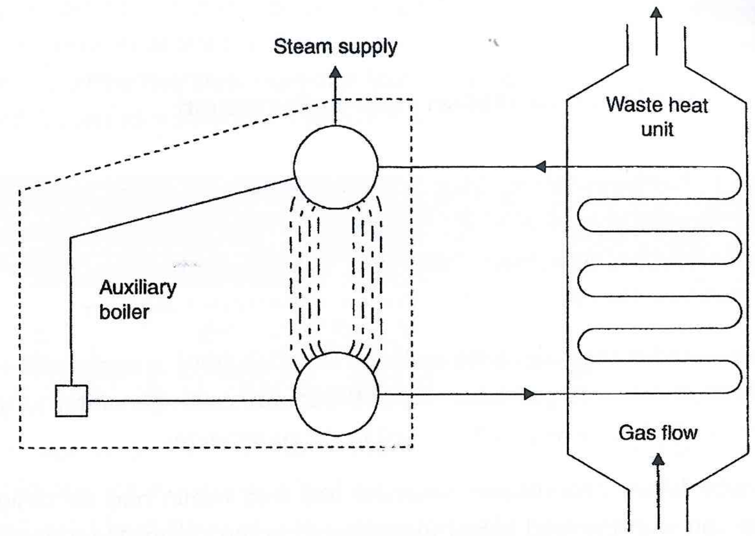
secured and all steam is supplied by the oil-fired main boilers. This system is suitable for use on vessels such as tankers where a comparatively large port steaming capacity may be required for operation of cargo pumps, but suffers from the disadvantage that the main boilers must either be warmed through at regular intervals or must be warmed through prior to reaching port. Further to this the main boilers are not immediately ready for use in event of an emergency stop at sea unless the continuous warming through procedure has been followed.

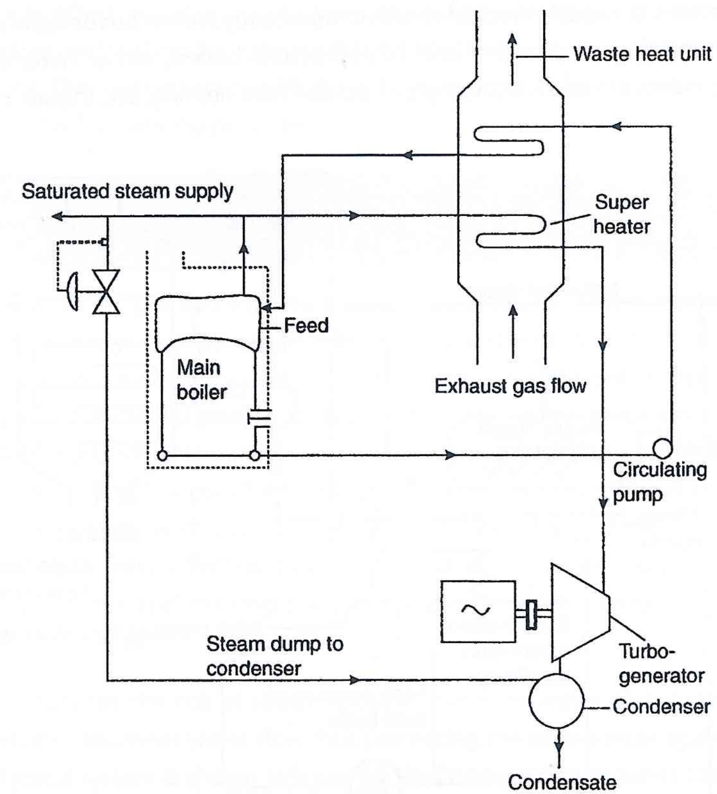
Forced circulation multi-boiler system

In order to improve the heat transfer efficiency and to overcome the shortcomings of the previous example a simple forced circulation system may be employed. The exhaust gas boiler is arranged to be a drowned heat exchanger which, due to the action of a circulating pump, discharges its steam and water emulsion to the steam drum of a water-tube boiler. The forced circulation pump draws from near the bottom of the main boiler water drum and circulates water at almost 10 times the steam production rate thus giving good heat transfer. The steam/water emulsion on being discharged into the water space of the main boiler drum separates out exactly in the same way as if the boiler were being oil fired. This arrangement ensures that the main boiler is always warm and capable of being immediately fired by manual operation or supplementary pilot operated automatic fuel burning equipment (figure 10.10). Feed passes to the main boiler and becomes neutralised by chemical water treatment. Surface scaling is thus largely precluded and settled out impurities can be removed at the main boiler blow-down. If feed flow only is passed through an economiser type unit parallel flow reduces risks of vapour locking. Unsteady feed flow at normal gas conditions can result in water flash over to steam and rapid metal temperature variations. Steam, hot water and cold water conditions can cause thermal shock and water hammer.

Contra flow designs are generally more efficient from a heat transfer viewpoint giving gas temperatures nearer steam temperature and are certainly preferred for economisers if circulation rate is a multiple of feed flow. The generation section is normally parallel flow and the superheat section is contra flow. Output control could be arranged by output valves at two different levels thus varying the effective heat transfer surface utilised. In addition a circulating pump by-pass arrangement gives an effective control method (figure 10.11).



▲ **Figure 10.10** *Natural circulation*

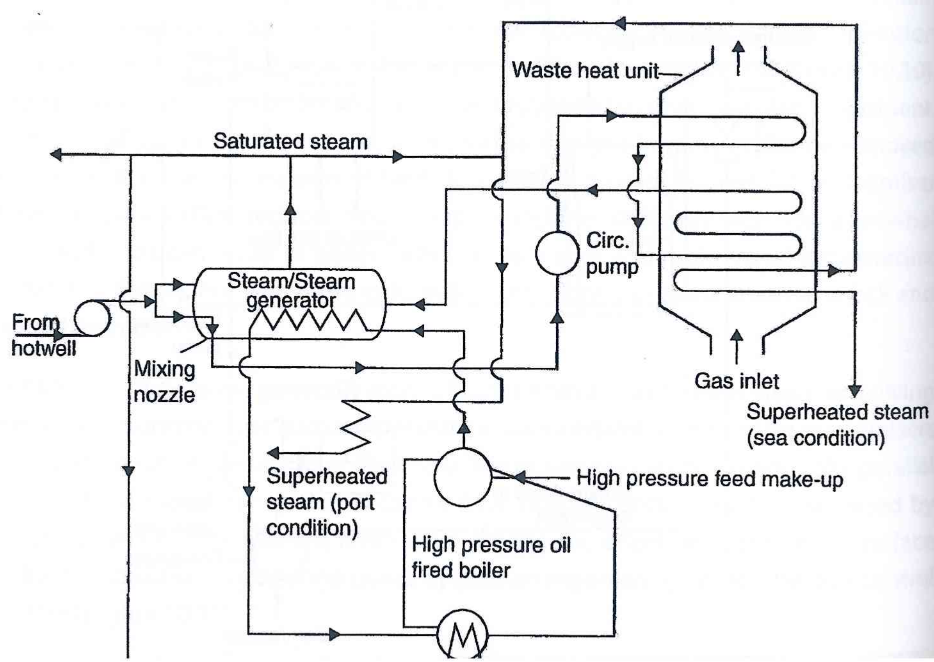


Dual pressure forced circulation multi-boiler system

This concept has been incorporated in the latest waste heat circuits and the sketch illustrates how the general principle can be applied in conjunction with a waste heat exchanger to supply superheated steam. By this means every precaution has been taken to minimise the effect of contamination of the water-tube boiler.

Steam generated in the water-tube boiler by either oil firing or waste heat exchanger passes through a submerged tube nest in the steam/steam generator to give lower grade steam which is subsequently passed to the superheater.

A water-tube boiler, steam/steam generator and feed heater may be designed as a packaged unit with the feed heater incorporated in the steam/steam generator. The high-pressure high-temperature system at say 10 bar will supply a turbo generator for all electrical services while the low-pressure system at say 21/2 bar would provide all heating services. Obviously the dual system is more costly. Numerous designs are possible including separate low-pressure and high-pressure boilers, either natural or forced circulation, indirect systems with single or double feed heating, etc. (figure 10.12).



It is very important that students are very familiar with the current thinking in boiler design and operational practice. This is an important safety issue and will be considered very carefully by the Flag State examiner. Students must understand the watchkeeping issues with boilers identified at the start of this chapter.

Water/Water Heat Exchangers

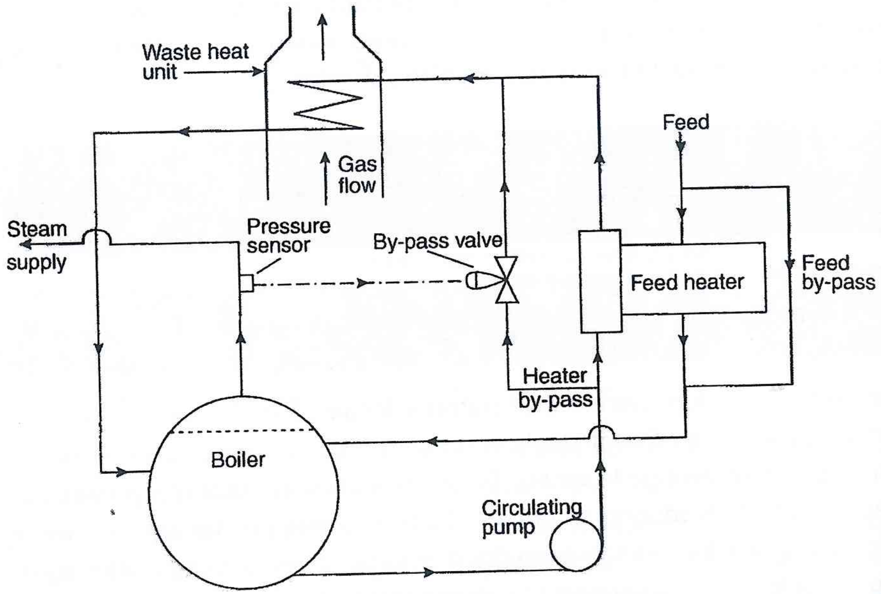
Evaporators

The basic information given on evaporators in Volume 8 should *first* be considered. In motor ship practice efficient single effect units incorporating flexible elements and controlled water level are in service. Evaporators utilising jacket cooling water as the heating medium producing an output of 20–25 tonnes per day are common. Flash evaporators have increasingly been fitted on large vessels utilising multi-stage units. Also multiple effect evaporators of conventional form are used. The steam circuit of many modern motor ships has developed in complexity to approach successful steam ship practice. The reverse osmosis (RO) plant is very popular for making large amounts of water mostly for drinking purposes.

Feed heating

The advantages of pre-heating feed water are obvious. Three methods will be considered, namely: economisers, mixture and indirect. Economiser types have been included in previous discussion and sketches. It is sufficient to repeat that such systems require a careful design to cope with fluctuations of steam demand and that particular attention is necessary to ensure protection against corrosive attack. Mixture systems employ parallel feeding with circulating pump and feed pump to the economiser inlet. Such circuits require careful matching of the two pumps and control has to be very effective to prevent cold water surges leading to reducing metal temperatures and causing corrosion. Indirect systems require a water/water exchanger feed heater.

This design reduces the risk of solid deposit in the economiser and maintains steady conditions of economiser water flow thus protecting the economiser against corrosive attack. A typical system is shown in figure 10.13. If boiler pressure tends to rise too high



▲ **Figure 10.13** *Indirect feed heating*

The effect will be twofold, that is, feed water will enter the boiler at a lower temperature and water temperature entering the economiser is at a higher temperature. These two effects serve to reduce boiler pressure and thus control the system. Obviously this system is more costly but is very flexible.

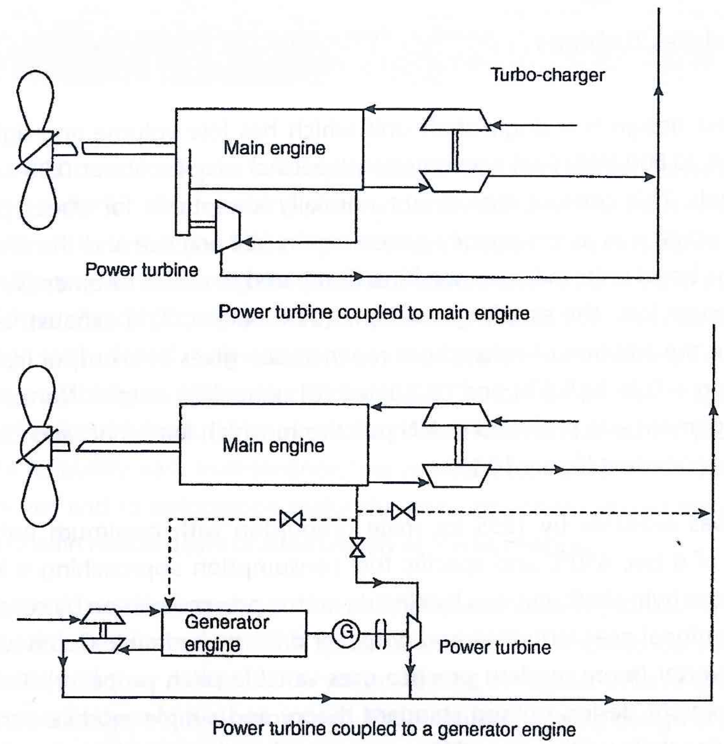
Combined Heat Recovery Circuits

The low grade heat of engine coolant systems restricts the heat recovery in such secondary circuits to temperatures near 7–8°C. As such it is normally restricted to use with distillation plants. Combined or compound units involving combination between engine coolant and exhaust gas systems are complicated by the need to prevent contamination and utilise the large volume of low temperature coolant in circulation. Jacket water coolant temperatures have increased in recent motorship practice but even if the engine design can be modified to suit even higher

Exhaust Gas Power Turbine

In an effort to improve overall plant efficiency the turbo-charger manufacturer ABB has developed a system which exploits surplus exhaust gas in a power turbine where the turbine's power output is fed either, to the engine crankshaft or, to an auxiliary diesel or steam turbine generator (figure 10.14). The latter is only feasible if the demand for electricity is greater than the output of the power turbine. This development has been made possible by the improved turbo-charger efficiencies achieved in recent years resulting in surplus energy being available in the exhaust gas.

