NS100
Fundamentals of Naval Science
Marine Propulsion Systems
Objectives:

1. Understand the main types of marine propulsion systems.

2. Describe the principle of operation and major components of a steam propulsion plant.

3. Be familiar with the main steam cycle in conventional and nuclear plants.
Objectives:

4. Describe the principle of operation and major components of a gas turbine propulsion plant.
5. Identify the different arrangements of gas turbine propulsion plants.
6. Describe the principle of operation and major components of an internal combustion engine.
Objectives:

7. Differentiate between two-stroke and four-stroke internal combustion engines.

8. Compare the current types of marine propulsion with regards to plant size, cost, fuel consumption, and efficiency.

9. Be familiar with the concepts of integrated power system and electric drive propulsion.
Introduction

-This lesson will cover:
  - Steam Propulsion (conventional)
  - Nuclear fueled steam propulsion
  - Gas turbines
  - Diesel engines
  - Electric Drive (Integrated Power System)
Steam Propulsion

- First type of propulsion to replace sail power.
- Uses fossil fuel (conventional) or nuclear power to produce steam.
- Fossil fuel steam plants – widely used in surface combatants until the late 60’s, when they began to be replaced by gas turbines.
- Nuclear fuel steam plants – currently used by the U.S. Navy in several aircraft carriers and all submarines.
The Steam Cycle

- Four phases:
  - Generation
  - Expansion
  - Condensation
  - Feed
Generation
Generation

- Takes place in the Boiler.
- Transforms chemical energy into thermal.
- Water is heated and Steam is generated:
  - Saturated steam (same temperature as water)
  - Superheater (further increases steam temp. and eliminates moisture)
- Steam is transferred to turbines.
Expansion
Expansion

- Thermal energy converted into mechanical
- Steam expands as it turns turbines:
  - High Pressure (HP) Turbine
  - Low Pressure (LP) Turbine
Condensation
Condensation

- Main condenser receives steam from LP turb.
- Steam is cooled and pressure drops (a vacuum is formed in the condenser)
- Steam turns back to liquid state (condensate)
Feed

Chemical energy in fuel converted to thermal energy in boiler firebox.

Thermal energy of steam converted to mechanical energy in turbines.

Thermal energy lost to circulating seawater in condenser.
Feed

- Condensate becomes Feedwater (preheated and free of oxygen)
- Economizer: further heats feedwater before sending it to boiler.
Nuclear Propulsion

- Steam cycle is similar to conventional.
- A reactor replaces the boiler to generate steam.
- Independent of air for combustion (ideal for submarines)
- Primary Loop – water heated by reactor
- Secondary Loop – main steam cycle (No direct contact between two loops)
Primary Loop
Secondary Loop
Gas Turbines

- Propulsion of choice for medium-size ships (replaced steam in such ships in the late 60’s)
- Lighter than other plants for same power.
- Medium to high fuel consumption.
Gas Turbines

- Main Components:
  - ✔ Compressor
  - ✔ Combustion Chamber
  - ✔ Turbine
**Compressor** – takes in air from atmosphere and delivers it, under pressure to combustion chamber.
Combustion Chamber – mixes fuel with compressed air and ignites the mixture
Turbine – turned by combustion gases, converts thermal energy into mechanical
Gas Turbines

• Different arrangements:
  ✓ Single-shaft
  ✓ Split-shaft
  ✓ Dual-shaft
Single-shaft – same shaft links compressor, turbine, and power couplers
Split-shaft – shaft for gas generation is different from power shaft
**Dual-shaft** – two concentric shafts move HP and LP turbines (Power section similar to split-shaft arrangement)
Diesel Engines

- Named for Dr. Rudolf Diesel
- Compression-ignition engine
- No electrical ignition system
- Fuel ignition caused by high temperature of compressed air.
- Compression ratios as high as 20:1 are common in shipboard diesel engines.
Internal Combustion Engine
Operating Cycle

Associated Terms:

**Intake:** The process by which air is drawn into the engine cylinders to support the combustion process.

**Compression:** The process of reducing the area occupied by the volume of air introduced during the intake stroke. Pressure and air temperature rise sufficiently to ignite the fuel injected into the engine cylinders.
Internal Combustion Engine Operating Cycle

Associated Terms:

**Combustion:** The burning of the fuel and air in a chemical process to produce work.

**Exhaust:** The process by which the products of combustion are removed from the engine.
Scavenging: A process by which the engine cylinders are cleared of the products of combustion and simultaneously re-charged with fresh air. The process is accomplished by a blower assembly. Used an all two-stroke and some four-stroke engines.
Internal Combustion Engine
Operating Cycle

Associated Terms:

**Turbo-charging:** The process of increasing engine power by supplying air to the engine cylinders at higher than atmospheric pressure. The process is also known as “Supercharging”.
Four Stroke vs. Two Stroke Cycles

