# Using Steam in the Power Plant

## Table of Contents


**Lesson One** Turbines......3

**Lesson Two** Boiler Instrumentation, Controls, and Safety......21

**Lesson Three** Electrical Power Fundamentals......37

**Lesson Four** Electrical Systems Analysis......53

**Lesson Five** Air-Conditioning Systems......69



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USING STEAM IN THE POWER PLANT

Lesson One

# Turbines

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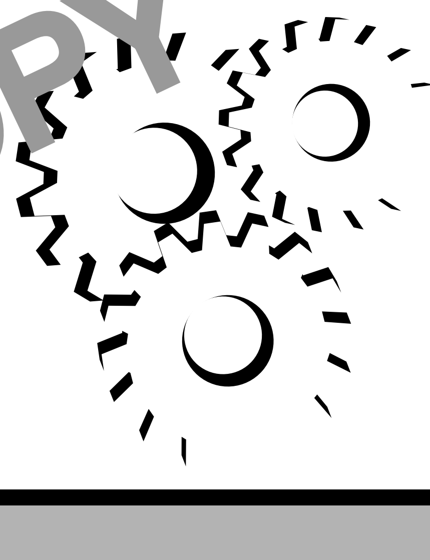

TPC Training Systems

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## Lesson 1

# Turbines

### TOPICS

What Is a Turbine?
Operating Principles
Turbine Classification
Gas Turbines
Condensers
Heat Rejection and Thermal Pollution
Boiler-Turbine-Generator Efficiency
Operating Data on Turbine-Generator Performance
Maintaining a Turbine-Generator System
Condenser Cooling Water Requirements
Cooling Water Systems

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### OBJECTIVES

**After studying this Lesson, you should be able to…**

- Name the five main parts of a steam turbine system and explain the function of each.
- Contrast the operating principle of an impulse turbine and a reaction turbine.
- Define the terms *tandem compound* and *cross compound.*
- Explain how a condenser improves turbine efficiency.
- Explain how an overspeed trip is activated.
- List three causes of turbine rotor vibration.
- Name the main cause of bearing failure in a turbine.

### KEY TECHNICAL TERMS

**Turbine** 1.01 machine that generates rotary motion from the kinetic energy of a fluid
**Cylinder** 1.03 steel or cast iron housing of a turbine
**Rotor** 1.04 rotating shaft that carries moving blades
**Impulse turbine** 1.07 uses the impact force of the steam jet to turn the shaft
**Reaction turbine** 1.10 uses the “kickback” force of the steam to turn the shaft
**Condenser** 1.27 heat-transfer device located at the turbine exhaust
**Thermal pollution** 1.37 occurs when large quantities or heated water discharge into a body of water
**Efficiency** 1.38 ratio of energy output to energy input

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**The kind of turbine most often used in a power plant is the steam turbine, which drives the electrical generator and auxiliary equipment. The steam turbine converts the kinetic energy of the steam into mechanical energy to perform work. Power plants also use gas turbines as standby units and peaking units to increase plant capacity.**

**This Lesson describes the main kinds of steam turbines, how they operate, and how they compare with gas turbines. It explains how a condenser operates, and the condenser's effect on efficiency. The Lesson also describes good maintenance practices that will help you keep the turbine-generator unit in your plant in good operating condition, and thus conserve energy.**

## What Is a Turbine?

1.01 A *turbine* is a machine that generates mechanical power in the form of rotary motion from the kinetic energy of a fluid (steam, air, or water). The most powerful and widely used turbines are steam turbines. Steam turbines drive many kinds of power plant equipment. This equipment includes electric generators, pumps, and compressors. The output capacity of a steam turbine ranges from less than 1 kW to more than one million kW. The larger capacity steam turbines drive the electric generators in power plants.

1.02 A steam turbine consists of the following parts:

- a cylinder (casing or shell) containing the fixed (stationary) blade system and a set of bearings to support the rotor shaft
- a rotor carrying the moving blades (buckets or vanes) with bearing journals on the ends of its shaft
- a governor and valve system to regulate the turbine's speed and power by controlling the steam flow, and an oil system for lubricating the bearings and for hydraulically operating the control valves by means of a relay system connected with the governor
- a coupling or gear reducer to connect with the machine driven
- pipe connections to the steam supply from the boiler at the inlet, and to an exhaust system at the outlet, of the casing.

A small single-stage turbine is shown in Fig. 1-1 on the following page.

1.03 A steam turbine's two main parts are the cylinder and the rotor. The *cylinder* (stator) is a steel or cast iron housing usually divided at the horizontal centerline. Its halves are bolted together for easy access. The cylinder contains fixed blades, vanes, and nozzles that direct steam into the moving blades carried by the rotor. Each fixed blade set is mounted in diaphragms located in front of each disk on the rotor, or directly in the casing. A disk and diaphragm pair form a turbine stage. Steam turbines can have many stages.

1.04 The *rotor* is a rotating shaft that carries the moving blades on the outer edges of either disks or drums. The blades rotate as the rotor revolves. The rotor of a large steam turbine consists of high-, intermediate-, and low-pressure sections.

## Operating Principles

1.05 In a multiple-stage turbine, steam at a high pressure and high temperature enters the first row of fixed blades or nozzles through an inlet valve or valves. As the steam passes through the fixed blades or nozzles, it expands and its velocity increases. The high-velocity jet of steam strikes the first set of moving blades. The kinetic energy of the steam changes into mechanical energy. This mechanical energy causes the shaft to rotate. The steam then enters the next set of fixed blades and strikes the next row of moving blades.

1.06 As the steam flows through the turbine, its pressure and temperature decrease, while its volume increases. The decrease in pressure and temperature