The power turbine can be brought in and out of service, as conditions require, by operating a flap in the exhaust line. The turbine part of the power turbine is similar to those of turbo-chargers. The drive from the turbine is via epicyclic gearing and a clutch to the chosen mode of power input.



▲ **Figure 10.14** *Recovery of surplus exhaust gas*

Gas Turbines

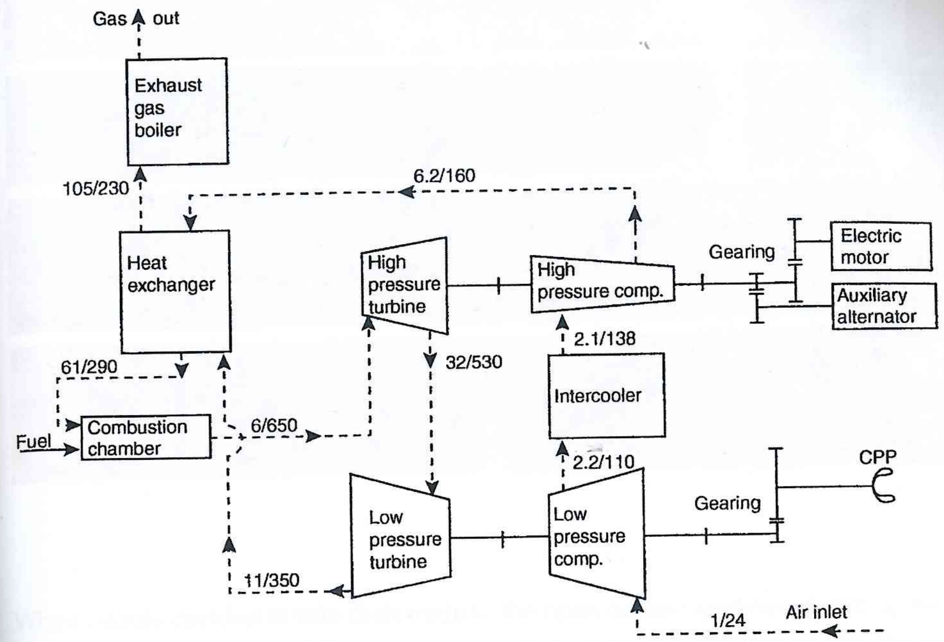
The gas turbine theoretical cycle and simple circuit diagram have been considered in Chapter 1. Marine development of gas turbines stemmed from the aero industry in the 1940s. Apart from an early stage of rapid progress the application to marine use has been relatively slow until recently. Consideration can best be applied in two sections, namely, industrial gas turbines and aero-derived types. In general this can largely be considered as a 'marinisation' of equipment originally designed for other duties.

Energy in a Power Turbine

Industrial Gas Turbines

The simplest design is a single-shaft unit which has low volume and light weight (5 kg/kW at 20,000 kW). Fuel consumption (specific) may be about 0.36 kg/kWh on residual fuels. This consumption is not normally acceptable for direct propulsion and initial usage was as emergency generators in MN practice and the RN for small vessels or as boost units in larger warships. Compared to steam turbines (32% output, 58% condenser loss) the simple gas turbine (24% output, 73% exhaust loss) is less efficient but the addition of exhaust gas regeneration gives 31% output (specific fuel consumption = 0.28 kg/kWh) and combined RN units 36% output. Normally a two-shaft arrangement was preferred in MN practice in which load shaft and compressor shaft are independent (figure 10.15).

A design was available by 1955 for main propulsion with maximum turbine inlet conditions of 6 bar, 650°C and specific fuel consumption approaching 0.3 kg/kWh. Starting of the twin-shaft unit was by electric motor, power variation by control of gas flow, conventional gear reduction and propeller drive by hydraulic clutch with astern torque converter (more modern practice uses variable pitch propeller). Turbine and turbo-compressor design utilised standard theory and simple module construction utilising horizontally split casings, diffusers, etc., and easily accessible nozzles.



▲ **Figure 10.15** *Open cycle marine gas turbine*

carried out with ceramic blades and with cooled metallic blades. Essentially the problem is the same for steam turbine plant and there has been no marked incentive for the shipowner to install gas turbine plant in preference to equally economic and established steam systems. During the 1960s experience was established in the vessels *Auris, John Sergeant* and *William Paterson.* It may well be that direct gas-cooled reactors in conjunction with closed cycle gas turbines in electric power generation may be an attractive possibility in nuclear technology. G.E.C. produce a wide range (4,000–50,000 kW) of industrial gas turbines now effectively marinised for marine propulsion. In addition to reliability, easy maintenance, low volume, etc., the very easy application to electric drives and to automation make the units attractive. Geared drive usually utilises locked train helical gears or alternatively epicyclic gearing.

CPP development has also broadened the possibilities of various propulsion systems, including geared diesel – gas turbine systems. Marine gas turbines do run with a high noise level and they require to be water washed at regular intervals, the latter depending upon the type of fuel being used. The recently changing design of ships has meant that the owner, or operator, needs to analyse propulsion systems carefully for all economic factors, which vary greatly for VLCC, Rolls-Royce, LNG, container vessels, etc.

Aero-derived

Apart from RN units so derived from aero gas turbines the first British MN vessel so engined was the g.t.s. *Euroliner* in 1970. Turbo Power and Marine Systems Inc. twin gas turbines, 22,500 kW each at 3,600 rev/min drive separate screw shafts at 135 rev/min through double reduction locked train gears, with CPP. Main electrical alternators are driven from the gearbox.

11

SAFETY AND ENVIRONMENTAL

When people decided to take their trade to the open ocean they knew that they were working in a harsh and difficult environment. Despite this the lore of the sea was compelling and many have succumbed to its power. However, modern life demands that we endeavour to make all our places of work and leisure as safe as possible.

The modern structure for determining the development of international shipping in a safe environment has been many years in construction and until recently has been based on a degree of common sense. Now the International Maritime Organisation (IMO) has started to develop several areas of recommendations that filter down to the different flag administrations for them to develop their own legislation.

The important areas for the modern student are MARPOL Annex VI and STCW (including the 2010 Manila amendments). The introduction of the ISM code has also had an effect on the operation of ships and should be studied carefully by the student.

Seafarer Safety in the Engineroom (crankcase explosions)

Introduction

The student should first refer to Volume 8 for a consideration of spontaneous ignition explosions have occurred steadily over the years with perhaps that of the *Reino-del-pacifico* in 1947 the most serious of all. In fact crankcase explosions have occurred in all types of enclosed crankcase engines, including steam engines. Explosions occur in both trunk piston types and in engines with a scraper gland seal on the piston rod. Much research has been done in this field but the difficulties of full experimentation utilising actual engines under normal operating conditions is almost impossible to attempt. The following is a simplified presentation based on the mechanics of cause of explosion, appropriate DoT regulations and recommendations and descriptive details of preventative and protective devices utilised.

Mechanics of a crankcase explosion

1. A hot spot is an essential source of such explosions in crankcases as it provides the necessary ignition temperature, heat for oil vapourisation and possibly ignition spark. Normal crankcase oil spray particles are in general too large to be easily explosive (average 200 μm). Vapourised lubricating oil from the hot source occurs at 400°C, in some cases lower, with a particle size explosive with the correct air ratio (average 6 μm). Vapour can condense on colder regions, a condensed mist with fine particle size readily causes explosion in the presence of an ignition source. A lower limit of flammability of about 50 mg/l is often found in practice. Experiment indicates two separate temperature regions in which ignition can take place, that is, 270–350°C and above 400°C.
2. Initial flame speed after mist ignition is about 0.3 m/s but unless the associated pressure is relieved this will increase to about 300 m/s with corresponding pressure rise. In a long crankcase, flame speeds of 3 km/s are possible giving detonation and maximum damage. The pressure rise varies with conditions but without detonation does not normally exceed 7 bar and may often be in the range of 1–3 bar.
3. A primary explosion occurs and the resulting damage may allow air into a partial vacuum. A secondary explosion can now take place, which is often more violent than the first followed by similar sequence until equilibrium.
4. The pressure generated, as considered over a short but finite time, is not too great but instantaneously is very high. The associated flame is also dangerous. The gas path cannot ordinarily be deflected quickly due to the high momentum and energy.
5. Devices of protection must allow gradual gas path deflection, give instant relief

6. Delayed ignition is sometimes possible. An engine when running with a hot spot may heat up through the low-temperature ignition region without producing flame because of the length of ignition delay period at low temperatures. Vapourised mist can therefore be present at 350–400°C. If the engine is stopped the cooling may induce a dangerous state and explosion. Likewise air ingress may dilute a previously too rich mixture into one of dangerous potential.
7. Direct detection of overheating by thermometry offers the greatest protection but the difficulties of complete surveillance of all parts is prohibitive.
8. A properly designed crankcase inspection door preferably bolted in place, suitably dished and curved with say a 3-mm thickness of sheet steel construction should withstand static pressures up to 12 bar although distorted.
9. There are many arguments for and against vapour extraction by exhauster fans. There is no access of free air to the crankcase and the fan tends to produce a slight vacuum in the crankcase. On balance most opinion is that the use of such fans can reduce risk of explosion. The danger of fresh air drawn into an existing over rich heated state is obvious. On the practical aspect leakage of oil is reduced.

Crankcase safety arrangements

The following are based on specific guidance to surveyors from a leading flag state – Maritime Coastguard Agency (MCA):

1. Means should be adapted to prevent danger from the result of explosion in crankcases with forced lubrication systems.
2. Crankcases and inspection doors should be of robust construction. Attachment of the doors to the crankcase (or entablature) should be substantial.
3. One or more non-return pressure relief valves should be fitted to the crankcase of each cylinder and to any associated gear or chain casing.
4. Such valves should be arranged or their outlets so guarded that personnel are protected from flame discharge with the explosion.
5. The total clear area through the relief valves should not normally be less than 115 cm^2/m^3 of gross crankcase volume.
6. Engines not exceeding 250-mm cylinder bore but larger than 200-mm bore with strongly constructed crankcases and doors may have two valves usually fitted at the crankcase ends. Similarly constructed engines not exceeding 200-mm cylinder bore or having a crankcase volume of less than 0.6 m^3 need not be fitted with relief valves.

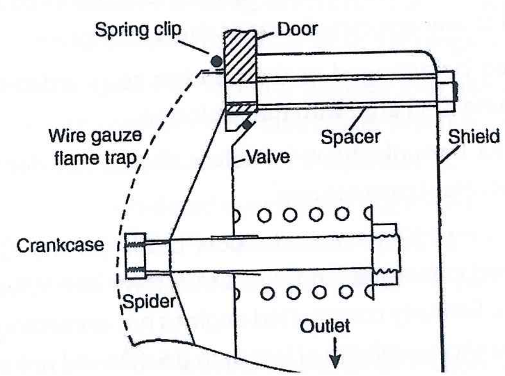
7. Lubricating oil drain pipes from engine sump to drain tank should extend to well below the working oil level in the tank.
8. Drain or vent pipes in multiple engine installations are to be so arranged so that the flame of an explosion cannot pass from one engine to another.
9. In large engines having more than six cylinders it is recommended that a diaphragm should be fitted at near mid length to prevent the passage of flame.
10. Consideration should be given to means of detection of over-heating and injection of inert gas.

Preventative and protection devices

In general the following aspects are worthy of consideration, that is, relief of explosion, flame protection, explosive mist detection and bearing temperature detection.

Crankcase explosion foor

A design is shown in figure 11.1. The sketch illustrates a combined valve and flame trap unit with the inspection door insertion in the middle. The internal section supports the steel gauze element and the spider guide and retains the spindle. The external combined aluminium valve and deflector has a synthetic rubber seal. Pressure setting on such doors is often 1/15 bar (above atmospheric pressure). Relief area and allowable pressure rise vary with the licensing insurance authority but a metric ratio of 1:90 should not normally be exceeded based on gross crankcase volume and this should not allow explosion pressures to exceed about 3 bar.



