Session 11: Turbines

Prepare to Teach

Session Overview

Session 11 introduces turbines, providing a thorough description of the most commonly used turbines in the refinery and petrochemical industries. This session covers the types, components, theory of operation, and associated hazards of turbines. Students are given various activities to learn this content. The remainder of turbine objectives will be covered in the next session.

Class Preparation Checklist

1. Familiarize yourself with the content to be presented in this session.
2. Copy all handouts as needed.
3. Arrange for flipchart easel, flipchart paper, and markers OR chalkboard and chalk.
4. Arrange for overhead projector and overheads, if used.
5. Bring P&ID diagrams that include turbine symbols.
6. Bring cutaways or models or arrange for vendor/lab visit.
7. Bring texts or other materials to be used in this course.

Objective(s)

Learning Objectives

1. Recall the purpose of turbines in the process industry.

2. Identify the common types/applications of turbines.

3. Recall the components of a turbine.

4. Explain the purpose of each component.

5. Describe the operating principles of turbines.

6. Describe safety and environmental hazards associated with turbines.

7. Identify typical procedures associated with turbines.

8. Describe the process technician's role in turbine operation and maintenance.
9. Identify typical problems associated with turbines.

Agenda

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Background

1. Turbines use kinetic energy (steam, gas, water, etc.) and convert it to mechanical energy. This mechanical energy is then used to operate plant equipment.

2. There are various types of turbines used in industry. The turbine used depends on numerous factors, including principle of operation and type of fluid used to operate them. Most turbines used in the petrochemical and refining industries are either steam or gas turbines.

Begin Lesson

1. Agenda

Time: 5 minutes

Agenda: Explain what you intend to accomplish in today's class.

DISPLAY SLIDE #1	***OR***	Write today's agenda on the flipchart or whiteboard.

2. Learning Objectives

Time: 5 minutes

DISPLAY SLIDE #2	***OR***	Write today's learning objectives on the flipchart or whiteboard.

Discuss the lesson's objectives with the learners in order to provide them with clear-cut guidelines for what is to be learned during the instructional session.

3. Turbine Overview

Time: 25 minutes

Summarize the following information to explain turbines and their use in the petrochemical and refining industries.

DISPLAY SLIDE #3	***OR***	Write slide contents on the flipchart or whiteboard.

1. **Purpose**: As students if they remember the purpose of turbines. Capture their ideas on a flipchart or whiteboard. Add to the list as needed to ensure the following points are covered:
   - convert compressed air or steam into mechanical energy to operate plant equipment
   - turbines are one type of prime mover, i.e., drivers for rotating machinery in process plants
   - turbines us a motive gas, which may be steam, high-pressure process gases, or fuel and air, as the fluid which provides input power
   - turbines convert the motive gas flowing from higher to lower pressure into mechanical energy to operate rotating equipment.
   -
2. **Types**: There are several types of turbines used in industry
   - steam (condensing, non-condensing, single stage and multi-stage)
   - gas (using liquid or gaseous fuels and air).

3. **Factors that Affect Turbines Used**: Ask students to brainstorm a list of what might affect the type of turbine used in a process. Capture these thoughts on a flipchart or whiteboard. Following the brainstorm, review the following various:
   - **principle of operation:** steam is the utility used most frequently to operate turbines. Using steam from one pressure level and letting down into one or two lower levels is an economical selection. In refineries and chemical plants, many uses for steam result in condensation at relatively low pressures. Steam from boilers is usually generated at the highest pressure required in the plant. Various turbines in the plant extract low-cost energy out of the steam in letting down the pressure. Most of the energy remains in the lower pressure steam to serve the condensing users.
   - **venting steam turbines:** the most inefficient in terms of energy recovered from the motive gas. However, these turbine installations are chap and have excellent applicability where the key consideration is a backup utility (e.g., for a service that must operate in an electrical power outage). Their usage is confined to typically small sizes (under 1000 horsepower).

   When a process involves a high-pressure gas letting down to a lower pressure, the possibility exists to apply an expander turbine as a power source. Such power is available almost "for free". Considerations involve the fact that availability of the power is dependent on that process operating. An especially attractive application exists if the power is used in a different area of the same process.