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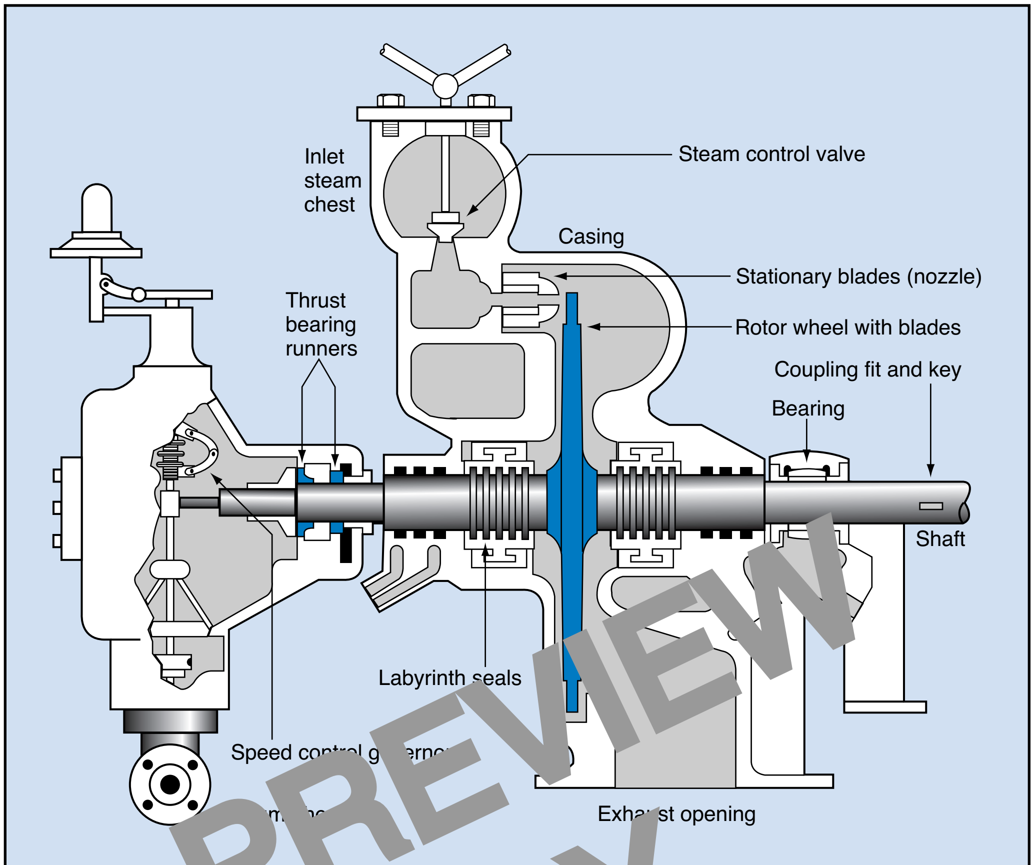
**Fig. 1-1. Small, single-stage steam turbine**

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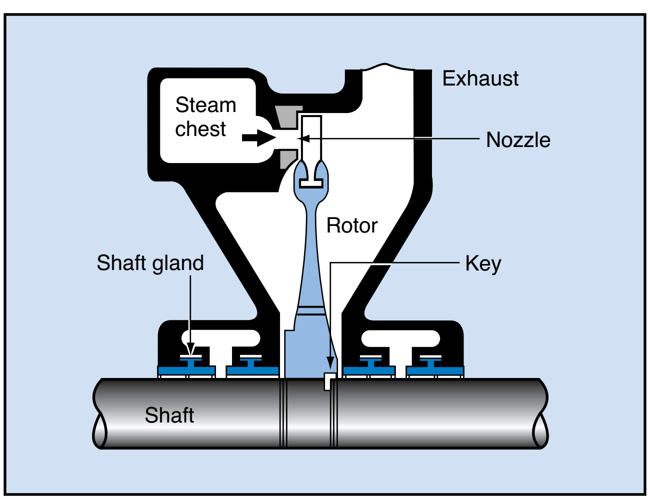
occurs as the steam transmits energy to the shaft and performs work. After passing through the last turbine stage, the steam exhausts into the condenser or process steam system.

**Fig. 1-2. Simple impulse turbine stage**




1.07 In a turbine, the kinetic energy of the steam changes into mechanical energy through the impact or reaction of the steam against the blades. An *impulse turbine* uses the impact force of the steam jet on the blades to turn the shaft. A simple impulse turbine stage is shown in Fig. 1-2. The steam expands as it passes through the nozzles. At this point, its pressure drops and its velocity increases. As the steam flows through the moving blades, its pressure remains the same, but its velocity decreases. The steam does not expand further as it flows through the moving blades.

1.08 A simple impulse turbine is not very efficient because it does not fully use the velocity of the steam. Many impulse turbines are *velocity-compounded turbines*, which means they have two or more sets of moving blades in each stage. The extra sets of moving blades make use of the high-velocity steam leaving the first set of moving blades. A row of fixed blades between the moving blades directs the steam onto the next set of blades.

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1.09 Another kind of impulse turbine, the *pressure-compounded turbine*, is shown in Fig. 1-3. It consists of two or more simple impulse stages contained in one casing. The casing contains diaphragms that connect to nozzles. The nozzles make efficient use of the steam pressure that remains after the steam flows through the previous stage. The pressure drops in each stage as steam expands through the nozzles.

1.10 A *reaction turbine* uses the "kickback" force of the steam as it leaves the moving blades to rotate the shaft. The moving blades and fixed blades have the same shape and act like nozzles, as shown in Fig. 1-4. Thus, steam expands, loses pressure, and increases in velocity as it passes through both sets of blades. All reaction turbines are pressure-compounded turbines.

1.11 Many large turbines use both impulse and reaction blading. These combination turbines usually have impulse blading at the high-pressure end, and reaction blading at the low-pressure end. The blade length and size increases throughout the turbine to use the expanding steam efficiently. Blade rows require seals to prevent steam leakage where the pressure drops. Seals for impulse blading are located between the rotor and diaphragm to stop leakage past the nozzle. Seals for reaction blading are located at the tips of both the fixed and moving blades.

### Turbine Classification

1.12 Because steam turbines vary widely in design, there are many different turbine classes. Steam turbines are commonly classified by blade design (impulse or reaction), steam pressure, exhaust conditions, steam path, or shaft arrangement.

1.13 **Steam pressure.** Steam pressure refers to the turbine design pressure. Low-pressure turbines operate at pressures of 150 psi or lower. Medium-pressure turbines operate at pressures between 151 and 450 psi. High-pressure turbines operate at pressures greater than 450 psi. The high-pressure turbines that drive electric generators operate at pressures up to 3500 psi.

1.14 **Exhaust conditions.** Exhaust conditions depend on whether the turbine is a condensing, noncondensing, extraction, reheat, or nonreheat unit. A *condensing turbine* exhausts steam into a condenser at a pressure less than atmospheric. A *noncondensing turbine* has an exhaust pressure the same or greater than atmospheric.

1.15 Condensing turbines are more efficient than noncondensing because they use more of the steam's heat energy. All large turbines that carry electrical loads for utilities are condensing turbines. Plants use noncondensing turbines to supply low-pressure steam for heating or as *"topping units"*. Topping units exhaust steam into another low-pressure turbine to improve plant capacity.