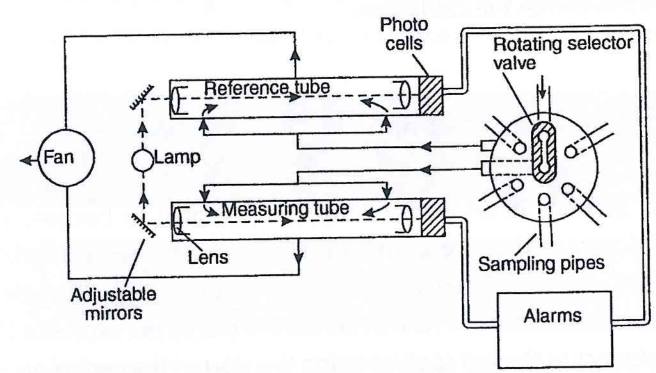
Flame trap

Such devices are advisable to protect personnel. The vented gases can quickly be reduced in temperature by gauze flame traps from say 1500°C to 250°C in 0.5 m. Coating on the gauzes, greases or engine lubricating oil, greatly increases their effectiveness. The best location of the trap is inside the relief valve when it gives a more even distribution of gas flow across its area and liberal wetting with lubricating oil is easier to arrange. A separate oil supply for this action may be necessary. The explosion door in figure 11.1 has an internal mesh flame trap fitted.

Flame traps effectively reduce the explosion pressure and prevent two-stage combustion. Gas-vapour release by the operation of an oil-wetted flame trap is not usually ignitable. Typical gauze mild steel wire size is 0.3 mm with 40% excess clear area over the valve area.

Crankcase oil mist detector

If condensed oil mists are the sole explosive medium then photoelectric detection should give complete protection but if the crankcase spray is explosive the mist detection will only indicate a potential source of ignition. The working of one design of detector should be fairly clear from figure 11.2. The photo cells are normally in a state of electric balance, that is, measure and reference tube mist content in equilibrium. Out-of-balance current due to rise of crankcase mist density can be arranged to indicate on a galvanometer which can be connected to continuous chart recording and auto visual or audible alarms. The suction fan draws a large volume of slow moving oil–air vapour mixture in turn from various crankcase selection points. Oil mist near the lower critical density region has a very high optical density. Alarm is normally arranged to operate at



▲ **Figure 11.2** *Crankcase oil mist detector*

21/2% of the lower critical point, that is, assuming 50 mg/l as lower explosive limit then warning at 1.25 mg/l.

Operation

The fan draws a sample of oil mist through the rotary valve from each crankcase sampling pipe in turn, then though the measuring tube and delivers it to atmosphere. An average sample is drawn from the rotary valve chamber through the reference tube and delivered to atmosphere at the same time. In the event of overheating in any part of the crankcase there will be a difference in optical density in the two tubes, hence less light will fall on the photo cell in the measuring tube. The photo cell outputs will be different and when the current difference reaches a predetermined value an alarm signal is operated and the slow turning rotary valve stops, indicating the location of the overheating.

Normal oil particles as spray are precipitated in the sampling tubes and drain back into the crankcase.

CO_2 drenching system

Thirty per cent by volume of this inert gas is a complete protection against crankcase explosion. This is particularly beneficial during the dangerous cooling period. Automatic injection can be arranged at, say 5% of critical lower mist density but in practice many engineers prefer manual operation. When the engine is opened up for inspection, and repair at hot source, it will of course be necessary to ensure proper venting before working personnel enter the crankcase.

Bearing temperature detection

The principal bearings in an engine have the potential to become the cause of a crankcase explosion. If they are becoming overheated for some reason the localized 'hot spot' causes vapourisation of the oil to form the oil mist and thereby setting up the conditions described above in 'The mechanics of a crankcase explosion'. The very same bearing can also act as the hot spot initiating the start of the explosion.

of catching the oil that had sprayed from the big end bearing and measuring the temperature of the oil to give an indication of the temperature of the bearing.

Compared to the indirect measurements of a conventional oil mist detector, direct continuous monitoring of the crankpin bearing temperature permits earlier detection of a bearing overheating. This prevents major failures of critical and highly costly engine components and protects against the direct consequences of the non-operational availability of the engine. It also avoids any extra costs related to unplanned expensive maintenance operations. To be able to continuously detect and monitor the temperature of rotating bearings in an accurate and reliable manner, Wärtsilä has recently developed an innovative wireless temperature-sensing device.

The operating principle is to directly measure the temperature of the connecting rod big end bearing using a temperature sensor fitted as close as possible (within a few millimetres) to the bearing surface. The sensor then keeps in touch with the outside world by using a patented, surface acoustic wave (SAW) radar technology, which has been proven to be the most reliable technology for real-time wireless temperature monitoring. The signal processing unit (SPU) generates a radio wave pulse, which is picked up by the stationary antenna and converted into an acoustic wave which is sent to the rotating sensor. This acoustic wave propagates along the surface of a SAW chip fitted with multiple reflectors, thus permitting the sensor to reflect back a pulse train to the stationary antenna; the time delay between echoes depends on the temperature of the SAW chip.

The wireless temperature sensors are installed in the rotating connecting rod big end. The stationary antennas are screwed to a custom-designed bracket fixed inside the engine block in such a way, that the sensors and antennas pass within a fixed distance of each other at each rotation of the engine crankshaft. The resultant signal is then transmitted via a thin cable passing through the engine block, to the SPU fixed to the engine, and from there to the control room cabinet placed in the engine room.

The Environmental Agenda of Shipping

Marine fuels and emissions

In the century that has passed since the diesel engine first showed its promise as a power source for ships, it has come to dominate the marine scene. Steam power, once dominant, is reduced to niches such as LNG carriers and nuclear warships. Gas turbines have penetrated the marine propulsion market to a limited extent, primarily in warships and some cruise vessels and fast ferries. Natural gas is starting to make inroads in marine propulsion while petrol and LPG are restricted to small craft. Thus in terms of fuel used and installed power, the fuels and emissions question centres on the diesel engine.

There are four main constituents of diesel engine exhaust which are of environmental concern NOx, SOx, CO_2 and particulates (soot). Until recently CO_2 was seen as a harmless naturally occuring gas neither controlled nor legislated against. Concern about NOx grew out of city smog problems. Sulphur has long been seen as a problem with fossil fuels. Columns of smoke, once seen as a positive sign of economic activity, are now frowned on at sea or ashore.

Cutting these emissions is not just an engineering matter, though some engineering solutions have been developed and others are under development. Looking at the broader picture, exhaust emissions from ships are a complex blend of politics, economics and engineering. Some of the engineering solutions are considered in more detail below but first it is instructive to look at the question of marine fuels.

Early in its history the diesel engine showed that with suitable design and adjustment it could burn a wide variety of liquid fuels. Sixty years ago there began a move towards using heavy fuels of the type used in boilers. This proved a successful and much cheaper solution than burning lighter distillate fuels, particularly in deep sea merchant vessels covering long distances.

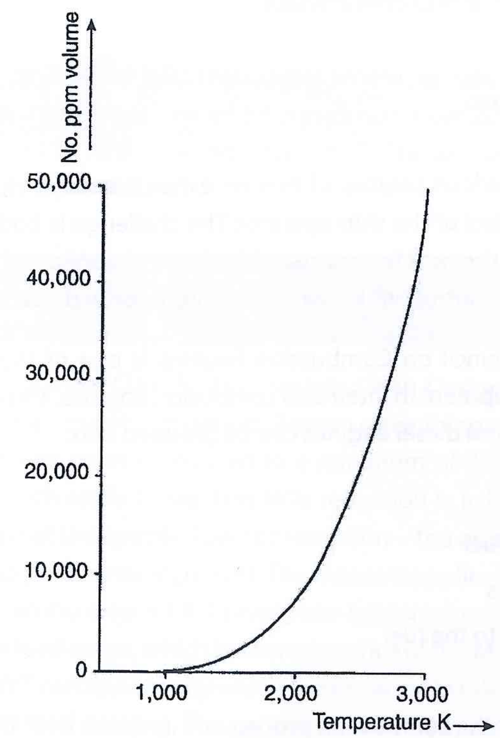
Then, 30 years ago the marine industry received warning from the oil industry that the quality of residual fuels was going to deteriorate substantially. Changing refinery processes in the quest for more valuable fractions for road and land use would leave a residue that the oil industry considered might be tough for the diesel engine to swallow. However, the engine manufacturers tackled the problem successfully, overcoming combustion troubles and also excessive wear caused by catalytic fines (abrasive particles) in the fuel. Ships' crews had to exert a much higher level of supervision, to ensure that fuel purification systems were run correctly, and also in fuel management, since the latest load of fuel to be bunkered might not be compatible with the previous lot. In addition came the problem of disposal routes for sludge. Both large main engines and small bore auxiliary engines were perfected to run on heavy fuel of dubious quality where viscosity and density were usually the only two parameters closely controlled. The incentive was low price. IF380 fuel for example is a fraction of the price of the light

Exhaust emissions

CO_2 is a product of combustion and the amount will depend on the chemical composition of the fuel, natural gas having a lower value than typical liquid fuels. Poor combustion will produce soot and unburned hydrocarbons in the exhaust.

NOx is a function of high-temperature combustion in the engine cylinders where the nitrogen in the air reacts with the oxygen (figure 11.3). Current and forthcoming legislation limits NOx emissions and this is one of the engine designers' biggest challenges. Apart from controlling NOx production within the engine cylinder, the exhaust stream can be treated by selective catalytic reduction to reduce final NOx emissions to very low levels.

SOx in the exhaust stream represent the sulphur that was present in the fuel. They can be removed from the exhaust by scrubbing, or by eliminating sulphur from the fuel in the refining process before it is supplied to the ship. Intertanko and various other



organisations have advocated the latter course. If this were done on a worldwide basis, vessels everywhere would burn an LSF. After all, the principle is applied on land. Vehicles, aircraft, heating systems and other consumers are supplied with LSFs. The proposal has been met with strong reactions – refineries are not geared to do this in the quantities needed, costs would be incurred and reorganisation required. However, to a limited extent this is happening with the introduction of ECAs in, for example, the Baltic, North Sea and some other coastal regions. There, sulphur in fuel is restricted to 1.5%, and this level will be successively reduced to 1% then even further in the course of the next few years. Residual fuel sold for ship bunkers outside the sulphur-controlled zones continues to have a high sulphur content.

Marine fuels are covered by an ISO specification and there are controls on various parameters. The standard also specifies that fuel shall not contain any added substance or chemical waste which jeopardises the safety of ships or adversely affects the performance of machinery or is harmful to personnel or contributes overall to air pollution. Although the limited routine bunker acceptance tests do not make a detailed chemical analysis, one specialist analysis company has reported that 2% or 3% of fuels analysed have evidence of chemical waste.

Reducing emissions

As seen, there are various sources of marine exhaust emissions, some of which are under the direct control of the ship operator. The challenge is both to meet emissions regulations covering the next few years and further to 'future proof' vessels, accounting for stricter emissions controls which will come into force in due course.

The International Council on Combustion Engines is one of the leading discussion groups for the development in internatal combusion engines. This group suggests that emmission control from diesel engines can be grouped into:

- *Pre-treatment*
  - Denitration of fuel
  - Alternative fuels
  - Water addition to the fuel
- *Primary methods*
  - Modification of the combustion process

  - Exhaust gas recirculation
  - Humid air motor
- *Secondary methods*
  - Re-burning
  - SCR
  - Plasma reduction systems
  - Emission abatement systems
    - Wet systems
    - Dry systems

One effective solution is to use less fuel for the amount of work done. Here, Ro-Ro is very active in its ship design side in developing new propulsion solutions and also offshore vessel hull designs which reduce the amount of fuel needed to carry out a given operational profile. Its work also covers engine design itself. The thermal efficiency of marine diesel engines is already very high compared with prime movers on land and in the air, but design development is still producing small increments in efficiency. At the same time the focus is on reducing NOx emissions by careful design of the combustion system.

NOx emissions are covered by IMO regulations where progressively stiffer limits are being phased in. Tier II was implemented for vessels built from 2011, and the very much tougher Tier III applies to new buildings from 2015. The actual permitted emissions vary somewhat with engine size.

Clean design

Ro-Ro Bergen engines meet Classification Society Clean Design notation now being widely specified by responsible shipowners. Among other things Clean Design requires that NOx in the exhaust gases is reduced to a minimum of 20% less than the IMO's permissible limits which apply today. This NOx reduction is achieved without loss of efficiency, meaning that the specific fuel consumption – the amount of fuel burnt per kilowatt of power output – is not increased. The means is application of the Miller cycle in combination with an increase in CR. To avoid low-load smoke and poor transient load behaviour in the low load range, which is a consequence of the Miller cycle, the engines are equipped with VVT mechanisms by which the Miller cycle inlet air valve timing may be turned off for low load running. The control of the VVT system is exercised by the

Bergen lean burn gas engines using natural gas as fuel (bunkered as LNG) already comply with the future Tier III requirements. Much of the NOx remaining in the diesel engine exhaust stream can, if required, be removed by selective catalytic reduction using urea. Many such systems are on the market.