   Selection of the turbine type must consider many factors, including:
   - reliability of service
   - allowable time between turnaround maintenance
   - availability
   - reliability
   - quality
   - demand for the motive gas.

4. **Major Components**: Use the Turbine Component Diagram (see Appendix) and an overhead or actual turbine cutaway to identify the parts of the turbine. Have students fill in the diagram to use when studying the turbine information for the test. Include a discussion of the following components:
   - **moving blades:** These absorb the energy of the flowing fluid and transfer it to the rotor.
   - **fixed blades:** The vanes which direct the motive fluid through the machine.
   - **rotor:** The moving part that extracts work form the motive fluid and transfers it to the shaft.
   - **radial/thrust bearings:** These support and restrain the rotor in place while offering minimum resistance to free rotation.
   - **carbon rings:** A component of seals
   - **seals:** The components which keep motive fluid from leaking outward past the rotor at its point of exit from the case.
   - **governor valve/housing:** This device is the primary power and rotation speed controller for the turbine. The valve is simply the regulator for admitting the motive fluid.
   - **overspeed trip:** If the turbine is allowed to spin with little load while motive fluid is freely supplied, the result is invariably excessive rotor speed and (often dangerously explosive) self-destruction. The function of the overspeed trip is a last resort stop valve for inlet fluid to prevent this destruction. The overspeed trip is ALWAYS the "second line of defense" against overspeed, and will function only when the other overspeed protection fails.
   - **casing:** The containment shell for the passages handling the moving parts and the motive fluid.
   - **compressor, combustion chamber, and intercooler**: Terms applying to gas turbines. All gas turbines have a compressor, which pressurizes air for entry into the combustion chamber. In some cases, as the air is compressed through several stages it is of advantage to cool it to reduce the volume to compress in latter stages. The compressed air is mixed with fuel in the combustion chamber where the temperature and velocity are boosted. The hot turbulent gas then flows into the turbine where energy is extracted. A portion of this energy drives the compressor while the excess is available as shaft work output.

5. **Terms:** Define the following terms as needed:
   - throttle valve
   - **trip throttle valve:** In a typical steam turbine installation, this is the valve in the steam supply line ahead of the governor valve. This valve is used as the activating element for the overspeed protection. It also serves as a manual throttle valve, which can be used for testing and startup. It is designed to run full open in normal machine operation and is able to close very quickly. Typically, it is activated by hydraulic oil pressure; oil pressure loss fails closed and with oil pressure on, it can be operated manually.
   - **hand valve:** On some steam turbines steam admission to the first stage can be via two or more manual plug valves built into the inlet section of case. Thus at full power, all of these are open; at reduced power some may be closed. The purpose is to improve efficiency at less than design power.
   - **extraction:** On some steam turbines the case is divided into two sections. High-pressure admission steam can be let down into two levels. The exhaust from the first section is referred to as extraction steam while the exhaust from the second is exhaust steam. The

power generation of the machine comes from sum of the two sections. This can be useful in a large plant since the extraction flow can be varied for plant operation demands while the machine continues to deliver required power.

- **induction:** This is the same as above with the exception of extracting medium level steam, some medium level flow is admitted into the second section of turbine while the machine delivers its design power.
- **steam driven:** powered by steam
- **backpressure:** In a reducing turbine, this refers to the exhaust steam header pressure.
- **buckets:** These are vanes attached to the rotor, that catch the force of the admitted motive fluid and cause the capture of energy.
- **overspeed trip devices:** This refers to the safety systems (normally there are at least two separate devices) that prevent runaway speed in case the motive steam is admitted while the machine is not loaded.
- **governor:** The device which maintains rotational speed at a set value while the load demand (power extraction) varies.
- **hot and cold alignment:** This refers to the positioning of the turbine relative to the driven machinery. It is extremely critical that the shafts of turbine and the driven machine align in order to avoid excessive vibration and stresses on **coupling** device, the case and the bearings. Typically the initial mechanical alignment (cold align) must be adjusted as both the turbine and the driven machine come to operating temperature.
- **superheat:** Refers to the degrees **above** boiling point of a liquid at a given pressure. Steam feed to a steam turbine typically must have some superheat. Otherwise, as pressure and temperature drops and power is extracted from it in the turbine, some water will begin to condense. This water is detrimental to the efficiency and can be damaging to the internals.
- **surge:** In gas turbines this is a consideration in the compressor end typically at startup conditions. Surge in a rotary compressor is a potentially destructive backward flow of fluid caused by low forward flow at high pressure differential.

