Lecture 5.41

Systems of Diesel Power Plant

Agenda

- Fuel Supply and Injection Systems
- Air Intake System and Supercharging
- Exhaust System and Waste Heat Recovery
- Engine Cooling Systems (Open vs. Closed)
- Lubrication System Mechanics
- Starting Systems (Compressed Air and Electric)

Fuel Supply System: Architecture and Flow

- Function: Delivers clean fuel from the main storage tank to the engine injection system at the required pressure and flow rate.
- Main Storage Tank: Usually located underground or outside the plant room; provides bulk storage for 15-30 days of continuous operation.
- Transfer Pumps: Typically gear or lobe pumps used to move fuel from main storage to the daily consumption (day) tank.
- Filtration Stages: Incorporates coarse strainers before transfer pumps and fine micron filters (paper or felt) before the injection pump to prevent injector nozzle clogging.
- Day Tank: An elevated gravity-feed tank inside the plant room that holds an 8-hour supply, providing positive suction head to the injection pump.

Fuel Injection System: Atomization and Metering

- Core Objectives: Accurately meter the fuel quantity per cycle based on load, time the injection precisely, and atomize the fuel for rapid combustion.
- Jerk Pump System: Utilizes a camshaft-driven plunger pump for each cylinder. The effective stroke of the plunger is varied by rotating it via a rack and pinion mechanism connected to the governor.
- Common Rail System: Maintains high-pressure fuel (up to 2000 bar) in a central accumulator (rail). Electronic Control Unit (ECU) actuates solenoid or piezo injectors.
- Atomization: Fuel is forced through nozzle orifices (typically 0.1 to 0.3 mm diameter) at extreme pressures, breaking into a fine mist with high surface area to volume ratio.
- Injector Design: Employs a spring-loaded needle valve that lifts when fuel pressure exceeds the spring force, ensuring sharp start and end of injection.

Air Intake System

- Requirement: A diesel engine requires roughly 15 to 20 kg of air per kg of fuel. High volumetric efficiency is essential for maximum power output.
- Filtration: Intake air must be free of dust. Types include dry paper filters, oil-bath filters, and impingement-type viscous filters.
- Intake Manifold: Designed to minimize flow restriction (pressure drop) and ensure equal distribution of air to all cylinders.
- Supercharging/Turbocharging: Increases the density of intake air. An exhaust-gas-driven turbine powers a centrifugal compressor.
- Charge Air Cooling (Intercooling): Compressing air raises its temperature, reducing density. Intercoolers (air-to-air or air-to-water heat exchangers) reduce the charge air temperature before it enters the cylinders.

Exhaust System

- Purpose: To safely route high-temperature (400-600\ensuremath{^\circ}C) exhaust gases out of the engine room with minimal backpressure and noise.
- Backpressure Limitations: Excessive exhaust backpressure prevents complete scavenging of cylinders, reducing volumetric efficiency and increasing specific fuel consumption.
- Silencers/Mufflers: Employ reactive (expansion chambers for low frequencies) and absorptive (fiberglass lining for high frequencies) acoustic designs.
- Flexible Connections: Stainless steel bellows are installed between the engine manifold and fixed exhaust piping to isolate vibrations and accommodate thermal expansion.
- Waste Heat Recovery (WHR): Exhaust gases carry away about 30% of the fuel's energy. WHR boilers can generate low-pressure steam or hot water for cogeneration purposes.

Cooling System: Thermodynamic Necessity

- Heat Dissipation: Around 25-30% of combustion heat is absorbed by engine components (cylinder walls, piston crowns, cylinder heads).
- Necessity: Without cooling, lubricating oil would degrade rapidly (carbonize), and thermal expansion would cause piston seizure.
- Coolant Mediums: Water is the most common due to its high specific heat capacity. Inhibitors are added to prevent scaling, corrosion, and cavitation.
- Coolant Jackets: Engine blocks and heads are cast with internal passages (water jackets) surrounding the combustion chambers for effective heat transfer.
- Thermostat Regulation: A thermostatic valve maintains optimum operating temperature (usually 80-90\ensuremath{^\circ}C) by bypassing the radiator/heat exchanger during cold starts.