1.16 In an extraction or bleeder turbine, part of the steam leaves the casing before reaching the exhaust end. The steam "bleeds off" through one or more

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**Fig. 1-3. Pressure-compound impulse turbine**

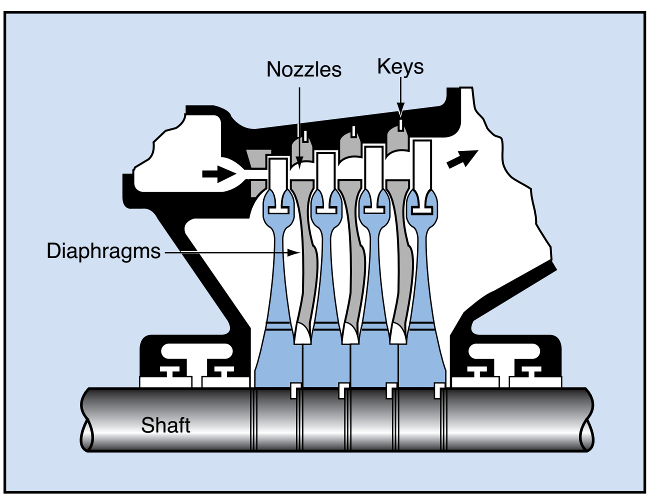


**Fig. 1-4. Steam flow through a reaction turbine**

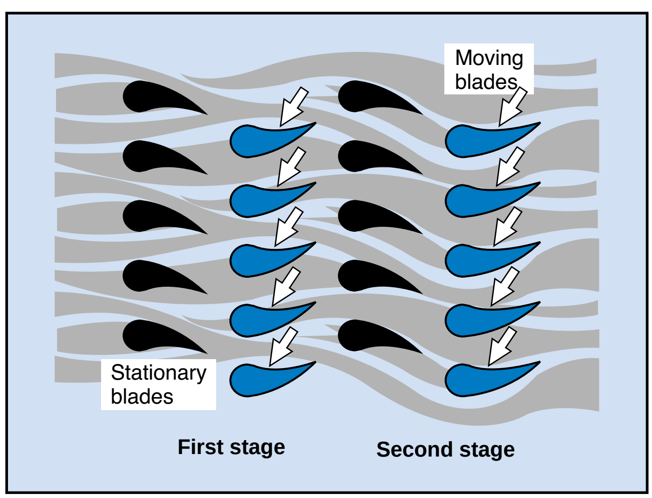


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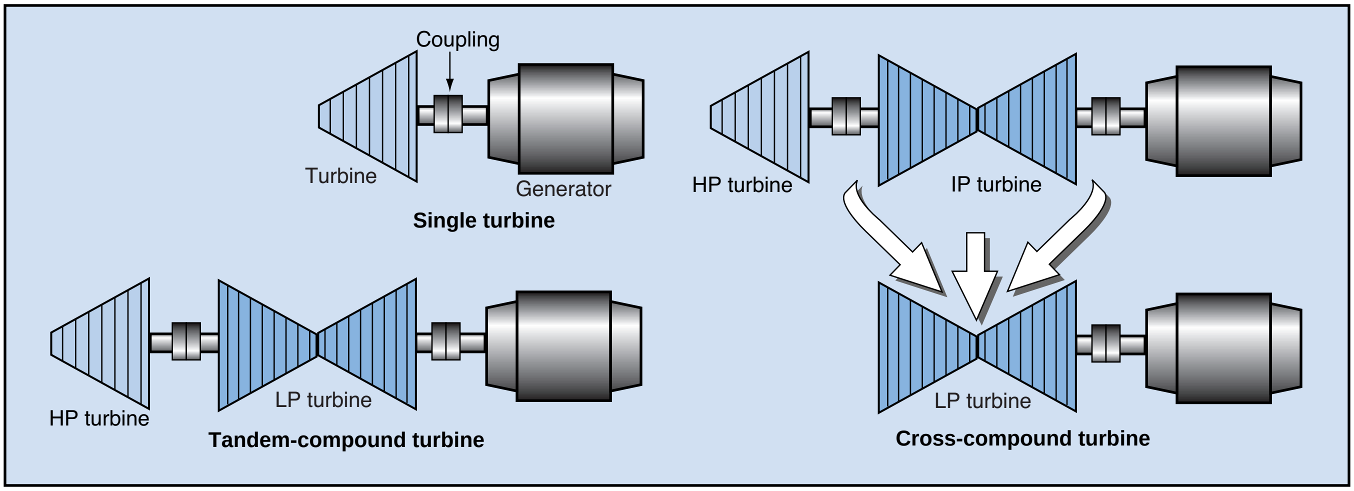
**Fig. 1-5. Various rotor shaft arrangements**




extraction lines at various stages of the turbine. The extracted steam heats condensate returning to the boiler for use as feedwater.

1.17 A *reheat turbine* sends steam that has expanded through part of the turbine to the reheater (reheat superheater) in the boiler. The reheater raises the steam temperature to, or near, its original temperature. The reheated steam then returns to the turbine and expands to the exhaust. Reheating dries the steam so that it travels farther through the low-pressure section before condensing. A *double-reheat turbine* has two reheat cycles. A *nonreheat turbine* has no reheat cycle. Steam enters a nonreheat turbine at a given temperature, and expands through the turbine to the exhaust.

1.18 **Steam flow.** Steam flow refers to the path the steam follows through the turbine. A turbine may have single flow, double flow, or triple flow. *Single flow* means the steam travels along a single path from the high-pressure section to the exhaust. *Double flow* means the steam "splits" and flows in opposite directions parallel to the shaft. *Triple flow* (not often used) means that a third part of the low-pressure steam is directed through its section parallel to the shaft. The steam flows in the same direction as the steam in one of the double flow sections. Double and triple flow paths accommodate the greater volume of low-pressure steam, and also help balance the axial (along the shaft) thrust of the turbine.

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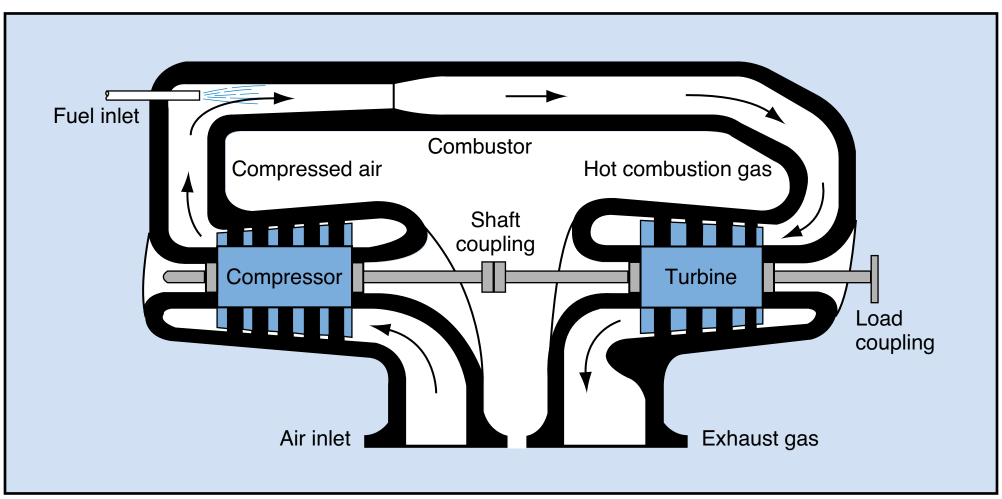
**Fig. 1-6. Gas turbine operation**

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1.19 **Shaft arrangement.** Shaft arrangement can be single, tandem-compound, or cross-compound. All three are shown in Fig. 1-5. A *single turbine* consists of one unit through which steam expands and exhausts. A *tandem-compound turbine* consists of a high-pressure section and low-pressure section that join end-to-end on a single shaft. The shaft drives a single generator. A *cross-compound turbine* consists of a high-pressure section (and intermediate-pressure section on large turbines) and low-pressure section on separate parallel shafts. Each shaft drives its own generator.