For the common liquid fuels, CO_2 emissions are largely related to the efficiency of the engine and ship. They can be reduced by about 20% if natural gas is used as fuel mainly because of the chemical composition. Ro-Ro marine gas engines in service have demonstrated this, together with a reduction in NOx of about 95% without further exhaust clean up and an absence of SOx and particulates. Ro-Ro aero-derivative gas turbines for marine propulsion can also burn natural gas very efficiently with even less unburned hydrocarbons.

As noted, LSFs can be either specified or mandated, but if economic forces promote HSFs for marine use, a number of proprietary scrubber systems are now being approved by IMO. These are claimed to remove a high percentage of sulphur compounds and also particulates from the exhaust.

Energy efficiency

IMO has introduced an Energy Efficiency Design Index (EEDI) to indicate the number of grams of CO_2 per tonne mile a particular design of ship will emit. It is intended that this will be refined over the coming years. The index is a formula that covers main engines plus auxiliary engines, shaft generators and electric motors set against the vessel's carrying capacity and speed. Among its uses is for it to be used as a tool in the operational management of the ship, for assessing levies on bunkers or as an input to possible emissions' trading schemes. For some types of merchant ship the calculations would be fairly straightforward. The difficulty in developing an equitable index is where vessels habitually use only a proportion of their installed power; examples include offshore vessels and tugs.

Ships are also required by IMO to have a Ship Energy Efficiency Management Plan (SEEMP). It is intended that the SEEMP should be developed by individual shipping companies recognising that no two companies will be alike therefore the owner will have to take into account parameters such as the ship's operation, type, machinery, charterer, routes and crew. The SEEMP is intended to improve a ship's energy efficiency by considering four stages: planning, implementation, monitoring, self-evaluation and

Planning

Here the ship manager should recognise that there are a number of strategies to use. These could be speed and trim optimisation, just in time operation, weather routing and hull and machinery maintenance plans. This will take into account the business of the ship and company and will be different depending upon the ship type, routes, cargos, etc.

There may be company internal structures to consider such as early communication between operators, charters, ports and traffic management services. Staff development might well plan a role. IMO are suggesting that goals should be set so that progress can be measured although these goals do not have to be widely publicised.

Implementation

When this stage has been designed by the senior managers it should be clearly communicated to the company staff especially the ship's staff.

Monitoring

The monitoring system used must be objective and quantitative and should be according to international standards. The IMO's Energy Efficiency Operational Index (EEOI) is such a monitoring tool and can be used for this monitoring task. Continuous, consistent and reliable data collection should be at the core of any system however IMO do not wish for another burden to be placed on the ship's staff and they suggest that the recording process is carried out ashore.

Self-evaluation and improvement

This part of the process is to identify the measures that work and the ones that do not. The next planning stage should be changed or modified in the light of findings from the first cycle.

Engineering strategies

IMO say that the following need to be considered by the company as a way of improving efficiency through better use of the propulsion machinery:

- Use of CBM
- Use of fuel additives

- Valve improvements
- Torque analysis
- Automated engine monitoring systems
- WHR (retrofit where cost effective)
- On-board energy management systems
- Different fuel types
- Renewable energy sources
- Regular engine management software upgrades.

Related to world trade levels

With the media and governmental spotlight firmly on the marine industry as a polluter, it has to be borne in mind that shipping is a reaction industry. If the amount of cargo decreases, the ships will either never be built, laid up or will go slowly to save fuel. While air freight has captured some high-value cargoes such as cut flowers, fresh vegetables and hig-value consumer electronics, some 90% of world trade goes by sea. The cost and emissions per tonne mile for transporting, say, a container on a container ship is a small fraction of that incurred transporting the same container by road. With the current downturn in the world's economies, many ships are resorting to slow steaming. Speed at sea costs money since the power requirement for a given vessel increases disproportionately as the speed goes up. Throughout the history of the powered ship, transit speeds in given trades have been determined by the ruling balance between fuel cost, other operational costs, capital invested in ships, the cost of capital invested in goods in transit and the acceptable time from dispatch to arrival of a particular consignment of goods. When this balance is upset, slow steaming may be one solution. Direct fuel costs will be reduced but may be partly cancelled out by the other factors.

For the coming years, ways will be found of reducing emissions from ships. Rolls-Royce will be playing its part in this, and also in the broader overall picture of increasing efficiency and ensuring that the least possible amount of fuel is burnt for the given amount of work done.

Other methods of reducing exhaust gas emissions

water requires an increase of 20–30% in fuel pump capacity. Precautions must also be taken to maintain the oil/water emulsion in a stable condition and to prevent corrosion of the fuel system components. Wärtsilä have favoured the water injection system where a controlled amount of water is injected alongside the fuel.

2. The use of SCR.

Selective catalytic reduction

SCR technology was developed for land-based installations and is being developed for main applications and involves injecting small amounts of a single atom nitrogen-based additive, such as ammonia [NH_3], into the exhaust. Due to the difficulties and dangers of handling ammonia on-board ship a safer more easily handled ammonia compound called urea {$2[NH_2]CO$} is being used. The principle is to combine the nitrogen atoms of the NOx and NH_3 compound to form a stable nitrogen [N_2] molecule which is the main constituent of air.

The principle catalytic reduction process of the ammonia compound is according to the following chemical reaction:

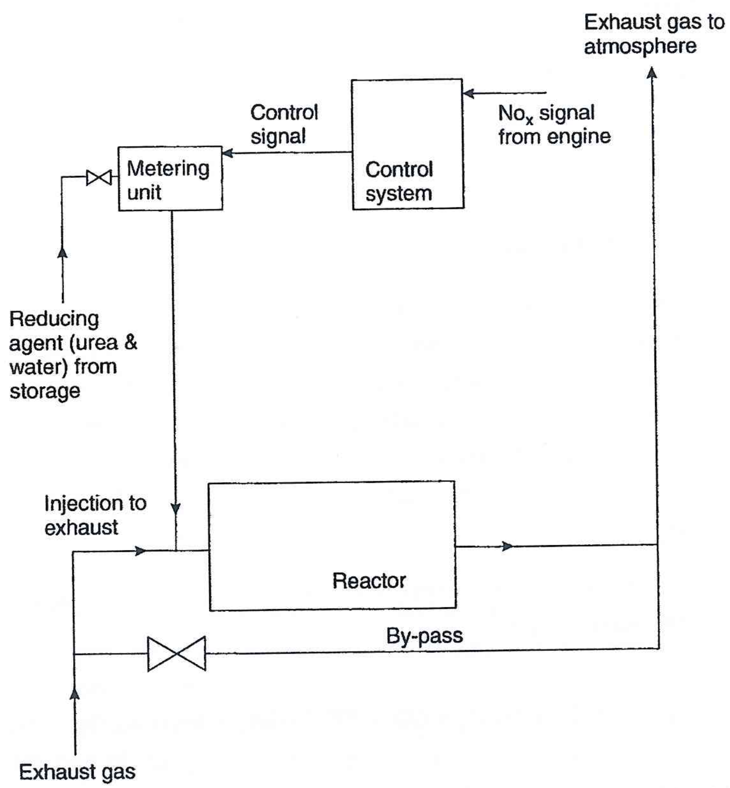
$$2NO + 2NH_3 + 1/2O_2 + CO_2 \xrightarrow{\text{catalysis}} 2N_2 + 3H_2O + CO_2$$

To accomplish this at the temperatures encountered in exhaust gas – 250–450°C a catalyst is required. The catalyst is an oxide of vanadium carried on a heat-resistant honeycomb of ceramic. In order to minimise the pressure drop across the reactor the gas passages of the honeycomb core must be of sufficient CSA.

The urea is mixed with water and metered into the exhaust gas upstream of the reactor at a rate dependent upon engine load (figure 11.4). The system is best suited to steady, high-load conditions and is less suited to low-load conditions. If the temperature is too low, the reaction rate will also be low and condensation of ammonia will poison the catalyst and if the temperature is too high, NH_3 will burn rather than react with the catalyst.

Exhaust gas recirculation (EGR)

Of all the post-combustion treatment systems currently being placed on engine to



▲ **Figure 11.4** *Selective catalytic reduction (SCR) apparatus*

Already a popular emission control technique for motor vehicles the technology is now starting to mature.

The theory of diesel engine combustion will have been covered in Volume 3 (Applied Heat). Here students will have learnt that for complete combustion the engine is supplied with more air than is required. The additional air is called excess air. EGR technology replaces some of that excess air with recycled exhaust gas. This has the effect of lowering the peak temperatures in the combustion space and therefore the NOx formed is also lower.

The technique used to accomplish this process is a valve working in the exhaust gas path. This could lead to the valve becoming clogged which would stop it from working properly. Therefore this will have to be considered an important maintenance item in

Developments in propulsion efficiency (including upgrading)

A study of the volume on Naval Architecture in this series of books will determine that a propeller's function is to drive a vessel as far forward as it can with every revolution. Working in a solid the distance travelled would match the pitch of the blade, which would be regarded as the maximum achievable, giving an efficiency index of 1.

Working in water, however, the propeller must generate a pressure difference automatically leading to an acceleration of the water. The reactive force is then transmitted through the shaft line and thrust block to the hull of the vessel. The distance travelled by the vessel from the force produced by each revolution, will not achieve the theoretical maximum for a number of reasons which are external to the propeller. These influences will be laminar flow of water into the propeller, cavitation produced and wakefield interaction as a result of the propeller disc rotating in a turbulent inflow of water following the water's disturbance having just passed over the hull of the vessel.

Optimising the function of a propeller, so that it performs as close to the theoretical maximum, means that the designer should not consider the propeller in isolation. She/he needs to make reference to its working environment and match the propeller to the design of the aft end of the hull. This is because the flow of water around the hull of a vessel and then into the propeller is not uniform. The hull and/or a number of fittings or appendages will disturb the water before it reaches the propeller and for this reason the conventional propeller blade will revolve in water of different inflow speeds, which translates as vibration that will be transmitted to the hull of the vessel.

One answer to this problem has been the development of the skewed propeller which due to its skewed propeller blade sections being located at different radii it does not enter this so-called wake peak. The blades of propellers travel in a different direction across the wake field. At the top they cross in one direction and at the bottom in the other. This again can cause fluctuating pressure pulses leading to inefficiency and increased vibration as a result of cavitation and again the resultant vibration is transmitted back to the vessel's hull through the propeller shaft and bearings.

One of the most important design considerations is the lift/drag equation. Each propeller blade is an 'areofoil' shape and therefore a larger blade area will not only set up larger 'lifting' forces but will also cause more resistance 'drag' due to friction. As a consequence larger blades may not necessarily increase efficiency and the shape of the blade has an effect on the cavitation produced.

It used to be thought that vibration occurrence at a specific combination of vessel speed and propeller revolutions per minute, was due to the resonance between the blade and the natural frequency of the hull, coupled with the clearances of the propeller. As a consequence it was sometimes possible to make improvements by changing the propeller for one with a different number of blades or changing the clearances between the blades and the hull of the ship. It has now been realised that any improvement in reducing vibration and increasing efficiency came about due to the new propeller being placed in a more favourable position in the vessels' wake field.

Hull to propeller tip clearance is also important for the prevention of vibration. Doubling the tip clearance reduces the pressure pulses and the integrated force by a factor of 2. Achieving a smooth inflow of water to each radial and circumferential position of the rotating propeller disc to enable an even force to be generated over the blade's surface, without creating cavitation, is not an easy task. However, research is now focused in this area as MAN Diesel & Turbo explain in their report on the hydrodynamics of ship's propellers.

Rolls-Royce has their own research centre in Kristinehamn Sweden. The hydrodynamic research centre (HRC) originally built by the Swedish propeller manufacturer Kamewa which is now part of the Ro-Ro group, has recently celebrated 40 years of operation. The cavitation tunnels are today a tool for analysing hydrodynamic performance complementing the fast developing field of CFD.

Rolls-Royce also say that they have good hydrodynamic comparisons between fixed pitch propellers (FPP) and CPP. Generally, in hydrodynamic comparison an FPP is 0.5–1.0% more efficient in open water. The difference can be reduced by increasing the manufacturing accuracy of the CPP and its installation.

MAN Diesel & Turbo and Rolls-Royce hold the view that the major difference in efficiency between an FPP and CPP is mostly related to the smaller hub of the former. A typical value for a non-ice class propeller is in the range of 1–1.5% from this effect alone. However, the CPP will regain most of this difference due to its flexibility in adapting to the various conditions that a vessel experiences.

There is still a need for observations to be made on vessels while they are in operation. These observations required the installation of a window in the hull of the vessel during drydocking. Lloyds Register (LR) have developed the system during the past 10 years and window-based observation techniques have evolved from still cameras, strobe lights and high-speed cine film to low-cost camcorders and high-speed digital video

The latest technique however is to use a 'keyhole' observation technique which has been pioneered by LR. The boreholes are tapped holes made in the hull of the vessel which can be carried out without the vessel being drydocked.

The techniques have been enhanced by the use of low light digital cameras operating at frame rates of 25 Hz and shutter speeds of up to 1/1,000 of a second. Although this is the main tool for propeller observations at LR a further development is the use of high-speed video systems. Using digital technology the cameras can be activated by a signal from the propeller shaft, which can also be synchronised with vibration and pressure pulse readings.

The resultant information can be brought together to better understand the relationship between the time-related cavity collapse event and the resultant information used to confirm the cause of erosion on propellers or surrounding fixtures.