4. Theory of Operation

Time: 15 minutes

DISPLAY SLIDE #4	***OR***	Write slide contents on the flipchart or whiteboard.

1. **Inlet Flows**
   - Describe the different inlet flows, including the different types of steam pressures.
     - ♦ In the case of steam turbines the steam must be dry and at the design temperature and pressure.

- ♦ Normally turbines can safely handle only small amounts of condensate, so that wet steam can cause internal damage.
- ♦ It is also important that it is free of materials, e.g., silica and CO_2, which may cause problems as the pressure and temperatures come down in the equipment.
- ♦ Pressure should be constant so that governor operation is stable.
- ♦ Some turbines have manual admission valves which can be opened or closed depending on how much power will be needed.

2. **Associated Utilities/Auxiliary Equipment**. Explain the following equipment:
   - **Governor/Speed control**: The operation or the turbine is maintained by the governor system. This may be considered a closed loop controller with the setpoint the desired RPM of the machine. The input sensor of the governor is typically an electronic shaft revolution counter set to produce a millivolt output signal proportional to the RPM. It may also be a mechanical flywheel RPM device whose output is the position of a control rod. The controller portion is either a mechanical linkage arrangement, which operates the shaft of the governor valve or may be an electronic analog or digital controller, which outputs a millivolt signal. The output of the electronic controller then controls a hydraulic oil servomechanism, which in turn operates the shaft of the governor valve. In the case of electronic governor, the speed set point can be selected by the operator or by a master controller. In the case of a mechanical governor, the speed can only be changed by internal adjustment. As the power demanded by the driven unit is changing, the function of the governor is to open up/close the steam admission valve as necessary to maintain speed.
   - **Lubrication system**: This system maintains turbine bearings lubrication and temperatures. The system usually operates independently of the rotation of the turbine, but may use a shaft driven oil pump. The system consists of the pump/spare, oil filters/spare, oil coolers, supply and return lines and oil reservoir. It may also contain an emergency pressure tank so that oil pressure can be maintained temporarily in event the oil pump stops. In larger machines to prevent damage it is imperative that oil flow starts before shaft rotation begins and also that oil flow continues for cooling after the shaft rotation stops. Oil flow, pressure and cleanliness are among the most critical factors in prevention of problems.
   - **Seals:** The shaft sealing system functions to keep the high pressure motive fluids in the proper passages by preventing excessive leakage along the rotating/non-rotating boundaries. There are a great variety of sealing designs depending on fluids, pressures and temperatures. Typical designs use labyrinths (close fitting rotating/non-rotating discs), rotating/non-rotating carbon rings and others. Sometimes **buffer fluids** such as nitrogen gas are used to exclude motive fluids from oil systems. The idea here is to allow some leakage of the buffer gas in order to prevent leakage of the motive fluid in the other direction
   - **Vibration and Shaft displacement monitoring systems:** In large turbines, as in large compressors, sensors are usually installed which continuously track these factors so that shutdowns will occur before machine damage does.