1.20 One or more of the above classifications can apply to a given turbine. For example, a single turbine can be a tandem-compound, double-flow, reheat unit. This turbine would have its low-pressure and high-pressure sections on a single shaft, two paths for steam flow, and a reheat cycle.

### Gas Turbines

1.21 A gas (combustion) turbine and steam turbine operate on a similar principle, but a gas turbine uses air instead of steam as its working fluid. A gas turbine converts the chemical energy of a fuel into mechanical energy through internal combustion. The hot combustion products expand through the turbine and perform work.

1.22 A simple gas turbine is shown in Fig. 1-6. Air drawn in from the atmosphere enters a rotary (centrifugal) compressor, which raises the pressure and air temperature. The pressurized, heated air leaves the compressor and enters the combustor for further heating. A portion of the air mixes and burns with the fuel in the combustor. The rest of the air mixes with the hot combustion gases to lower the air-gas mixture temperature entering the turbine.

1.23 The hot gases enter the turbine at a temperature of about 1200 to 2000°F (650 to 1095°C). As the hot gases expand through the turbine, they strike the blade, causing the shaft to rotate. The turbine drives both the load (generator, pump, or fan) and the compressor. The hot gases exhaust from the turbine at about 1000°F (540°C) and atmospheric pressure.

1.24 Gas turbines have several advantages over steam turbines. Gas turbines do not require separate auxiliary equipment (boilers and condensers) as do steam turbines. A gas turbine is a single unit containing all of its auxiliary equipment. It is lighter and smaller. A plant can install a gas turbine more quickly and at a lower cost than a steam turbine.

1.25 Gas turbines require less time to start up and accept a load. Many power plants use gas turbines as "peaking units" to supply power during peak demands. Gas turbines also serve as standby units to provide power when the main turbine-generators are starting up or are out of service.

1.26 The main disadvantages of a gas turbine are low efficiency, limited capacity, and high maintenance costs. Gas turbines are less efficient and more costly to operate for generating power than steam turbines, requiring more fuel per kilowatt hour. They have smaller capacities (1 to 200,000) than steam turbines. And, they have higher maintenance costs because they operate at higher temperatures.

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### Condensers

1.27 A *condenser* is a heat-transfer device located at the turbine exhaust that condenses steam by means of cooling water. The two kinds of condensers are direct contact and indirect contact condensers. *Direct-contact condensers* mix the steam directly with sprays of cooling water. Few power plants use direct contact condensers because the cooling water contaminates the condensate. Thus, condensate is unsuitable for use as feedwater without extensive treatment.

1.28 The condensate from an *indirect-contact condenser* requires little feedwater treatment because it does not mix with the cooling water. The main kind of indirect contact condenser is a surface condenser, as shown in Fig. 1-7 on the following page. This condenser consists of an airtight shell with a water box at each end. Many surface condensers have divided water boxes so that part of the unit can be shut down for maintenance. Tube sheets around the water boxes prevent water leakage into the steam space. The water boxes connect to many small-diameter (½ to 1 in.) tubes.

1.29 A pump sends cooling water to the inlet water box and through the condenser tubes. Exhaust

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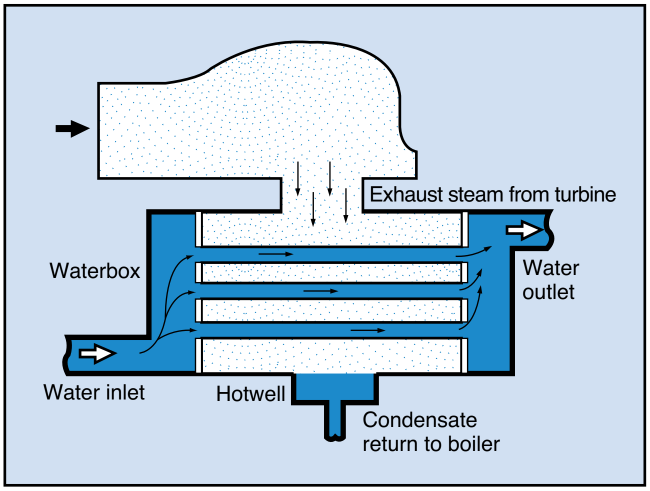
**Fig. 1-7. Surface condenser**




steam enters the top of the condenser and flows downward around the cold tubes. The steam condenses on the outside tube surfaces, and the condensate flows into a reservoir (hotwell). The warmed cooling water enters the outlet water box and discharges from the condenser.

1.30 The main purpose of a condenser is to allow steam to perform more work by expanding it to a lower pressure and temperature. A condenser increases the pressure drop through the turbine by maintaining a vacuum at the turbine exhaust. As steam condenses, its volume decreases greatly, which lowers the pressure in the condenser below atmospheric pressure (14.7 psi). This reduced pressure or vacuum decreases the turbine back pressure, and increases turbine efficiency.

1.31 Vacuum is measured in psi and in inches of mercury (in. Hg). A 1 in. Hg vacuum equals 0.491 psi, and 29.92 in. Hg equals standard atmospheric pressure. Back pressure equals the difference between the atmospheric pressure and vacuum.

1.32 The vacuum must be maintained at the equipment rating to ensure a low back pressure, as shown by the following example. Assume the design back pressure of a turbine is 1 psia. The initial pressure of steam as it enters the turbine is 400 psia. Steam at 400 psia has an enthalpy of 1205 Btu/lb. Steam exhausting at 1 psia has an enthalpy of 1106 Btu/lb. If the turbine is operating at its design back pressure of 1 psia, it will obtain 99 Btu (1205 to 1106) from each pound of steam (with no energy losses).

1.33 If the vacuum decreases and the back pressure increases to 2 psia, the exhaust steam will have an enthalpy of 1116 Btu/lb. The turbine can then obtain only 89 Btu (1205 - 1116) from each pound of steam. The loss in efficiency equals:

$$\frac{99-89}{99} \times 100 = 10.1\%$$

**The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of your Book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.**

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| | |
|---|---|
| 1-1. A turbine rotor consists of a shaft with ________ blades mounted on it. | 1-1. MOVING or ROTATING<br>Each blade set connects to a drum or disk.<br>Ref: 1.04 |
| 1-2. Steam expands in an impulse turbine when it flows through the ________. | 1-2. NOZZLES<br>Ref: 1.07 |
| 1-3. The kind of turbine that uses the kick-back force of steam is the ________ turbine. | 1-3. REACTION<br>Ref: 1.10 |
| 1-4. The exhaust pressure of a condensing turbine is ________ than atmospheric pressure. | 1-4. LESS or LOWER<br>Ref: 1.14 |
| 1-5. A turbine that has both its high-pressure and low-pressure sections mounted on a single shaft is a(n) ________ ________ turbine. | 1-5. TANDEM-COMPOUND<br>Ref: 1.19 |
| 1-6. A gas turbine performs work by means of hot ________ gases. | 1-6. COMBUSTION<br>The gases expand through the turbine.<br>Ref: 1.21 |
| 1-7. A surface condenser is a(n)________ - contact condenser. | 1-7. INDIRECT<br>Ref: 1.28, Fig. 1-7 |
| 1-8. How does a condenser allow steam to perform more work? | 1-8. BY MAINTAINING A VACUUM AT THE TURBINE EXHAUST<br>Ref: 1.30 |

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### Heat Rejection and Thermal Pollution

1.34 The largest single loss of energy in a power plant is the heat rejected to the condenser. More than half of the heat energy of the steam leaving the boiler is rejected or discarded to the condenser cooling water. The heat lost is *low-level heat*, which means its temperature is too low for practical heat recovery.