With fuel costs now accounting for a high proportion of the running cost of a ship and the need to reduce CO_2 emissions from sea transport, developments in propulsion technology that save fuel and consequently reduce emissions can be very attractive.

Senior engineers will be interested in retro fit developments such as the integrated propulsion system Promas developed by Ro-Ro which could be one option in achieving efficiency goals as part of the SEEMP described elsewhere in this chapter.

Promas is an integration of the conventional propeller and rudder configuration of a typical single or twin screw vessel. A special hubcap is fitted to the propeller which smooths the flow of water from the propeller onto a bulb forming part of the rudder, while the spade rudder itself has a special form with a twisted leading edge. The resulting improvement in efficiency is made up of several components. One is the reduced loss in the hub region of the propeller. The second is that the shape of the rudder converts some of the swirl energy in the propeller slipstream, which is normally lost, into additional forward thrust. The third component is that the shape of the rudder gives a much higher side force for a given rudder angle in the ±5° range normally used for course corrections. Increased side force at low speeds also improves manoeuvrability.

The best results are achieved on blunt single-screw vessels with a block coefficient greater than 0.8 and a design speed in the 14–16 knot range. Here efficiency gain can be as much as 6–9% compared with conventional solutions. Faster and slenderer single-screw vessels such as car carriers can have an efficiency gain of 2–5%. In a well-designed twin screw vessel there is less improvement to be had, but even so 1–3% can represent a substantial amount of money at today's fuel prices, and the increased cost of the propulsion equipment can be quickly recovered.

Development work was carried out on many vessel types and a variety of rudder shapes and bulb configurations. Initial work was done using CFD methods, and promising solutions were then verified at model scale at the Ro-Ro Hydrodynamic Research Centre.

In particular, the interactions between the hubcap and the curved leading edge of the bulb were studied at different loading conditions and rudder angles. In theory, the gap between the hubcap and the forward part of the rudder bulb should be as small as possible. In practice there has to be a gap sufficient to allow for the structural deflection under load of the propeller aperture and rudder, and this Ro-Ro system also takes account of the tolerances that can be realistically achieved under real shipbuilding conditions.

In addition to achieving a high efficiency, the aim with Ro-Ro propulsion systems is always to reduce noise and vibration. With Promas, pressure pulses from the propeller can be reduced. Due to the presence of the hubcap and bulb, the risk of hub vortex cavitation is removed. Consequently the radial distribution of hydrodynamic loads on the propeller blades can be modified, increasing the loading in towards the hub and reducing the loading at the tips, which helps to cut the intensity of blade pressure pulses.

Rolls-Royce also provides a simplified version of Promas (Promas Lite) for upgrading existing vessels. In this case the ship's existing rudder can be retained, but is fitted with a bulb, while the propeller is equipped with the special hubcap and new blades. Several ropax ferries that have had this treatment have shown dramatic improvements in efficiency, with payback times of 1–2 years. Often the vessels still have worn original propellers optimised for sea trial speed. Fitting new propellers, or new blades in the existing CPP hubs, optimised using the latest design techniques for the actual service speed, give a substantial cut in fuel consumption, helped by the other components, even though the rudder shape is not ideal.

Another Rolls-Royce propulsion product, the Azipull azimuth thruster, draws on the same knowledge base as Promas with regard to hydrodynamic and mechanical interactions. Work on Azipull began in 1997, with a view to combining the theoretical advantages of pulling propellers and expertise in conventional azimuth thrusters to give a new concept. Azipull provides the shipowner with a very efficient propulsor which at the same time uses well-proven gear technology and is a low-risk solution. The inboard gearhouse and steering system is the same design as is used in other

diesel electric transmission. CPP or FPP can be specified to suit the drive system and application.

The innovative part of the concept is the underwater unit, which has the lower bevel gear set enclosed in a streamlined housing behind a pulling propeller. The leg is hydrodynamically optimised to convert into an additional forward thrust some of the swirl energy in the propeller slipstream which would otherwise be wasted. As the propeller works in a clean flow of water, provided the hull design is suitable, efficiency is increased and noise and vibration reduced. The shape of the underwater unit provides a much larger rudder effect than conventional azimuth thrusters, which in practice cuts fuel consumption since less thrust vectoring is needed to maintain a steady course.

The aim of the Azipull concept was to extend azimuth thruster technology into a higher-speed range. This has been achieved. The first units of this design have been very successful in a ferry operating at a 22-knot service speed. The advantages also hold good at much lower speeds, in the 13–15-knot range, where hundreds of these thrusters have been applied to offshore platform supply vessels, coastal and short sea cargo vessels and other types.

Application areas have been extended further, for example to short sea tankers, where twin Azipull azimuth thrusters are each coupled directly to a diesel engine which also drives a generator set. The result is much better manoeuvrability than traditional solutions, and an enhanced level of safety through propulsion redundancy. Bergen Star is an excellent example, operating on the Norwegian coast.

Passenger vessels are another Azipull application, where efficiency and manoeuvrability combined with low levels of noise and vibration are key factors. A 12,700GT vessel has the distinction of being the first cruise ship to specify Ro-Ro Azipull thrusters for main propulsion, and the installation has proved very successful. Maneuverability is reported to be very good and vibration levels exceptionally low. Two Azipull AZP120 thrusters with pulling propellers provide propulsion and steering. Each has a rated input power of 2,310 kW supplied by a four-engine diesel electric system. Due to the operating area, the thrusters have LR ice class 1A notation.

Promas and Azipull can be combined in a single vessel. A ferry ordered in 2011 has a centre line CPP in a Promas configuration, flanked by two electrically driven Azipull thrusters. The thrusters manoeuvre the vessel in and out of the confined harbours and control it through a strong current setting across the piers, then at about 80% of service speed the main propeller provides the extra power for full speed.

The Professionalism of Marine Engineers

Initial education and training and the need for professional development

One of the primary aims of this book is to help – qualified engineers and engineers under initial education and training – in preparing for the motor engineering knowledge part of the certificates of competency as engineering officers on merchant vessels of all types and size.

The primary issue that we face is that the skill set required of a marine engineering officer is changing all the time. Just a few short decades ago the industry was faced with steeply rising capital and running costs, very little research and development, difficult recruitment patterns and an ageing workforce.

Not all of these problems have been solved but one of the most important has changed dramatically. The industry is now at the cutting edge of technology with our knowledge of material science often holding back the pace of development. This is having the effect of projecting a more positive image of the industry and making it an exciting place to work and therefore attractive to young persons.

Modern marine engineers have to spend more of their time as 'systems engineers' than they did in the past. The maintenance requirement of the job role is still important but has to take a more secondary role to the watchkeeping for the following reasons:

- The machinery is becoming much more reliable and therefore does not need the service intervals of the older machinery.
- Reduction is staff means that the current staff have less time to spend on maintenance activities.
- Due to increases in technology the engineers must devote a larger proportion of their time to ensure that they understand the theory behind the machinery's operation.
- Education and training systems around the world are not all as good as each other in producing the calibre of engineering officer required to operate the modern fleet and maintenance-induced failure is a growing trend.

The impact of Standards for the Training and Certification of Watchkeepers (STCW)

We all appreciate that a major driver in setting the criteria for the education and training of modern ship's engineers is the IMO Standards for the Training and Certification of Watchkeepers (STCW). It has been a slow process from the original version but finally, with the Manila amendments, it looks like we will have a reasonable international base from which to build.

A second important influence on the education of seafarers is cost. Ship owners operate ships to make money and cost-effective staffing arrangements are essential. Therefore a ship owner or management company offering cadetships in the United Kingdom, for example, will be obliged to use the established education systems that are available. To step outside of the 'standard' system would mean that students would not achieve national qualifications and it would also be more expensive.

A recent EU funding project (Unification of Marine Education and Training – UniMET) aimed at sharing best practice throughout Europe has praised the UK officer cadetship system. The partnership formed by the Merchant Navy Training Board, the Maritime Coastguard Agency, industry and representatives from academic institutions, is an example of a system that other administrations could learn from.

The qualifications are now also linked to foundation degrees which must give the students the opportunity to complete a full honours degree, although this could be after the completion of their cadetship. Importantly, the new qualification structure reflects an up-to-date syllabus required by national and international regulatory authorities.

However, it is important that the education and training evolves to meet the changing requirements of the tasks of the sea-going engineer. IMO has now given a commitment to review the STCW criteria every 5 years.

Officer cadetships

In the United Kingdom the mix of technical content, skills and experiential learning within the officer cadetship programmes are also continually being reviewed by the members who make up the Maritime Skills Alliance. This is the employer-led organisation that has responsibility for setting the standards and keeping maritime skills, education and training relevant to the job role.

In the United Kingdom, the Merchant Navy Training Board (MNTB) considers that it is vitally important that all parts of the industry work together. This way, issues are identified, discussed and agreed, their involvement and 'buy-in' is secured and industry needs are met. This approach recognises and values all parts of the industry and their contribution to it.

The members of the Institute of Marine Engineering, Science and Technology (IMarEST) have a chance to play a part in the development of the UK's Education and Training system. This is because IMarEST has a place at IMO and through the correct mechanisms can influence decisions. It is also a member of the International Association of Marine Institutions (IAMI) which is an academic discussion group and also has an important role to play in the UK decision-making process.

Initial education and training in the United Kingdom might start with the requirements of STCW but more importantly we are teaching the engineers to expand upon their understanding and to think for themselves in difficult situations. This takes the UK marine engineer beyond the basic requirements determined by IMO and is a feature that is so important for the successful management of modern tonnage. The technological advancements that are due in the next few years will be difficult to understand and the consequences of operational mistakes will be more severe.

For example if the EGR valve on the main engine starts to malfunction (as happens all too often on a modern road car) then the exhaust gas emissions will not be correct and if the vessel is in a SECA then the engineers will have to be ready with a detailed knowledge of the system and all the problem-solving skills that they can muster. If not the owner will be faced with administrations looking to recover costs for environmental damage.

Increases in electronic systems at sea are placing more emphasis on the work of the Electro Technical Officer (ETO) and the latest problem with the Queen Mary 2 investigated by the MAIB shows the growing need for understanding complex control systems, and places a strong emphasis on the requirement for quality professional development of staff. Towards this end Videotel has plans to expand its online academy and Viking recruitment is planning a new training and conference centre which will be used to set up staff development discussions about different technical issues, such as 'future fuel' or which ballast water technology will be the most cost effective.

Advances in control engineering mean that in the near future mechanical components

diagnose faults or poor performance. However, this increase will require engineers to apply their problem-solving skills and logical thinking across complicated systems that may be interacting and dependent upon each other.

With the increased reliability of machinery comes another problem. How many senior staff will we soon have that have not seen a main engine unit opened up? Manufacturers are predicting that main engines will run from dry dock to dry dock. This would lead to only staff present at the dry dock being involved with the main engine overhaul. If this is the case then possibly it is time for ship owners and managers to regard dry docking as major opportunity for the staff development of the fleet's most senior officers.

Shipping company's staff development programmes and individual engineer's professional development are going to make the difference between the successful technical management of ships and struggling to stay out of trouble. Therefore the on-going professional development of marine engineers, beyond completing their class one certificate of competency, is essential.

Membership of an institute such as IMarEST is a very good method of professional development. The technical publications that accompany membership supply quality and up-to-date information about developments in marine equipment and infrastructure. Many websites and discussion groups give product information free of charge and more and more are supplying technical information. Engineers can also subscribe to newsletters, free of charge, which give a brief overview of what is going on within the industry without the cost of a full subscription.

However, focused staff development should also be used as a powerful management tool available to senior managers. Conferences and seminars are expensive and it is not cost effective to send the entire staff on one seminar. However, any person who does have the opportunity should then be asked to complete a briefing note for the chief engineers of the fleet. This would be a cost-effective way to keep everyone up to date.

In the near future marine engines will all carry equipment such as SCR systems or EGR valves. They will all have electronic combustion control, VVT and the performance and condition will be monitored closely by various computer-controlled systems.

A little further on time and the equipment will need to be so efficient that it will be totally enclosed with very little indication that it is even operating. This is a very different working environment from the one just a few years ago when touching a hot surface or being allowed close to rotation machinery was a real possibility. This new world will be an environment needing a sophisticated skill set from the engineers in

Watchkeeping duties

The maritime industry is full of tradition and often for a good practical reason. The maritime way of life, procedures and routines have been developed over many years and they should not be set aside without careful consideration.