3. **What Happens Within the Equipment**:
   - **back pressure versus condensing** : Inlet gas is at high pressure and low velocity. Inside the turbine the fluid pressure and flow converts to kinetic energy through high velocity passages, turning the shaft in the process. The power extracted from incoming fluid is maximized as the exhaust backpressure is minimized. However, as the pressure reduces, the volume of the gas greatly expands, so that the passages and moving vanes in the lower pressure zones must be larger to minimize duct pressure drop. In reducing steam turbines the exhaust pressure is simply the pressure of the appropriate plant steam header. In condensing turbines the exhaust pressure is usually well below atmospheric and is set mostly by the temperature of the cooling water for the condenser. The steam condenses to water under vacuum conditions.
   - **control systems**: Principle control systems are the governor and (in the case of an extraction turbine) extraction/induction system, the oil system, and the safety/trip system. The basic operation of the governor is described in B. i. above. In an extraction/induction turbine, an additional governor valve is located in the inlet passage of the low-pressure section. This valve is used to control the extraction steam pressure. In order to maintain set pressure of the extraction this valve may admit more or less steam into the low-pressure section. To compensate for this to maintain steady machine speed, the high-pressure admission valve must open and close. This action is accomplished by the electronic governor. The safety/trip system consists of all sensors which cause shutdowns (such as high vibration, low oil pressure) and a logic controller which permits or dumps oil pressure to the Trip/throttle valve. Dumping oil pressure to this valve closes off machine steam supply.
   - **extraction/induction** : Principle control systems are the governor and (in the case of an extraction turbine) extraction/induction system, the oil system, and the safety/trip system. The basic operation of the governor is described in B. i. above. In an extraction/induction turbine, an additional governor valve is located in the inlet passage of the low-pressure section. This valve is used to control the extraction steam pressure. In order to maintain set pressure of the extraction this valve may admit more or less steam into the low-pressure section. To compensate for this to maintain steady machine speed, the high-pressure admission valve must open and close. This action is accomplished by the electronic governor. The safety/trip system consists of all sensors which cause shutdowns (such as high vibration, low oil pressure) and a logic controller which permits or dumps oil pressure to the Trip/throttle valve. Dumping oil pressure to this valve closes off machine steam supply.
   - **shaft movement**: In gas turbines, the air compressor section is always integral with the turbine section because it generally shares a common shaft. Hot high pressure air form the compressor outlet enters the combustion chamber where liquid or gaseous fuel is mixed and burns, raising the inlet temperature and greatly increasing volume of the gas. The hot combustion gas then gives up energy to the rotor as it flows to the exit at lower pressure. About two thirds of the power is needed for turning the compressor, leaving one third of turbine power as output. The exhaust gas from the turbine has a great deal of excess O_2 and is at a high temperature, so larger industrial installations almost always duct this gas into a secondary steam boiler

4. **Performance Aspects:**
   - Explain how and why steam letdown via turbine pumps is used in industry.
     - ♦ Steam turbines are most often selected as prime movers in a process plant because of the convenient and efficient fit with the overall plant steam distribution. The equivalent conversion efficiency of source fuel into useful work in a reducing steam turbine is the highest of all the prime movers (can be 80%). The easiest way to visualize this is to consider the fact that the electrical energy in an electric motor has been generated by a boiler/condensing turbine/generator set at the power utility station, and then sent out through power distribution lines to the motor. The best efficiency attainable in this arrangement equates to some 30% of the energy contained in the source fuel, with the biggest loss due to the fact that the exhaust steam heat from the turbine containing latent heat is lost to cooling water.
     - ♦ Therefore, it is easy to see that if a need exists for the exhaust steam in another process unit in a condensing/heating service, the supply of work from a reducing turbine is cheap indeed.
     - ♦ There are other less common situations where a condensing turbine might be chosen. Such a case might come about if a process plant has excess steam (many processes generate steam in the process of e.g. cooling chemical reactions) which would otherwise be vented. In this case a condensing turbine might recover both some work and all of the steam condensate.
     - ♦ Likewise, gas turbines fit a plant energy picture in a different way. If there exist fuels in excess of those needed in the boiler and/or the hot exhaust gas from a turbine can be used to generate needed steam, it is possible to install a co-generation gas turbine/generator set to generate cheaper electricity than can be purchased from the local utility company.