1.35 The low-level heat has a low temperature because the condenser is under vacuum. An increase in vacuum decreases the temperature at which steam condenses, as shown in Table 1-1. For example, steam at 1 psia condenses at 102°F (39°C), whereas steam at normal atmospheric pressure condenses at 212°F (100°C).

1.36 The condenser requires a constant supply of low-temperature cooling water to absorb and carry away the heat released by the condensing steam. As the cooling water absorbs heat, its temperature increases. The difference between the water inlet and outlet temperature indicates the circulating water temperature rise. The *circulating water temperature rise* measures the amount of heat that each pound of water absorbs from the steam. For example, a circulating water temperature rise of 10°F indicates that each pound of water absorbs 10 Btu from the exhaust steam. Depending on the turbine load, the circulating water temperature rise can range from 5 to 20°F (3 to 11°C).

1.37 If large quantities of heated cooling water discharge into a river, lake, or other natural water source, *thermal pollution* will result. The heated cooling water will increase the temperature of the receiving water, damaging plant and animal life.

**Table 1-1. Pressure and condensing temperature relationship**

| | Absolute pressure (psia) | Boiling or condensing temperature °F | Boiling or condensing temperature °C |
|---|---|---|---|
| Vacuum | 1.0 | 102 | 39 |
| Vacuum | 2.0 | 126 | 52 |
| Vacuum | 3.0 | 141 | 61 |
| Vacuum | 4.0 | 152 | 66 |
| Vacuum | 5.0 | 162 | 72 |
| Vacuum | 6.0 | 170 | 77 |
| Vacuum | 7.0 | 177 | 81 |
| Vacuum | 8.0 | 182 | 84 |
| Vacuum | 9.0 | 188 | 87 |
| Vacuum | 10.0 | 193 | 89 |
| | 14.7 | 212 | 100 |

### Boiler-Turbine-Generator Efficiency

1.38 The *efficiency* of the boiler-turbine-generator unit equals the ratio of the energy output to the energy input. Thus, efficiency equals the electrical energy produced by the generator, divided by the heat supplied to the boiler. The heat input is measured in Btu, and the electrical energy output is measured in kilowatt-hours (kWh). One kilowatt-hour has a heat equivalent of 3412 Btu.

1.39 The efficiency of the entire steam and power generating unit is low. Even in the most efficient plants, efficiency will not exceed 40%. As noted above, the main energy loss occurs in the condenser. A typical modern power plant requires 9000 Btu input to the boiler to produce each kilowatt-hour of electricity. Thus, efficiency equals:

$$\frac{\text{Output}}{\text{Input}} = \frac{3412\ \text{Btu}}{9000\ \text{Btu}} \times 100 = 37.8\%$$

1.40 Boiler efficiency alone is much higher than the efficiency of the entire boiler-turbine-generator unit. Boiler efficiency also equals the ratio of heat output to heat input. Most plants have a boiler efficiency of 80 to 90%. The largest single heat loss from the boiler is stack loss, which results when hot gases exhaust to the atmosphere.

### Turbine-Generator Performance Operating Data

1.41 The best way to ensure that a turbine-generator is running efficiently is to take operating data on a regular schedule. Check the turbine and generator instruments every hour. A change in the readings could indicate steam, oil, or water leakage from the system. Accurate records of operating data will help you detect small losses, which could become major losses if not corrected.

1.42 The main checkpoints to include in your regular inspection are: steam flow to the turbine inlet, inlet steam pressure and temperature, exhaust steam pressure, extraction steam pressure and temperature, bearing lubrication system temperature and pressure,

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generator temperature, generator load (in kW), inlet cooling water temperature, and outlet cooling water temperature. Be sure to note any unusual conditions (excess noise, chatter, vibration) in your log book.

### Maintenance of Turbine-Generator System

1.43 A good preventive maintenance (PM) program that includes frequent checks on equipment will help keep a turbine-generator system operating efficiently. If a PM inspection indicates a problem in the system, take corrective action as soon as possible. Check the manufacturer's manual for the recommended maintenance practices. Although specific maintenance practices depend on the unit's design, the guidelines given below will help you reduce four common maintenance problems: overspeeding, vibration, bearing failure, and overload.

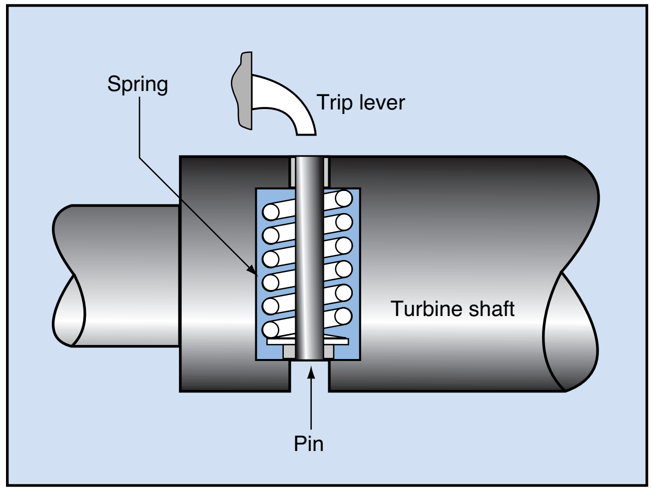
1.44 **Overspeeding.** Steam turbines that drive electric generators operate at high speeds—either 1800 or 3600 revolutions per minute (rpm). If the speed increases above normal, the centrifugal force acting on the rotor and other moving parts will also increase. As the centrifugal force increases, it places mechanical stresses on the turbines. Eventually, the turbine will weaken and burst.

1.45 Normally, the turbine governing system prevents overspeeding. If the governor malfunctions, or fails to control a sudden unloading of the turbine, overspeeding will occur. When the turbine overspeeds by 10%, of its normal speed, the increase in centrifugal force should activate an overspeed trip mounted on the rotor.

1.46 An overspeed trip is shown in Fig. 1-8. When the turbine overspeeds 10% above normal, the centrifugal force causes a spring-loaded steel pin to move outward from the rotor surface. The pin strikes a lever which then operates a trip relay, causing all steam valves to close. When the turbine is operating at normal speed, the spring restrains the pin and prevents the unit from tripping.