A ship at sea obviously has to operate 24/7 and it must also be staffed to the correct level to maintain the safety of the vessel and crew. Traditionally the shift patterns, or watches, as they are called at sea, have been broken into three 4-h work periods for every 12-h period. The same pattern is repeated for the second 12-h period. This means that three people would have covered the watches as follows:

- 08.00 h to 12.00 h – This is the morning watch and the start of the working day. The watch will be very busy due to the work and interruptions from day working staff and senior engineers undertaking their duties. The end of a 24-h period main engineroom log is usually taking during the time just before mid-day.
- 12.00 h to 16.00 h – The afternoon watch. Not quite as busy as the previous watch due to the lunch break and afternoon tea. Not so many interruptions and therefore the engineer is left to complete his/her own work
- 16.00 h to 20.00 h – This is a slightly difficult watch due to the timing of dinner on-board, which is usually 18.00 h. This means that the watchkeeper must have a replacement while she/he goes for dinner or alternatively the engineer will have to wait until 20.00 h when she/he completes the watch.
- 20.00 h til midnight 00.00 h – Not a bad watch but usually the watchkeeper misses out on the social activities going on elsewhere on-board.
- 00.00 h to 04.00 h – Probably the most difficult watch. Mostly because it is difficult to achieve a long rest period. Breakfast at 05.00 h watching the sun come up is a rare treat on this watch.
- 04.00 h to 08.00 h – Usually regarded as the best watch. The only drawback is having to start work at 04.00 h but once that is over this is the work pattern that fits into the ship's daily routine the best.
- This brings us back to the start of the day. Three people complete the two 4-h work shifts making up the 8-h day.

Unmanned machinery space

These were mentioned at the end of Chapter 6 due to the special considerations required with the technical arrangements to operate a vessel in such a way. Considerable investment has been put into the design and construction of vessels designed to run UMS. The return on that investment is a:

- more efficient method of operation
- system that is more aligned to natural rest patterns
- machinery plant that can be operated safely with a fewer number of engineers.

The system is that three people are again required to carry out the watchkeeping. However, due to the automation and the special machinery space design (as described in Chapter 6) the watchkeeper does not have to be in the machinery space 24/7. She/he is still responsible for the watch and will have to respond to any machinery alarm within 90 s of its activation no matter where they are on-board.

The first of the three watchkeepers is in charge for 24 h after which she/he hands over to the next watchkeeper who carries out their 24-h shift. If the machinery is running at a steady state with no malfunction and the watchkeeper has completed all his/her routine tasks then there should be no alarms and the watchkeeper should be able to leave the machinery space unattended for a period of up to 8 h.

During the engineer's 48-h period when she/he is not responsible for the watch then that engineer falls back onto day work and has maintenance and up-keeping duties to complete. The UMS system of operation is generally regarded by the engineers as the better system because it fits into a daily routine better, they can get a good night's rest, especially on their two nights when not looking after the alarm and a lot of the old watchkeeping chores are carried out by the automation leaving the job actually more interesting than before.

Tasks of the engineering watchkeeper

When an engineer is assigned to the machinery watch for a period of time then she/he must regard that as his/her primary task. IMO point out in STCW that the engineering officer is a representative of the chief engineer while on duty and she/he should use their judgement accordingly. They should not for example hand-over a watch if they

Taking over a watch

It is always ideal to arrive at the engineroom early to prepare to take over the watch at the allocated time. There are three primary reasons for this, which are as follows:

- So that the engineer taking over can familiarise him/herself with the current status of the machinery plant, including the level of any fluids in the bilge. This may not have changed much since the last time the engineer was in the engineroom but it is a very important aspect of taking over a watch.
- Since the incoming engineer, at that stage, is additional to the current watch it gives him/her the luxury of being able to walk around the plant and check for early signs of any defects in the operating plant. This should include a careful examination for any leak of fluids.
- Early arrival puts the current watchkeeper at ease as she/he may be tired following a busy spell on duty.

If it is during the daylight hours the engineer taking over should start by going outside and having a look at the flue gasses and making a note of any visible smoke from the funnel. Record the colour of the smoke and identify the engine that it is coming from.

Entering the engineroom high up and working down the engineer can inspect any WHR boiler plant that may be situated in the engine exhaust. Inspect for exhaust or water leaks. The engineer should then follow the trunking down to the turbo-chargers which are next viewed for safe operation. The turbo-chargers will be placed close to the engine tops which are where the exhaust valves will also be sited on a two-stroke engine. Older types of engine may well have the operation of rocker gear and physical springs to view but the latest engines will have all the moving parts totally enclosed. However, the engineer should be listening for abnormal noises or feeling for unusual vibration or heat.

If the cylinder heads are viewable at this level then each one should be inspected for the following:

- Fuel leaks from the high-pressure pipework
- Hydraulic leaks from the exhaust valve actuation
- Air leaks from the air return spring system on the latest engines.

- *Air start valve leaks* – checking for this fault is very important as leaking air start valves have in the past been a source of serious fire in enginerooms. The check is made by feeling the temperature of the air start line leading to the cylinder head. If the air start valve is leaking then a high temperature will be detected in the air start pipe adjacent to the valve.
- Check for loose supports and indeed any loose guard rails.

Down one level on the engine and the engineer would see the high-pressure fuel delivery pumps, cylinder lubricators and hydraulic pumps for the exhaust valve actuation. Around the back of the engine could be the charge air coolers and pipework for the engine services such as the cooling water and lubricating oil.

This level might also be a main engineroom level giving access to the auxiliary machinery and the points to watch out for will be covered after the main engine section. It might also be the point to visit the machinery control room and let the out-going watchkeeper that you are there and are preparing to take over the watch.

At the lower level of the main engine the engineer should be checking the crankcase explosion relief doors to ensure that they are not leaking oil. If they are then the rubber 'O' ring needs replacing. The lower level will also be the place to inspect any reduction gearing, shafting and/or thrust block, etc.

The correct function of the auxiliary machinery is vital for the efficient operation of the machinery plant and the engineer should conduct a comprehensive review of the auxiliary machinery making a note of which pumps are running and which generators are supplying the electrical load. Generators should be checked for any fuel, water or oil leaks.

It is very important to check the pressure of compressed air inside the starting air receiver. This is vital for starting the main and auxiliary engines and if the pressure is low then it may be difficult to get the ship going again following a breakdown. Another very important inspection is the daily running tanks or service tanks. If these run low then there is a danger that the main engine of the auxiliaries will stop operating.

The auxiliary boiler will always be a source of concern because if they are neglected or are not understood well they can be a source of extreme danger. The flag state examiners know this and will want to satisfy themselves that engineers gaining a certificate of competency are safe to operate auxiliary boilers.

While inspecting auxiliary boilers engineers should look for efficient operation. As the boiler starts to work there should be a short purge cycle and then when the fuel is admitted the boiler should light up straight away. If it is struggling to do this then adjustments or cleaning may be needed. However, if the incoming watchkeeper sees a boiler working inefficiently then she/he would do well to pay attention to the boiler as soon as possible because it is likely to let him/her down during the next watch period.

Examiners will also be keen to find out that students understand the dangers from fire associated with boilers. Therefore, the engineer coming on watch should look out for any oil or fuel that may have accumulated around the boiler's burner. Engineers must check the boiler gauge glasses for the correct level of water. Low water levels have in the past been a major cause of accidents involving boilers.

While walking the machinery space the engineer should make time to visit the steering flat. It might be remote from the main machinery space and therefore could be difficult for the main watchkeeper to inspect without first arranging someone else to cover main space. Checks here would be correct and prompt operation, no abnormal noise and no oil leaks. Operation of stand-by pumps will be undertaken at set times so it would not be necessary to run these at every change of watch.

On the way back to the MCR the engineer should be listening to abnormal noise from running pumps, air compressors, purifiers and other machinery. Once back in the MCR the incoming engineer will be able to discuss the current status with the knowledge that she/he has just reviewed the machinery in operation. Once in the MCR the engineer can compare any temperatures and pressures taken locally with the ones that are showing remotely in the MCR and discrepancies can be discussed as part of the hand-over procedure.

It is important that both engineers discuss any issues that may have come up during the previous watch and also discuss anything that might need attention during the next watch. Anything that needs attention should be undertaken as soon as possible and not left to the next watchkeeper to deal with. This just leads to bad feelings and poor working relationships.

Depending upon the type of ship and the current operations the watch keeper might need to contact or work with other people in the ship's company; for example, if the vessel has a large refrigeration plant or there is a need for inert gas generation or large electrical power for discharging cargo.

TEST QUESTIONS

(**S** shows questions used in the past as Examination questions)

Chapter 1 – Class One

1. (a) With reference to fatigue of engineering components explain the influence of stress level and cyclical frequency on expected operating life.
   (b) Explain the influence of material defects on the safe operating life of an engineering component.
   (c) State the factors which influence the possibility of fatigue cracking of a bedplate transverse girder and explain how the risk of such cracking can be minimised.
2. With reference to engine performance monitoring discuss the relative merits of electronic indicating equipment when compared with traditional indicating equipment.
3. As Chief Engineer Officer how would you ascertain if the main engine is operating in an overloaded condition?

   If the engine is overloading what steps would you take to ensure that the engine was brought within the correct operating range?
4. A set of indicator cards suggests that the power from each of the individual cylinders of the main engine is not balanced:

   Describe the action you would take to rectify the problem.

   Outline how you would check the accuracy of the cards.
5. Explain, by referring to the theoretical considerations how the efficiency of an IC engine is dependent upon the CR.

   State why an actual engine power card is only an approximation to the ideal cycle.

Chapter 2 – Class One

1. (a) State with reasons the main causes of normal and abnormal cylinder liner wear.

(c) State the possible consequences of operating an engine with a cylinder liner worn beyond normally acceptable limits.

2. (a) Describe three methods of crankshaft construction indicating the type of engine to which each method is most suited.

(b) State the nature of and reasons for the type of finish used at mating surfaces of a shrink fit.

(c) Explain each of the following:

a) Why slippage of a crankshaft with a shrink fit can occur.

b) How such slippage may be detected.

c) How slippage may be rectified.

3. During recent months it has been necessary to frequently re-tighten some main engine holding down bolts as the steel chocks have become loose:

(a) Explain possible reasons for this.

(b) State the reasons why re-chocking using a different material might reduce the incidence.

(c) Explain the possible consequences if the situation is allowed to continue unchecked.

4. (a) State, with reasons, why engine air inlet and exhaust passageways should be as large as possible.

(b) Explain how such passageways can become restricted even when initially correctly dimensioned.

(c) Explain the consequences of operating an engine with:

(i) Restricted air inlet passageways.

(ii) Restricted exhaust passageways.

5. (a) Describe, using sketches if necessary, a main engine chocking system using resin-based compounds, explaining how such a system is installed. **S**

(b) State the advantages and disadvantages of resin-based materials for use as chocks when compared with iron or steel.

Chapter 3 – Class One

be used as there is insufficient old oil supply available to enable the ship to reach the nearest port. Explain with reasons what action should be taken to minimise damage and enable safe operation of the engine if the following fuel properties were above or below specified levels: **S**

(a) Viscosity.

(b) Compatibility.

(c) Sulphur.

(d) Ignition quality.

(e) Conradson carbon.

(f) Vanadium and sodium.

2. (a) Describe using sketches a VIT fuel pump and explain how timing is varied while the engine is in operation. **S**

(b) Explain why it is necessary to adjust the timing of fuel pumps individually and collectively.

3. With respect to residual fuel explain the effects of EACH of the following on engine components, performance and future maintenance, stating any step which should be taken in order to minimise these effects:

(a) High Conradson carbon level.

(b) Aluminium level of 120 ppm.

(c) Low ignition quality.

(d) 450 ppm vanadium plus 150 ppm sodium.

4. (a) With reference to 'slow steaming nozzles' as applied to main engine fuel injectors. State with reasons when and why they would be used. **S**

(b) State with reasons the engine adjustments required when changing to a fuel having a different ignition quality. Explain the consequences of not making such adjustments.

(c) State the procedures which should be adopted to ensure that main engine fuel injectors are maintained in good operative order indicating what routine checks should be made.

5. With respect to fuel oil:

(a) Explain the meaning of term 'ignition quality' and indicate the possible problems of burning fuels of different ignition quality. **S**

(b) State how an engine may be adjusted to deal with different fuels of different ignition qualities.

(c) State how fuel structure dictates ignition quality.

Chapter 4 – Class One

1. (a) Sudden bearing failure occurs with a turbo-charger which has been operating normally until that point. Explain the possible causes if the turbo-charger has:
   (i) Ball or roller bearings.
   (ii) Sleeve bearings.
   (b) State with reasons the measures to be adopted to ensure that future failure is minimised.
2. With respect to turbo-chargers indicate the nature of deposits likely to be found on EACH of the following and in each case state the possible consequences of operating with high levels of such deposits and explain how any associated problem might be minimised:
   (a) Air inlet filters.
   (b) Impeller and volute.
   (c) Air cooler.
   (d) Turbine and nozzles.
   (e) Cooling water spaces.
3. (a) State what is meant by the term *surge* when applied to turbo-chargers. **S**
   (b) State why surging occurs and how it is detected.
   (c) Explain how the possibility of surging may be minimised.
   (d) State what action should be taken in the event of a turbo-charger surging and explain why that action should not be delayed.
4. It is discovered that delivery of air from a turbo-charger has fallen even though engine fuel control has not been changed. State the reasons:
   (a) The causes of such reduced delivery. **S**
   (b) The effects of this reduced air supply on the engine.
   (c) The immediate action to be taken.
   (d) How future incidents might be minimised.
5. At certain speed vibration occurs in a turbo-charger.
   (a) State with reasons the possible causes. **S**

Chapter 5 – Class One

1. (a) State the possible reasons for an engine failing to turn over on air despite the fact that there is a full charge of air in the starting air receiver and explain how the problem would be traced.
   (b) Explain how the engine could be started and reversed manually in the event of failure of the control system. **S**
   (c) Outline planned maintenance instructions which could be issued to minimise the risk of failure indicated in (a) and (b).
2. Describe the safety interlocks in the air start and reversing system of a main engine.