Open vs. Closed Cooling Systems

- Open System: Water is drawn from a natural source (river, lake), pumped through engine jackets, and discharged back. Rarely used due to scale formation and debris.
- Closed (Double Circuit) System: Demineralized, treated primary water circulates through the engine jackets in a closed loop.
- Heat Exchanger: The primary hot water transfers heat to a secondary raw water circuit in a shell-and-tube or plate heat exchanger.
- Cooling Towers: The secondary raw water rejects heat to the atmosphere via an evaporative cooling tower before recirculating.
- Radiator Cooling: Common for smaller plants (¡5 MW); primary water is cooled directly by an engine-driven or electrically driven fan blowing air across a finned-tube radiator.

Lubrication System: Function and Properties

- Functions: Reduces friction and wear (hydrodynamic lubrication), acts as a coolant for pistons, seals the piston rings, and flushes away wear particles and soot.
- Oil Properties: Requires correct viscosity index, high flash point, oxidation stability, and detergency/dispersancy additives to handle diesel soot.
- Wet Sump System: Lubricating oil is stored in the oil pan (sump) at the bottom of the engine crankcase.
- Dry Sump System: Oil is evacuated from the crankcase by a scavenge pump and stored in an external reservoir. Preferred for very large stationary engines.
- Full-Flow vs. Bypass Filtration: Full-flow filters trap 10-40 micron particles from all oil heading to bearings. Bypass centrifugal filters handle 10% of flow, trapping sub-micron soot.

Lubrication System Components

- Oil Pump: Typically a positive displacement gear pump driven by the engine crankshaft.
- Oil Cooler: A shell-and-tube heat exchanger where hot oil transfers heat to the engine coolant circuit. Necessary to maintain oil viscosity.
- Main Oil Gallery: A primary passage drilled through the engine block that distributes pressurized oil to the main crankshaft bearings.
- Drilled Crankshafts: Oil flows from main bearings through drilled passages in the crankshaft webs to lubricate the connecting rod (big end) bearings.
- Valve Train Lubrication: Oil is routed up to the cylinder head to lubricate camshafts, rocker arms, and valve stems, then drains back to the sump via gravity.

Starting System: Requirements

- Overcoming Inertia: Diesel engines have high compression ratios (14:1 to 22:1). Starting requires significant torque to overcome mechanical inertia, friction, and compression pressures.
- Cranking Speed: The engine must be rotated at a minimum cranking speed (typically 100-200 RPM) to generate sufficient compression heat for auto-ignition of fuel.
- Electric Starting: Uses a DC electric motor with a pinion gear that engages the engine flywheel ring gear. Powered by heavy-duty lead-acid battery banks.
- Limitation of Electric Starts: Generally limited to smaller diesel generators due to the massive battery capacity required to crank very large MW-scale engines.
- Pre-Lubrication: Large engines require an electrically driven pre-lube pump to pressurize the oil galleries before cranking prevents dry metal-to-metal contact.

Compressed Air Starting System

- Primary Method for Large Plants: Standard for medium and large stationary diesel engines.
- Air Compressors: Multi-stage reciprocating compressors fill high-pressure air receivers (typically 30-40 bar).
- Air Distributor: A mechanically driven rotary valve synchronized with the camshaft that directs compressed air to the correct cylinders.
- Air Starting Valves: Pneumatically actuated valves installed in the cylinder heads. High-pressure air enters the cylinder during the expansion stroke, driving the piston down.
- Operation: The compressed air effectively acts as a pneumatic motor using the engine's own cylinders until firing speed is reached and fuel injection begins.

Summary

- The Fuel System must meticulously filter and inject fuel at extreme pressures for proper atomization and combustion.
- Air Intake and Exhaust Systems utilize turbocharging to increase volumetric efficiency and often employ waste heat recovery to boost overall plant thermal efficiency.
- Closed-loop Cooling Systems with treated water are essential to maintain thermodynamic balance and prevent internal scaling.
- The Lubrication System relies on high-quality oils and cooling to provide hydrodynamic lubrication and piston cooling.
- Starting Systems transition from electric motors to compressed air systems as engine capacity and compression ratios increase.

Next Lecture Preview

- Topic: 5.4 Gas Turbine Power Plant - Brayton Cycle
- Thermodynamic analysis of the ideal and actual Brayton cycle.
- Components of a Gas Turbine: Compressors, Combustors, and Turbines.
- Methods for improving Gas Turbine efficiency: Intercooling, Reheating, and Regeneration.
- Comparison of Diesel and Gas Turbine power plants for peaking load applications.