1.47 Be sure to test the trip operation regularly, as recommended by the turbine manufacturer. Unload the generator and then slowly raise the turbine speed until the trip operates. Record the speed at which the unit trips in your log, and reset the trip. If the unit fails to trip at the set speed, reduce the turbine speed to normal and report the trip for maintenance.

**Fig. 1-8. Overspeed trip**




1.48 **Vibration.** Turbine rotors are subject to vibration because they operate at high speeds. Common causes of rotor vibration are imbalance of rotating parts, excessive bearing clearances, and water carry-over with steam. Imbalance of rotating parts can result from broken or eroded blades, scale deposits on blades, a bent or warped shaft, and worn or misaligned couplings. When a turbine is down for overhaul, check the blade condition. Remove scale deposits from dirty blades, and repair or replace damaged blades as necessary. Check the shaft condition. A bent or warped shaft needs repair or replacement. Repair or replace worn couplings, and realign them if necessary.

1.49 Excessive bearing clearances result when bearings becomes worn. Wear is caused by overheating due to improper lubrication. Bearings support the rotor, and excessive clearances cause rotor or coupling misalignment. Replace worn bearings, and make sure the bearing clearances are within manufacturer's design clearances.

1.50 To detect the cause of spindle vibration, check mechanical imbalance due to a bent shaft, missing blade, or rotor imbalance. Also inspect couplings for misalignment or wear, blades for damage or erosion, loose wheels on the shaft or loose thrust-bearing collars, and for slugs of water in steam or solids carry-over.

1.51 **Bearing failure.** Bearing clearances between stationary and moving turbine parts can vary from 0.001 to 0.0025 in. per inch journal diameter before replacement, except in special pressure-type bearings.

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Examine bearings regularly for wear, wiping, grit-cutting, electrolysis (generator bearing), and static electrolysis (turbine-end bearing) or thrust. Bearing failure seriously damages turbines.

1.52 The main cause of bearing failure is improper lubrication. Lubricating oil conducts heat away from the bearings and allows the shaft to rotate freely. You can prevent bearing failure by supplying the proper kind and amount of lubrication, and by keeping the oil in good condition. Follow the manufacturers instructions. Be sure to keep the oil supply in the reservoir at the proper level.

1.53 Lubricating oil must be free of dirt particles and water to prevent damage to and corrosion of highly polished bearing surfaces. Oil tends to collect dirt as it flows through the supply system. Lubricating systems that recirculate oil have strainers filters and purifiers to clean the oil before it re-enters the turbine. Check these regularly and maintain as required.

1.54 Water leakage into oil lines can contaminate oil and cause bearing failure. A frequent cause of water contamination is steam leakage through turbine glands. Keep turbine glands properly maintained and replace oil if leakage occurs. Another cause of water contamination is condensed moisture in the sump tank. Check the sump tank daily by drawing off an oil sample to check for water entrainment.

1.55 **Turbine overloaded.** If a turbine is unable to carry its load, check the daily operating data for indications of trouble. The problem could be caused by a low inlet steam pressure or a high exhaust pressure. If the inlet pressure is low, check the steam supply valves to be sure that they are providing steam at the proper pressure. A high exhaust pressure could be caused by dirty condenser tubes, air leakage into the condenser, or warm condenser cooling water.

1.56 Other items to check are the steam strainer, governor, and blades. The steam strainer prevents large solids from entering the turbine at the steam stop valve. Check the strainer for plugging, and remove dirt deposits. The governor might require adjustment or cleaning. Make sure the governor valve stem is clean and that the valve opens completely. Check fixed and moving blades for clogging, wear, and damage. Remove dirt from clogged blades; replace worn or damaged ones.

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### Condenser Cooling Water Requirements

1.57 A condenser requires large quantities of cooling water to absorb the latent heat of condensing steam. In general, a condenser uses between 75 and 100 lb of cooling water to condense each pound of steam. Changes in turbine load affect the amount of water needed to maintain the design back pressure. If the turbine load decreases below normal, less exhaust steam enters the condenser. Thus, the condenser requires less water to condense the decreased supply of steam. If the turbine load increases, more exhaust steam flows to the condenser. Then it requires more cooling water to condense the steam at the design exhaust temperature and back pressure.

1.58 The cooling water inlet temperature must be maintained at design temperature for efficient condenser and turbine operation. If the inlet water temperature rises above the design temperature, the warmer water will increase the temperature in the condenser. As the condenser temperature rises, the back pressure also increases. An increase in the back pressure reduces the pressure drop through the turbine, and the steam will perform less work.

1.59 Cooling water must circulate through the condenser at a steady rate to maintain the required vacuum. Common causes of reduced water flow are blockage of water intake screens, pump wear, and fouling of tube sheets. Intake screens at the cooling water source (stream, lake, river) trap leaves, wood, and other suspended solids. If the screens are dirty, the debris will plug the screen openings and restrict water flow into the condenser. Wear on the impeller of the circulating pump reduces the amount of water it can send to the condenser. Tube sheet fouling results when breaks in the intake water screens allow debris to enter the condenser. The debris can plug the inlet ends of the condenser tubes and restrict water flow.

1.60 Other factors that reduce condenser efficiency are dirty tubes, leaking tubes, and air leakage into the steam space. Dirty (fouled) tubes reduce heat transfer from the exhaust steam to the cooling water. Leaking tubes allow cooling water to enter the steam space

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and contaminate the condensate. Air leakage decreases the vacuum.

1.61 **Dirty tubes.** Tube fouling occurs when scale, slime, and algae collect on the water side of the tubes. Thick deposits reduce both heat transfer and water flow through the condenser. You can clean tubes with a hydraulic gun, by chemical treatment, or by backwashing. A hydraulic gun shoots rubber plugs through the tubes with a water jet. The plugs rub against the tube walls, and dislodge slime and soft scale. You can remove deposits chemically by adding chlorine or chlorine compounds to the water supply on a regular schedule. The chlorine destroys algae and reduces slime buildup. Backwashing reverses the water flow which flushes out the inlet ends of the tubes.

1.62 **Tube leakage.** Leakage occurs when tube ends pull away from the tube sheet and when tubes split or crack. You can detect tube leakage in several ways. One common method is to slant down the condenser (except for the steam jets) and pass a lighted candle around the tubes and tube sheets. If there is a leak, the candle flame will flicker or go out. Another way to detect leaks is to shut down the condenser and circulate water through the tubes. Water will drip through the tubes if leaks are present. Or, you can fill the steam space (instead of the tubes) with water. Water will collect in the water boxes if tubes are leaking.

1.63 These methods will tell you if large leaks are present, but small leaks are more difficult to find. One way to check for small leaks is to measure the conductivity of the condensate with a conductivity meter. Condensate is high quality water that contains few dissolved minerals (ions), and has a low electrical conductivity. Cooling water contains a higher concentration of dissolved minerals and has a higher electrical conductivity. If cooling water has leaked into the condensate, it will increase the condensate's electrical conductivity and that will show on the meter.

1.64 Repair tube leaks as soon as possible after you discover them. When the condenser is down for short maintenance periods, you can repair a split tube by inserting a fiber or metal plug into the tube end. When the condenser is down for an extended period, replace damaged tubes.