   What maintenance do these devices require?

   At what interval would they be tested?
3. As Chief Engineer Officer what standing orders would you issue to your engineering staff regarding preparing the main engines for manoeuvring?
4. Routine watchkeeping reveals that a cylinder air start valve is leaking.

   What are the dangers of continued operation of the engine?

   What steps would you take if the vessel was about to commence manoeuvring?
5. Describe the main engine shutdown devices. How and how often would you test them?

   The shut down system on the main engine fails, immobilising the engine. Checks reveal that all engine operating parameters are normal. What procedures would you, as Chief Engineer Officer, adopt to operate the unprotected engine to enable the vessel to reach port?

Chapter 6 – Class One

1. (a) Describe briefly the operation of an electrical or hydraulic main engine governor.
   (b) For the type described indicate how failure can occur and the action to be taken if immediate correction cannot be achieved and the engine must be

2. Complete failure of the UMS, bridge control and data logging systems has occurred resulting in the need for the main engine to be put on manual control and monitoring:
   (a) State with reasons six main items of data which require to be monitored and recorded manually.
   (b) Explain how a watchkeeping system should be arranged to provide for effective monitoring and control of the main engine. S
   (c) Explain how the staff will be organised to allow the engine to be manoeuvred safely and state the items of plant which will require attention during such manoeuvring.
3. Discuss the relative merits and demerits of hydraulic and electronic main engine governors.
4. Describe, with the aid of a block diagram, a bridge control system for main engine operation.

   As Chief Engineer Officer what standing orders would you issue to your engineering staff when the vessel was operating under bridge control?
5. Describe a jacket cooling water system temperature controller. When operating under low load conditions for an extended period how can cylinder liner corrosion be minimised?

Chapter 7 – Class One

1. During a period of manoeuvring it is noticed that difficulty is being experienced in maintaining air receiver pressure:
   (a) State, with reasons, possible explanations.
   (b) Explain how the cause may be traced and rectified. S
   (c) State what immediate action should be taken to ensure that the engine movements required by the bridge are maintained.
2. (a) Explain why it is essential to ensure adequate cooling of air compressor cylinders, intercoolers and aftercoolers.
   (b) State, with reasons, the possible consequences of prolonged operation of the compressor if these areas are not adequately cooled. S

   (ii) Which internal areas of large receivers should receive particularly close attention. S
   (iii) How the internal condition of small receivers is checked.
   (b) Where significant corrosion is found during an internal inspection what factors would you take into account when revising the safe working pressure?
4. It has been found that during recent periods of manoeuvring a number of air start valve bursting discs or cones have failed:
   (a) Explain the possible reasons for this.
   (b) Indicate how the actual cause might be: S
      (i) Detected.
      (ii) Rectified.
5. (a) State why starting air compressor performance deteriorates in service and how such deterioration is detected. **S**
   (b) Explain the dangers associated with some compressor faults.

Chapter 8 – Class One

1. (a) Explain the advantages and problems of using aluminium in the construction of composite pistons for medium speed engines.
   (b) Briefly describe the removal, overhaul and replacement of a pair of pistons connected to a single crank of a vee-type engine, explaining any problems regarding the bottom end bearings.
2. (a) Explain the advantages of fitting highly rated medium-speed engines with double exhaust and air inlet valves.
   (b) State the disadvantages of double valve arrangements. S
   (c) Explain the possible causes of persistent burning of exhaust valves if it is:
      (i) General to most cylinders.
      (ii) Specific to a single cylinder.
3. Explain the problems associated with medium-speed diesel exhaust valves when operating with heavy fuel oil.

   How can these problems be minimised?
   (a) By design.
   (b) By maintenance.

4. Describe a suitable maintenance schedule for one unit of a medium-speed diesel engine operating on heavy oil?

5. Describe the torsional vibration of medium-speed diesel engine crankshafts.

   Describe, with the aid of sketches, a coupling that will aid the damping of torsional vibration.

Chapter 10 – Class One

1. As Chief Engineer Officer, what standing orders would you issue your engineering staff to ensure that the auxiliary boiler was operated in a safe and efficient manner?

2. Describe a waste heat plant that is able to produce sufficient steam to a turbo-generator to supply the entire ship's electrical load at sea.

   Due to trading requirements the vessel is sailing at reduced speed.

   Describe the steps you would take to ensure the slowest ship's speed commensurate with supplying sufficient steam to the turbo-generator without allowing the boiler to fire or starting diesel generators.

3. Describe, with the aid of sketches, an auxiliary boiler suitable for use with a waste heat unit.

   Explain how the pressure of the steam plant is maintained when operating under low steam load conditions.

4. Sketch and describe a composite thimble-tube boiler. Describe how the thimble tubes are fitted and discuss burning of tube ends and other possible defects.

5. You are the Chief Engineer Officer of a motor vessel equiped with a steam plant incorporating a waste heat unit in the engine uptake. On passage it is reported to you that the uptake temperature is rising.

   (a) What would this information indicate and what steps would you take?

   (b) How could you prevent a reoccurrence?

Chapter 1 – Class Two

(b) Give reasons why the actual cycle is made approximate to the ideal heat exchange process. S

(c) State how the combustion process in the actual cycle is made approximate to the ideal heat exchange process.

2. (a) State why bottom end bolts of four-stroke engines are susceptible to failure.

   (b) Sketch a bottom end bolt of suitable design.

   (c) Explain how good design reduces possibility of failure. S

   (d) State how the possibility of failure is reduced by good maintenance.

3. (a) Explain why in large, slow-speed engines, power balance between cylinders is desirable.

   (b) State why it is never achieved in practice.

   (c) Describe how power balance between cylinders of a medium-speed engine is improved. S

   (d) Describe how power balance in a slow-speed engine is improved.

4. (a) Give an example of each of the four types of two-stroke engine indicator diagrams, explain how each is taken and the use to which it is put.

   (b) Illustrate two defects which can show up on a compression card. S

   (c) How is cylinder power balance checked on a higher-speed engine?

5. (a) Explain how the power developed in an engine cylinder is determined:

   (i) From indicator cards. S

   (ii) By electronic means.

   (b) State which of these is the most representative and why.

Chapter 2 – Class Two

1. (a) State TWO reasons why large crankshafts are of semi-built construction.

   (b) State SIX important details of crankshaft construction that will reduce the possibility of fatigue failure. S

   (c) List FOUR operational faults that may induce failure in a crankshaft.

2. (a) State the nature of the stresses to which crank webs of large diesel engines are subjected. S

   (b) Explain how they are designed and manufactured to resist these stresses.

3. (a) State the reason for fitting crosshead guides to engines and explain why 'ahead' and 'astern' faces are required with uni-directional engines. S
   (b) Describe how crosshead guide clearance is checked and adjusted.
   (c) List reasons for limiting such crosshead clearance.
4. (a) State why bedplates of large engines are fitted with chocks rather than directly on foundation plates.
   (b) Sketch an arrangement of lateral chocking showing the position relative to the engine. S
   (c) State why such an arrangement is employed.
   (d) State the factors that determine the spacing of the main chocks.
5. With reference to auxiliary diesel engine machinery:
   (a) (i) State why this may be mounted on resilient mountings.
   (ii) State why such mountings have great flexibility. S
   (b) State why limit stops are provided.
   (c) State how the external piping is connected.

Chapter 3 – Class Two

1. (a) Describe, with the aid of sketches, a fuel pump capable of VIT.
   (b) State why injection timing might need to be changed. S
   (c) State how injection timing is adjusted while the engine is running.
2. (a) Sketch and describe a fuel valve for a diesel engine.
   (b) State FOUR factors which indicate that fuel valve(s) require attention. S
3. (a) State the factors that influence:
   (i) Droplet size during fuel injection.
   (ii) Penetration. S
   (b) State TWO methods of improving air turbulence.
4. (a) Sketch and describe a jerk-type fuel pump that is not helix controlled.
   (b) Explain how the pump may be timed. S
   (c) State TWO advantages of this type of pump.

   (b) Explain how the fuel quantity and timing are adjusted. S
   (c) To what defects is this type of pump subject and how is the pump adjusted to counter their effects?

Chapter 4 – Class Two

1. (a) Describe with the aid of sketches:
   (i) A pulse turbo-charger system.
   (ii) A constant pressure turbo-charger system.
   (b) State the advantages and disadvantages of each system in Q.1(a) for use with marine propulsion engines. S
   (c) In the event of turbo-charger failure with one of the systems in Q.1(a) state how the engine could be arranged to operate safely.
2. (a) Sketch a simple valve timing diagram for a naturally aspirated four-stroke engine.
   (b) Sketch a simple valve timing diagram for a supercharged four-stroke engine. S
   (c) Comment on the differences between the above two diagrams.
3. (a) Sketch and describe a turbo-charger with a radial flow gas turbine showing the position of the bearings. S
   (b) State the advantages of radial flow gas turbines.
4. (a) State why turbo-chargers are used to supply air to an engine rather than expanding the gas further in the cylinder and then employing crank-driven scavenge pumps.
   (b) Explain what measures should be adopted to ensure safe operation of the engine should all turbo-chargers be put out of action. S
   (c) State why a two-stroke cycle engine relies upon a pressurised combustion air supply but a four-stroke cycle engine does not.
5. (a) Explain why air coolers and water separators are fitted to large turbo-charged engine. S
   (b) Sketch a water separator, explain how it operates and indicate its positioning in the engine.
   (c) What are the defects to which coolers and separators are susceptible?

Chapter 5 – Class Two

1. (a) Sketch a starting air distributor used for a large reversible engine.
   (b) Explain how the engine may be started with the crankshaft in any rotational position. S
   (c) Explain how the engine is started on air in either direction.
2. (a) Sketch a pneumatically operated starting air valve.
   (b) Explain how the valve is operated. S
   (c) State what normal maintenance is essential and the possible consequence if it is neglected.
3. (a) Sketch and describe the reversing system for a large slow-speed diesel engine. S
   (b) List the safety devices fitted to the air start system.
4. (a) Explain why it is necessary to have air start overlap.
   (b) Show how air start timing is affected by exhaust timing. S
   (c) State why the number of cylinders have to be taken into consideration.
5. (a) Sketch an engine air start system from the air receiver to the cylinder valves and describe how it operates. S
   (b) List the safety devices and interlocks incorporated in such a system and state the purpose of each.

Chapter 6 – Class Two

1. With reference to a jacket water temperature control system:
   (a) Sketch and describe such a system:
   (b) (i) Explain how disturbances in the system may arise. S
   (ii) Describe how these disturbances may be catered for.
2. (a) Construct a block diagram, in flow chart form, to show the sequence of operations necessary for the starting of a diesel engine on bridge control. S

3. (a) Sketch a cylinder relief valve suitable for a large engine.
   (b) State with reasons why such a device is required.
   (c) If the relief valve lifts state the possible causes and indicate the rectifying action needed to prevent engine damage. S
   (d) State why the relief valve should be periodically overhauled even though it may never have lifted.
4. With reference to mechanical/hydraulic governors explain:
   (a) Why the flyweights are driven at a higher rotational speed than the engine.
   (b) How dead band effects are reduced. S
   (c) How hunting is reduced.
   (d) How the output torque is increased.
5. Sketch and describe a hydraulic governor with proportional and reset action.

Chapter 7 – Class Two

1. (a) Sketch a jacket water cooling system.
   (b) State why chemical treatment of the jacket cooling water is necessary. S
   (c) Describe how the correct concentration of the chemicals in the jacket water cooling system may be determined.
2. (a) Explain how oil may become mixed with starting air and state the attendant dangers.
   (b) Describe how this contamination may be reduced or prevented. S
   (c) Outline the dangers of lubricating oil settling in air starting lines.
   (d) How may an air start explosion be initiated?
3. (a) Explain why air compression for starting air duties is carried out in stages and why those stages are apparently unequal. S
   (b) What is the purpose of an intercooler and explain why it is important that it is kept in a clean condition?
   (c) What is the significance of clearance volume to compressor efficiency?
   (d) What is bumping clearance and how is it measured?
4. (a) State why compressor suction and delivery valves should seat promptly.
   (b) Explain the effect on the compressor if the air is induced into the cylinder at a

(c) What would be the effect of the suction valves having too much lift.

(d) Explain why pressure relief devices are fitted to the water side of cooler casings.

5. (a) State why inhibitors are employed with engine cooling water even though distilled water is used for that purpose.

(b) State the merits and demerits of the following inhibitors used in engine cooling water systems: S

(i) Chromate.

(ii) Nitrite-borate.

(iii) Soluble oil.

(c) Briefly explain how each inhibitor functions.

Chapter 8 – Class Two

1. Describe, with the aid of sketches, an exhaust valve of a medium-speed diesel engine suitable for use with heavy fuel oil. Explain the procedure adopted when overhauling this valve.
2. Describe, with the aid of sketches, a piston suitable for use in a medium-speed engine. Why is aluminium being generally superceded for pistons on highly rated medium-speed engines.
3. Describe with the aid of sketches a system for main propulsion in which two medium-speed diesel engines are coupled to a single propeller.
4. Describe the advantages and disadvantages of medium-speed diesel engines compared to large slow running engines.
5. Explain why lubricating oil consumption is greater in medium-speed engines than in slow running diesels and the steps taken to minimise the consumption.

