliary components have often failed during their operation in recent years. Of course, their maintenance policy does not fall within the framework of the general maintenance of engines and preventive maintenance is followed at specific time intervals. However, the quite frequent unexpected occurrence of damage to auxiliary components, sometimes affects the performance of the engines and increases the dead operating times of the engines, since many times they are taken out of operation for the complete restoration of their auxiliary components. In particular, the frequent malfunction of the fuel separators in the two internal combustion sub units is something that is observed quite often, as a result of which the engines are put out of service until their damage is repaired. The maintenance policy followed for all auxiliary components of the station falls within the framework of preventive maintenance, where according to the statutes of the manufacturers of each machine, maintenance is carried out at specific time intervals. But the systematic appearance of damage beyond certain limits is something that should concern the management of the station, so that more emphasis is placed on preventive maintenance methods of these components, with continuous recording of their measurements to make it easier to determine their performance and duration their lives.

With a combination of elementspreventive and predictive maintenance, the managers of the station will be able to draw easier conclusions for the replacement of the auxiliary equipment with new more reliable machines if this is not economically unprofitable. This shows the importance of the Automation and Control department, where it should undertake the systematic collection of data through measurements for the hours when the mechanical equipment is out of operation and the recording of the dead times, so that the management of the station can do the necessary with the predetermined operating objectives and to take the corresponding corrective actions.

Also, beyond the planned scheduled maintenance of the auxiliary components, the case of including their maintenance in the framework of the general maintenance of the engines should be considered by the management, for a better and more immediate adaptation of the entire system. In addition, it is generally accepted by everyone at the station that the installation of modern pollution control catalysts in two stroke engines has affected to a considerable extent, the reduction of their overall efficiency.

Finally, it is worth mentioning the existence of direct cooperation with the headquarters of the EAC, so that correct and rational quantities of spare parts are ordered, but also there is a commitment to deliver suitable spare parts and without time delay.

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6. Appendix

Table 6.1 : Deposit material consumption

	Description Material	**Consumption 2015**	**Consumption 2016**	**Consumption 2017**	**Way Disposition**	**Current Condition**	**Quantity last Order**
1	Separator fuel oil (FO) Cover Cover	0	1	0	Lot	3	3
2	FO separator Spare parts	2	0	2	Lot	2	3
3	FO separator Pump shaft	0	0	0	Piece	2	0
4	FO separatorPump ring	0	0	0	Piece	4	0
5	FO separator Sealants	76	17	33	Piece	325	538
6	FO separator Piping	0	6	0	Piece	3	0
7	FO separator Control valves	0	1	0	Piece	6	0
8	transfer axis Sealants	0	1	0	Lot	3	0
9	transportation Rings	0	0	0	Piece	2	0
10	Lube oil Sealants	1	2	0	Piece	1	3
11	lubricant O ring	0	1	0	Piece	2	0
12	cooling water O ring	0	0	0	Piece	8	0
13	cooling water Sealants	1	0	0	Piece	4	0
14	preheater O rings	0	0	0	Piece	3	0

15	preheater Sealants	0	0	0	Piece	3	0
16	condenser Sealants	0	0	0	Piece	1	0
17	water separator (WO) Cover	0	0	0	Piece	1	0
18	water separator Stuffing box	0	0	0	Lot	3	0
19	Oil filter	0	0	0	Piece	4	0
20	Fuel filter	0	0	0	Piece	6	0
21	Water filter	0	0	0	Piece	6	0
22	Air filter	0	0	0	Piece	5	0
23	high pressure Spherical bulbs	0	4	0	Piece	4	0
24	welding Spherical bulbs	0	1	0	Piece	6	0
25	butterfly valves	0	0	0	Piece	3	0
26	Security check	0	0	0	Piece	1	0
27	generator lift pump	0	0	0	Piece	1	0
28	generator ignition pipes Sealants	0	0	0	Piece	12	0
29	generator ignition pipes seals	0	0	0	Piece	52	0
30	Crankshaft Shell	0	0	0	Piece	8	0
31	Crankhaft Shell	0	0	0	Piece	3	0
32	Crankshaft Stem	0	0	0	Piece	4	0
33	Crankshaft Stem	0	0	0	Piece	4	0
34	Crankcase check valve	0	0	0	Piece	1	0
35	Camshaft Chain	0	0	0	Piece	4	0
36	Cylindrical caps miscellaneous types	24	189	8	Piece	148	300