1.65 **Air leakage.** Because a condenser is under vacuum, air tends to leak through seals, joints, and condensate lines. It is also possible for air to enter the condenser through leaks in the cooling water tubes. Any air remaining in the condenser forms a film or blanket on condenser tubes. This film reduces heat transfer. Air leakage will decrease or ruin the vacuum.

1.66 Most condensers use steam-jet ejectors to remove air from the steam space. A simple steam-jet ejector consists of a nozzle, suction chamber, and diffuser, as shown in Fig. 1-9. The nozzle shoots a high-pressure steam jet through the suction chamber and diffuser. As the steam passes through the suction chamber, it sucks in air, which travels with the steam to the diffuser. The diffuser transforms the velocity energy of the air-steam mixture into pressure. The increased pressure allows the air to escape to the atmosphere.

1.67 You can check for air leaks by passing a lighted candle around joints and other common leak points, as described in paragraph 1.62. Another way is to brush a solution of soapy water on potential leak points, and send low-pressure air through the system. Bubbles will form where there are leaks. A third way is to shut down the condenser and maintain the vacuum for about an hour. If the vacuum decreases more than 9 in. Hg, air is leaking into the condenser.

**Fig. 1-9. Simple steam-jet ejector**

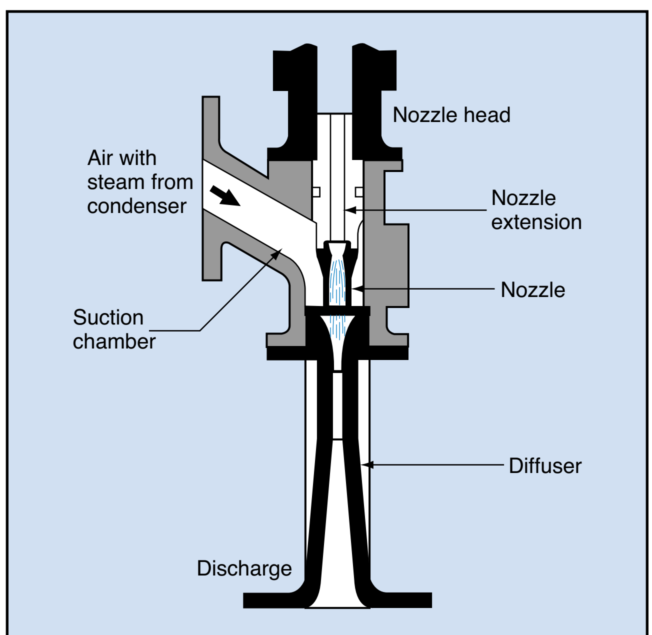


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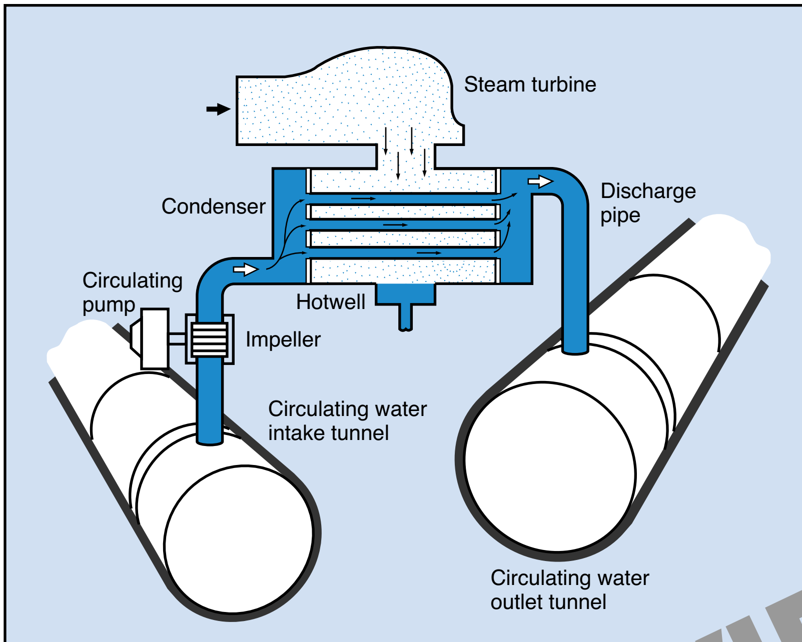
Fig. 1-10. Once-through cooling system



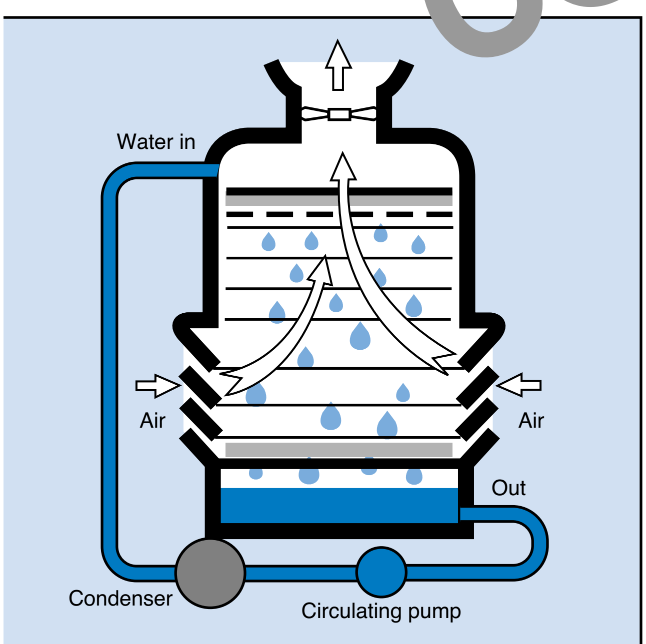

## Cooling Water System

1.68 Which kind of condenser cooling water system a given plant uses depends on the available supply of cool water. The two kinds of systems are once-through and recirculation systems. A *once-through system* pumps water from a natural water source, through the condenser, and back to the source. A once-through system is illustrated in Fig. 1-10.

1.69 In a once-through system, water flows to the plant through large pipes or channels called *intake tunnels*. Before entering the tunnel, the water flows through a bar rack, which is a screen consisting of closely spaced bars. The bars prevent large solids from entering the circulating system. The water then flows through a rotating screen to remove smaller solids. After passing through the screens, the water enters an intake well where a circulating pump sends it through the condenser.

1.70 Power plants that have a limited water supply available for cooling use a *recirculating system*. This system removes heat from previously used, prewarmed cooling water, and returns the water to the condenser. A recirculating system requires only a small amount of makeup water (5 to 10%) to replace losses.

Fig. 1-11. Cooling tower




1.71 One kind of recirculating system, the *cooling tower*, is shown in Fig. 1-11. Air flows through the tower by natural draft or by mechanical draft (produced by fans). Warm water enters the top of the tower, flows downward over wood, ceramic, or fiberglass strips, and collects in a basin. Air enters the side of the tower through louvers, flows upward, and mixes with the water. The water temperature decreases through evaporation and heat transfer to the air. A pump in the basin returns the cooled water to the condenser.