Chapter 10 – Class Two

1. (a) Describe, with the aid of sketches, an arrangement for producing electricity

(c) State the circumstances which could lead to an emergency shut-down of the steam plant in Q.9(a) and the use of diesel engines for electrical generation.

2. Describe the inspection of an auxiliary boiler.

What precautions should be taken prior to entering the boiler?

3. Describe, with the aid of sketches, a boiler which may be alternatively fired or heated with main engine exhaust gas in which the heating surfaces are common. Describe the change-over arrangements and state any safety devices fitted to this gear.

4. What are the precautions that should be taken before and during the 'flashing up' operation of an auxiliary boiler?

State the checks carried out on the boiler when a fire is established.

5. What are the advantages and disadvantages of forced circulation and natural circulation multi-boiler installations?

How can the steam pressure of the waste heat plant be controlled when operating on exhaust gas?

6. Describe the dangers of dirty uptake in the waste heat unit. Explain how these dangers are minimised.

SPECIMEN QUESTIONS

(**S** shows questions used in the past as Examination questions)

Class One

1. (a) Define the term *hot spot*.
   (b) State SIX specific areas in a diesel engine where hot spots have occurred. **S**
   (c) State other factors that may contribute to the occurrence of a crankcase explosion.
2. With reference to crankcase explosions state:
   (a) The conditions that may initiate an explosion.
   (b) What may cause a secondary explosion. **S**
   (c) How a crankcase explosion relief valve works.
3. (a) State the basic processes leading up to a crankcase explosion and explain how a secondary explosion can occur. **S**
   (b) List with reasons the precautions which can be taken to minimise the risk of a crankcase explosion occurring.
4. (a) Explain how a primary crankcase explosion is caused and how it may trigger a secondary explosion.
   (b) Indicate the possible benefits or dangers of the following features on the likely development of a crankcase explosion: **S**
      (i) Oil mist detector.
      (ii) Inert gas injection.
      (iii) Infra-red heat detectors.
      (iv) Bearing shells having a layer of bronze between the white metal and steel backing steel.
5. (a) Describe, using sketches if necessary, the procedure for complete inspection of a propulsion engine main bearing and journal.
   (b) State the possible bearing and pin defects which might be encountered. **S**

6. (a) Explain the reason for fitting crossheads and guides to large slow speed engines.
   (b) Explain:
      (i) Why guide clearance is limited. **S**
      (ii) How guide clearance is adjusted.
      (iii) How guide alignment is checked.
7. (a) During an inspection it is noticed that tie-rods of certain main engine units have become slack, state with reasons the possible causes of this.
   (b) Explain how correct tension is restored and the risk of future slackness minimised. **S**
   (c) A tie-rod has fractured and cannot be replaced immediately. State with reasons the course of action to be adopted in order to allow the engine to be operated without further damage.
8. (a) Explain the term *fuel ignition quality* and indicate how a fuel's chemical structure influences its value.
   (b) State, with reasons, the possible consequences of operating an engine on a fuel with a lower ignition quality than that for which it is timed. **S**
   (c) (i) Explain how an engine might be adjusted to burn fuel of different ignition quality.
      (ii) State what checks can be carried out in order to determine that the engine is operating correctly.
9. (a) Describe the phenomenon of surging as applied to turbo-chargers.
   (b) Explain why turbo-chargers are not designed to completely eliminate the possibility of surging. **S**
   (c) State with reasons the possible consequences of allowing a turbo-charger to continue to operate while it is surging.
10. With reference to turbo-charger systems state how deposit build-up might be detected on the following parts and explain the consequences on turbo-charger and engine operation of excessive deposits:
   (a) Suction filter.
   (b) Impeller.
   (c) Turbine nozzle and blades.
   (d) Air cooler.

11. Difficulty is experienced in starting an engine even though there is full air pressure in the air receivers and fuel temperature is correct. Explain how the cause of the problem can be: S

 (a) Detected.

 (b) Rectified.

12. With reference to piston ring and liner wear:

 (a) State, with reasons, the causes of abnormal forms of wear known as cloverleafing and scuffing (microseizure);

 (b) Explain how cylinder lubrication in terms of quantity and quality can influence wear; S

 (c) Describe the procedure for determining whether piston rings are suitable for use.

13. With reference to main engine holding down studs/bolts:

 (a) Explain the causes of persistent slackening.

 (b) State, with reasons, the likely consequences of such slackening. S

 (c) Describe how future incidents of slackening might be minimised.

14. (a) Inspection of an engine indicates an unexpected increase in cylinder liner wear rate, state with reasons the possible causes if:

  (i) The problem is confined to a single cylinder.

  (ii) The problem is common to all cylinders. S

 (b) Explain how cylinder wear rate may be kept within desired limits and indicate the instructions to be issued to ensure that engine room staff are aware as to how this can be achieved.

15. Cracks have been discovered between the crankpin and web on a main engine crankshaft:

 (a) Describe action to be taken in order to determine the extent of the cracking. S

 (b) Explain the most likely reasons for the cracking.

 (c) State, with reasons, the action to be taken in order that the ship may proceed to a port where thorough inspection facilities are available.

16. It is found that tie-rods are persistently becoming slack:

 (a) State, with reasons, the possible causes.

 (b) State, with reasons, the likely effects on the engine if it is S

17. As Chief Engineer Officer, explain the procedure to be adopted for the complete inspection of a main engine cylinder unit emphasising the areas of significant interest. S

18. (a) The water jacket on a turbo-charger casing has fractured allowing water into the turbine side. State possible reasons for this.

 (b) Explain how the engine may be kept operational and the restrictions now imposed upon the operating speed. S

 (c) State how the fracture can be rectified and how future incidents can be minimised.

19. (a) State the conditions which could result in a fire in the tube space and/or uptakes of a waste heat boiler.

 (b) State how such conditions can occur and how the risk of fire can be minimised. S

 (c) State how such fires can be dealt with.

20. As Chief Engineer, explain the procedure to be adopted for the survey of an air compressor on behalf of a classification society. S

21. (a) Identify, with reasons, the causes and effects of misalignment in large, slow-speed, engine crankshafts.

 (b) Describe how the alignment is checked. S

 (c) State how the measurements are recorded and checked for accuracy.

22. (a) Explain why side and end chocking arrangements are provided for large direct drive engines.

 (b) State, with reasons, why non-metallic chocking is considered superior to metallic chocking. S

 (c) State why top bracing is sometimes provided for large engines and explain how it is maintained in a functional condition.

23. (a) As Chief Engineer, describe how a complete inspection of a main engine turbo-charger may be carried out indicating, with reasons, the areas requiring close attention. S

 (b) Describe defects which may be found during inspection and their possible cause.

24. The main engine has recently suffered problems related to poor combustion and inspection indicates that a number of injector nozzles are badly worn:

 (a) Explain the possible causes of the problem and how they may be detected. S

 (b) [illegible]

25. With reference to fuel pumps operating on residual fuel:
   (a) (i) State, with reasons, the defects to which they are prone.
   (ii) Explain the effects of such defects on engine performance. S
   (b) State, with reasons corrective action necessary to restore a defective fuel pump to normal operation.
   (c) Suggest ways in which the incidence of these defects might be minimised.

Class Two

1. Describe the routine maintenance necessary on the following components in order to obtain optimum performance from a main engine turbo-charger: S
   (a) Lubricating oil for ball bearings.
   (b) Air intake silencer/filter.
   (c) Turbine blades.
   (d) Diffuser ring.
2. (a) List the advantages of multi-stage air compression with intercooling compared with single stage compression.
   (b) Explain the faults which may be encountered during overhaul of the H.P. stage and indicate how they may be rectified. S
3. (a) Outline the problems associated with air compressor cylinder lubrication indicating why it should be kept to a minimum.
   (b) State why a restricted suction air filter might make the situation worse and lead to the possibility of detonation in the discharge line. S
   (c) Explain why the compressor discharge line to the air receiver should be as smooth as possible with the minimum number of joints and connections.
4. (a) Explain the need for additives in engine jacket water cooling systems.
   (b) State what factors determine the choice of chemicals used. S
   (c) State why chromates are seldom used.
5. (a) Give a simple line sketch of a jacket water cooling system.
   (b) Describe a control system capable of maintaining the jacket water temperature within close limits during wide changes in engine load. S

6. (a) Sketch an arrangement for securing turbo-charger blades to the blade disc.
   (b) How is blade vibration countered?
   (c) What is the cause of excessive turbo-charger rotor vibration? S
   (d) Briefly describe an in-service cleaning routine for the gas side of a turbo-charger.
7. (a) Describe with sketches a scroll-type fuel pump.
   (b) Explain how the quantity of fuel is metered and how the governor cut out functions. S
   (c) State how this type of pump is set after overhaul.
   (d) State the reasons that necessitate pump overhaul.
8 (a) Sketch a fuel injector.
   (b) Explain how it operates and what determines the point at which injection occurs. S
   (c) Describe the defects to which injectors are prone.
   (d) How can injection be improved when a low-speed engine is to operate at prolonged low load?
9. With reference to turbo-charging:
   (a) (i) Explain the terms pulse system and constant pressure system.
   (ii) List the advantages of each.
   (b) State how in a pulse system the exhaust from one cylinder may be prevented from interfering with the scavenging of another. S
   (c) State why electrically driven blowers are usually fitted in addition to turbo-chargers.
10. (a) Show how combustion forces are transmitted to the cross members of the bedplate. S
   (b) Describe TWO means by which the stresses within the cross members can be accommodated.
11. (a) Describe how crankshaft alignment is checked.
   (b) Identify, with reasons the causes of crankshaft misalignment. S
   (c) State how the measurements are recorded.
12. (a) Sketch a cross-section of a main engine structure comprising bedplate, frames and entablature showing the tie bolts in position.
   (b) Explain why tie bolts need to be used in some large, slow-speed engines. S
   (c) Explain in detail how the tie bolts are tensioned.

13. Give reasons why, when compared to the other bearings of large slow-speed engines, top end bearings: **S**
   (a) Are more prone to failure.
   (b) Have a greater diameter in proportion to pin length.

14. (a) State how engine cylinder power is checked and approximate power balance is achieved.
   (b) Explain why the methods of checking may differ between low- and high-speed engines. **S**
   (c) State why perfect cylinder power balance cannot be achieved.
   (d) State the possible engine problems resulting from poor cylinder power balance.

15. (a) Describe with sketches the mono-box frame construction which is being used to replace the traditional A-frame arrangement for some crosshead engines. **S**
   (b) State why this form of construction is considered to be more suitable than one using A-frames.

16. (a) State TWO reasons why large crankshafts are of semi-built or fully built construction.
   (b) State SIX important details of crankshaft construction that will reduce the possibility of fatigue failure. **S**
   (c) State FOUR operational faults that may induce fatigue failure.

17. (a) Define the cause of corrosive wear on cylinder liners and piston rings.
   (b) Explain the part played by cylinder lubrication in neutralising this action. **S**
   (c) State how the timing, quantity and distribution of cylinder oil is shown to be correct.

18. With reference to large fabricated bedplates give reasons to explain:
   (a) Why defects are likely to occur in service and where they occur. **S**
   (b) How these defects have been avoided in subsequent designs.

19. (a) Define the cause of cylinder liner and piston ring wear. **S**
   (b) Describe how cylinder liner wear is measured and recorded.
   (c) Explain the possible consequences of operating a main engine with excessive cylinder liner wear.

20. (a) Sketch a main engine holding down arrangement employing long studs and

   (b) Explain why the arrangement sketched in Q.6(b) may be employed in preference to short studs. **S**
   (c) Describe, with the aid of sketches, how transverse movement of the bedplate is avoided.

21. (a) Briefly discuss the relative advantages and disadvantages of oil and water for cooling.
   (b) Sketch a piston for a large two-stroke crosshead engine indicating the coolant flow. **S**
   (c) State the causes of piston cracking and burning, and how it can be avoided.

22. (a) Sketch the arrangement of a large two-stroke engine cylinder liner in position in the cylinder block.
   (b) Describe how jacket water sealing is accomplished between liner and cylinder block. **S**
   (c) For the liner chosen illustrate the directions of cooling water flow, exhaust gas flow and combustion air flow.
   (d) Explain how thermal expansion of the liner is accommodated.

23. (a) Give the reasons for progressive 'fall-off' of piston ring performance in service.
   (b) State, with reasons, which ring clearances are critical. **S**
   (c) State what effects face contouring, bevelling, ring cross-section and material properties of rings and liners have on ring life.

24. (a) Sketch the arrangement for connecting a piston to the crosshead.
   (b) State the type of piston coolant employed and show how the coolant is directed to and from the piston. **S**
   (c) State the precautions to be exercised when lifting or overhauling the piston described.

25. (a) Explain the reasons for employing two air inlet and two exhaust valves for high-powered trunk piston four-stroke engines. **S**
   (b) State the problems relating to tappet setting with such valves.
   (c) Sketch a caged valve as fitted to a trunk piston engine.

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