37	Cyl. caps cooling jacket O rings	0	10	0	Piece	104	30
38	Piston rods	0	0	0	Piece	6	0
39	Piston Rings	37	12	1	Piece	35	25
40	Cylindrical coatings	0	0	0	Piece	7	0
41	Grinding stones	0	0	0	Piece	9	144
42	Cylinder pipes coatings	0	0	0	Piece	21	0
43	Cylinder coating Sealants	0	96	0	Piece	244	300
44	coatings O rings	0	32	0	Piece	390	360
45	Cooling mantle coating	0	0	0	Piece	6	0
46	Transport housing filling	0	0	0	Piece	6	0
47	civ filling Scraping Rings	0	0	0	Piece	241	144
48	Water seal Bearing rings	0	8	0	Piece	41	36
49	Oil sealBearing	32	0	0	Piece	172	144
50	Box blades filling	0	180	0	Piece	571	648
51	Gearbox springs filling	0	30	0	Piece	93	108
52	Telescopic tubing	0	0	0	Piece	1	0
53	Fuel pumps (433A)	140	264	15	Piece	1428	640
54	Fuel Pump pistons	0	0	0	Piece	16	0
55	Fuel pumps Drilling valves	0	0	7	Piece	2	0
56	Fuel pumps Shock absorber	0	0	0	Piece	7	0

57	Pistons Bearing rings	0	41	0	Piece	138	60
58	Exhaust valves	28	170	27	Piece	855	490
59	Exhaust valves Sealants	0	12	0	Piece	35	0
60	Exhaust valves O rings	15	33	7	Piece	52	80
61	Exhaust valves Mechanism	3	24	0	Piece	242	70
62	Exhaust valves O rings	239	72	8	Piece	343	300
63	Startup valves assy	0	0	0	Piece	3	0
64	Startup valves O Rings	0	0	0	Piece	44	0
65	Cylinder lubrication Sealants	0	0	0	Piece	10	0
66	O rings oil cylinder	0	0	0	Piece	8	0
67	Fuel high pressure pipes	0	0	0	Piece	3	0
68	Flue pipes O rings	51	64	16	Piece	258	180
69	Bearing rings lub cyl	0	0	0	Piece	4	0
70	Expansion valve	0	0	0	Piece	46	40
71	Check valve	4	0	0	Piece	8	0
72	Machine frame retention Screws	0	0	0	Piece	2	0
74	Camshaft Screws	0	0	0	Piece	1	0
75	Generator Axle	0	0	0	Piece	1	0
76	Piston crown O	0	8	0	Piece	45	50
77	Rings O box filling	1	12	1	Piece	51	36
78	Cross connection piston rod	0	0	0	Piece	1	0

79	Axial vibrations Sealing rings	0	0	0	Piece	3	0
80	Control air Repair	0	0	0	Lot	7	0
81	Turbocharger Protective grid	0	1	0	Piece	3	0
82	Turbocharger hexagonal screwsr	81	0	0	Piece	48	0
83	Turbocharger rotor	1	0	0	Piece	2	1
84	Turbocharger bearing O rings	7	0	0	Piece	3	0
85	Turbocharger Sealants	1	0	0	Piece	11	0
86	Turbocharger Support screws	0	0	0	Piece	12	0
87	Turbocharger safety Nuts	6	0	0	Piece	12	0
88	Turbocharger	3	0	0	Piece	1	1
89	Turbocharger tools	0	0	0	Piece	3	0
90	Turbocharger oil Colander	0	0	0	Piece	26	0
91	Air pipes	0	0	0	Piece	4	0
92	Fuel inlet Piping	2	0	0	Piece	18	0
93	Cooling water Preheater	2	0	0	Piece	2	3
94	Ball bearings	0	0	2	Piece	44	0
95	Supply water pipes	4	46	2	Piece	161	120
96	Return pipes	10	8	2	Piece	108	40
97	Indication Units	12	98	4	Piece	542	180
98	Rod pistons screws	0	0	0	Piece	183	0
99	Piston gasket	0	0	0	Piece	2	0

100	Control box air cleaner	0	0	0	Piece	25	12
101	Fuel Heating Activator	1	7	0	Piece	14	0
102	Fuel supply Piping	0	0	0	Piece	14	0
103	Drainage Pump	0	0	0	Piece	11	0
104	Supply pump	1	0	0	Piece	10	0
105	Main lubrication pipes	1	6	0	Piece	3	0
106	Engine Sealants	0	36	3	Piece	41	80
107	Rolling guides	0	0	0	Piece	5	5
108	Startup valve Branched out pipest	0	0	0	Piece	18	18
109	Startup valve Distributor	0	0	0	Piece	12	12