1.72 As water evaporates from a cooling tower, the concentration of scale-forming impurities (calcium and magnesium) increases. If the water returns to the condenser without proper treatment, scale deposits will form in condenser tubes. Scale will reduce condenser efficiency by decreasing the heat transfer rate, and by restricting water flow through the tubes. You can reduce scale formation by adding phosphate, or phosphate compounds to the cooling

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water. Phosphates react with scale-forming impurities and precipitate them into a sludge. The sludge then drains from the system during blowdown. Phosphates contribute to algae growth, which you can control with chlorine or chlorine compounds.

1.73 High pH (alkalinity) also causes scale formation. The cooling water's pH should range from 6.8 to 7. You can reduce alkalinity by adding sulfuric acid to the water.

1.74 If the cooling water is acidic (pH below 7.0), however, corrosion will result when the water flows through the condenser. Another cause of corrosion is dissolved oxygen. Water picks up oxygen as it mixes with air in the cooling tower. You can control corrosion due to low pH by adding lime, sodium phosphates, or other alkalis to the cooling water. You can control corrosion due to dissolved oxygen by using a corrosion inhibitor.

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| | |
|---|---|
| 1-9. The condensing temperature decreases as the vacuum ________. | 1-9. INCREASES<br><br>Ref: 1.35, Table 1-1 |
| 1-10. The efficiency of the boiler-turbine-generator unit equals the ratio of the electrical energy output to the ________ input. | 1-10. HEAT<br><br>Ref: 1.38 |
| 1-11. Turbine overspeeding can occur when the ________ malfunctions. | 1-11. GOVERNOR<br><br>Ref: 1.45 |
| 1-12. Excessive bearing clearances cause misalignment of the ________ or coupling. | 1-12. ROTOR<br><br>Ref: 1.49 |
| 1-13. Two main causes of lubricating oil contamination are dirt and ________ leakage. | 1-13. WATER<br><br>Ref: 1.54 |
| 1-14. You can clean condenser tubes with a hydraulic gun, with chlorine, or by ________. | 1-14. BACKWASHING<br>Backwashing reverses the water flow through the condenser.<br><br>Ref: 1.61 |
| 1-15. A steam-jet ejector is a device commonly used to remove________ from a condenser. | 1-15. AIR<br><br>Ref: 1.66 |
| 1-16. Scale reduces condenser efficiency by restricting water flow and reducing the rate of ________. | 1-16. HEAT TRANSFER<br><br>Ref: 1.72 |

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**Answer the following questions by marking an "X" in the box next to the best answer.**

1-1. The moving blades of a turbine connect to which of the following?

☐ a. Cylinder
☐ b. Diaphragm
☐ c. Disc or drum
☐ d. Stator

1-2. What kind of turbine rotates the shaft using the kickback force of the steam?

☐ a. Pressure-compounded impulse
☐ b. Reaction
☐ c. Simple impulse
☐ d. Velocity-compounded impulse

1-3. A turbine that has two steam paths and has its high-pressure and low-pressure sections on a single shaft is classed as

☐ a. cross-compound, double flow
☐ b. cross-compound, reheat
☐ c. tandem-compound, double flow
☐ d. tandem-compound, single flow

1-4. A condenser allows steam to perform more work in the turbine by

☐ a. decreasing the pressure drop
☐ b. increasing the back pressure
☐ c. increasing the condensing temperature
☐ d. increasing the pressure drop

1-5. If the circulating water temperature in a condenser rises 5° F. each pound of water absorbs how much heat?

☐ a. 1 Btu
☐ b. 5 Btu
☐ c. 10 Btu
☐ d. 15 Btu

1-6. Which of the following activates an overspeed trip?

☐ a. Decrease in bearing clearances
☐ b. Decrease in centrifugal force
☐ c. Decrease in turbine speed
☐ d. Increase in centrifugal force

1-7. Which of the following will result if the condenser inlet water temperature rises above the design temperature?

☐ a. Back pressure will decrease
☐ b. Pressure drop through the turbine will decrease
☐ c. The amount of work performed by the steam will increase
☐ d. The temperature in the condenser will remain the same

1-8. You can use a conductivity meter to check for

☐ a. condenser air leakage
☐ b. condenser tube leakage
☐ c. improper bearing clearances
☐ d. worn turbine blades

1-9. A cooling tower removes heat from water by means of

☐ a. air
☐ b. cold water
☐ c. jet ejectors
☐ d. special oils

1-10. You can control condenser tube corrosion due to low pH by adding which of the following to the cooling water?

☐ a. Calcium
☐ b. Dissolved oxygen
☐ c. Lime
☐ d. Sulfuric acid

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## SUMMARY

**A turbine is a machine that generates mechanical power from the kinetic energy of a fluid. Steam turbines are the most widely used kind. A steam turbine's two main parts are the cylinder and the rotor. In an impulse turbine, the impact force of the steam jet on the blades turns the shaft. Impulse turbines can be velocity compounded or pressure-compounded. A reaction turbine uses the kickback force of the steam to rotate the shaft. Steam turbines can be classified not only by blade design, but also by exhaust conditions, steam path, or shaft arrangement.**

**Gas turbines and steam turbines operate on similar principles. A gas turbine, however, uses air instead of steam as its working fluid. A gas turbine converts the chemical energy of a fuel into mechanical energy through internal combustion.**

**A condenser is a heat-transfer device located at the turbine exhaust. It uses cooling water to condense steam. The two kinds of condenser are direct contact and indirect contact. Direct-contact condensers mix the steam directly with sprays of cooling water. The condensate from an indirect-contact condenser does not mix with the cooling water.**

**The largest single loss of energy in a power plant is the heat rejected to the condenser. The efficiency of the boiler-turbine-generator unit equals the ratio of the energy output to the energy input. Good preventive maintenance is your best tool in keeping a turbine-generator system operating efficiently. Common maintenance problems are overspeeding, vibration, bearing failure, and overload.**

**The kind of condenser cooling water system used in a given plant depends on the available supply of cool water. A once-through system pumps water from a natural source, through the condenser, and back to the source. In a recirculating system, the cooling water is returned to the condenser. It is commonly used when a limited amount of water is available for cooling.**

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**Answers to Self-Check Quiz**

1-1. c. Disc or drum. Ref: 1.04

1-2. b. Reaction. Ref: 1.10

1-3. c. Tandem-compound, double flow. Ref: 1.20

1-4. d. Increasing the pressure drop. Ref: 1.30

1-5. b. 5 Btu. Ref: 1.36

1-6. d. Increase in centrifugal force. Ref: 1.44,1.45.

1-7. b. Pressure drop through the turbine will decrease. Ref: 1.58

1-8. b. Condenser tube leakage. Ref: 1.63

1-9. a. Air. Ref: 1.71

1-10. c. Lime. Ref: 1.74

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