Each piston, regardless of engine type, completes two strokes for each rotation of the crankshaft. A stroke is defined as either an up or down movement of the piston.
Four Stroke vs. Two Stroke Cycles

The number of strokes required to complete the thermodynamic cycle for a particular engine determines whether an engine is operating on a two stroke cycle (one power stroke every shaft revolution) or a four stroke cycle (one power stroke every two shaft revolutions).
Characteristics of a Four-Stroke Cycle

1. Piston has two up and two down movements in each cycle.

2. Combustion occurs every fourth stroke.

3. Intake and exhaust are accomplished by movement of the piston in two distinct strokes.
Fuel
Air
Exhaust Air & Combustion Gases
Cylinder
Piston
Power
Events of a Four-Stroke Cycle

**Intake:** Air is drawn into the cylinder through intake valves as the piston moves downward.

**Compression:** Air is compressed and heated as the piston moves upward.

**Power:** Fuel is injected into the cylinder and combustion occurs causing the piston to move downward once again.
TDC to BDC intake stroke 180° turn crankshaft
BDC to TDC compression stroke
180° turn crankshaft
TDC to BDC power stroke
180° turn crankshaft
Events of a Four-Stroke Cycle

**Exhaust:** Movement of the piston upward forces the products of combustion out of the cylinder
BDC to TDC
exhaust stroke
180° turn
crankshaft
Characteristics of a Two-Stroke Cycle

1. Piston has one up and one down stroke in each cycle.
2. Combustion occurs every other stroke.
3. Scavenging - the combination of the intake and exhaust process.
Events of a Two-Stroke Cycle

**Intake/Exhaust:** As a piston moves towards the bottom of its stroke, air is forced into the cylinder by a blower. At the same time, exhaust gases from the previous power stroke are forced out of the cylinder.

**Compression:** As the piston moves upward, air is compressed and heated. Fuel is then injected into the cylinder.

**Power:** Ignition occurs after fuel injection forcing the cylinder down once again.
SCAVENGING
INJECTION AND COMBUSTION

Air
Air

EXPANSION
Classification of Internal Combustion Engines

**In-Line:** Simplest arrangements, all cylinders parallel and in a single line. Usually no more then 8 cylinders due to weight and strength limitations.

**V-Type:** Piston cylinders are angled (45 - 75°) in a V configuration include reduction in size from the in-line design. Most V-Type engines have either 8 or 16 cylinders.
IN-LINE ENGINE
V-TYPE ENGINE
## Comparison of Marine Propulsion Systems

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>Steam</th>
<th>Nuclear</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size (lb/hp)</strong></td>
<td>3</td>
<td>15</td>
<td>35</td>
<td>.28</td>
</tr>
<tr>
<td><strong>Cost ($/hp)</strong></td>
<td>low</td>
<td>med/high</td>
<td>very high</td>
<td>low/med</td>
</tr>
<tr>
<td><strong>Fuel Consump.</strong></td>
<td>low</td>
<td>medium</td>
<td>N/A</td>
<td>med/high</td>
</tr>
<tr>
<td><strong>Consump. Max spd</strong></td>
<td>low</td>
<td>high</td>
<td>N/A</td>
<td>med/high</td>
</tr>
</tbody>
</table>
Integrated Power System

USS Zumwalt
DD 21
Integrated Power System

- To be installed in DD-21
- Not just an electric motor
- Single system will provide:
  ✓ Power generation
  ✓ Propulsion
  ✓ Ship service distribution
  ✓ Combat systems support
Integrated Power System

Revolution in propulsion plant configuration:

- Same prime movers can be used for propulsion and power generation
- Prime movers do not need to be rigidly connected to propeller shaft (much shorter drive trains)
- Optimization of space
Traditional Plant

PRIME MOVER

POWER CONVERSION AND DISTRIBUTION

GEN.

REDUCTION GEAR

PROPELLER

PRIME MOVER

PRIME MOVER

PRIME MOVER

PRIME MOVER
Integrated Power System

- Prime Mover
- Generator
- Motor Drive
- Motor
- Propeller

Power Conversion and Distribution
Integrated Power System

Navy is considering the use of superconductor technology for IPS
Integrated Power System

Advantages of IPS:

- Increased flexibility and space reduction.
- More freedom of ship design.
- Reduction of acoustic signature.
- Lower cost (fuel economy/reduced manning).
- Rapid reconfiguration of power (greater combat sustainability).
- Concentrated energy availability (future pulse-power weapons).
Review Questions

1. What are the phases of the main steam cycle?

2. What is the basic difference between fossil-fuel and nuclear-fuel steam plants?

3. What are the main components of a gas turbine?

4. How does a two-stroke internal combustion engine differ from a four-stroke engine?
Review Questions

5. Compare the four main types of marine propulsion with regards to plant size.

6. Compare the four main types of marine propulsion with regards to fuel consumption.

7. What are the advantages of Integrated Power System?