5. **How Operation Affects Process**:
   - Review how the operation and failure of turbines can affect the plant process.
     - ♦ Since turbines are prime movers of (typically large and single-train) machinery, the failure usually shuts down processing in a unit. The sudden shutdown of a large steam turbine due to an interlock activation will often cause a severe control swing in the entire plant steam system (which in itself can cause other problems). Shutdown of many processes result in flaring and total loss of light gasses in process. Also environmental impacts can result from smoke, noise generation etc.
     - ♦ In the case of gas turbines and co-generation facilities, usually the loss of the turbine/generator set does not cause widespread process unit outage, because when the electrical loss occurs, the backup outside utility power makes up. The boiler downstream of the turbine may or may not be able to run without the turbine operating. Because gas turbine installations are not inherently as reliable as steam turbines their typical use is more built around an outage NOT causing a widespread plant problem. However reliability of properly designed gas turbine installations is continually improving and their use as process equipment drivers continues to increase.

6. **Consequences of Deviation from Normal Operation**:
   - Use the Consequences of Deviation Chart (see Appendix) as a note-taking guide as you explain how the following can impact the equipment life and potentially the plant operations. Students will only complete the COD section of the chart. The remaining sections will be completed later in this session.
   - loss of lubrication
   - impingement
   - fouling
   - pitting
   - corrosion
   - assembly errors
   - loss of overspeed shutdown systems.

Break 10 minutes

5. Procedures

Time: 25 minutes

Learning Activity:

1. Divide class into groups of 4 or 5 students (depending on your class size and facilities). Have each group move to separate areas of the room so they cannot hear other groups. Have the groups brainstorm a list of tasks that they think are necessary for Process Technicians to perform when monitoring turbines or performing routine and preventive maintenance on turbines (e.g., check for seal leaks). Ask one person in each group to record the group's ideas.

   Use flipchart paper (one for each group) and have each group write their task list on the paper. When the groups are finished, have each group post their list on the wall. Read through each list with the entire class.

   Distribute copies of a monitoring procedure and routine/preventive maintenance procedure to each student. Review these procedures, highlighting each task identified by the groups. Use this activity to emphasize the importance of routine monitoring of equipment and maintenance tasks. Tie this discussion back to the previous session's discussion of consequences of deviation from normal operations. Emphasize the role of routine and preventive maintenance to avoid deviation from normal operations. Count the number of correct tasks identified by each group. Award a prize to the group with the most correct tasks identified correctly.

2. Review remaining procedures associated with turbines. Emphasize the Process Technician's role in performing each procedural step:
   - lockout/tagout

- overspeed testing: Overspeed trip devices are safety systems (normally there are at least two separate) which prevent runaway speed in case the motive steam is admitted while the machine is not loaded. If the turbine is allowed to spin with little load while motive fluid is freely supplied, the result is invariably excessive rotor speed and (often dangerously explosive) self-destruction. The function of the overspeed trip is a last resort stop valve for inlet fluid to prevent this destruction. The overspeed trip is ALWAYS the "second line of defense" against overspeed, and will function only when the other overspeed protection fails.
- startup (include discussion of critical speeds)
- shutdown
- emergency.

6. Turbine Problems

Time: 15 minutes

1. Review the following typical troubleshooting situations and suggested solutions associated with turbines. Use the Turbine Consequences of Deviation Chart and have students complete remaining sections.

   - **loss of lubrication** - results from oil pump failure or more likely oil filter plugging. Turbine bearing failure is generally traced to dirt in the oil or a block in the oil supply. Therefore, filtration must be adequate to retain particles whose size may exceed the oil film thickness. Bearing damage results from excessive temperatures and pounding from vibration caused by shaft bowing or other shaft misalignment problems. Close attention must be given to excessive vibration so that causes can be eliminated before major damage occurs.
   - **impingement** - occurs when the steam quality decreases to the point that steam condensate exists in the turbine. Water droplets impinging on turbine blades contribute to wear by causing erosion of the blades. The steam entering the turbine must be adequately superheated to avoid condensation and impingement.
   - **fouling/pitting/corrosion** - Most **corrosion-erosion** problems come from damage that takes place when the turbine is not running. A slight steam leak will let steam condense inside the turbine, and salt from the boiler water will collect on the surfaces and cause **pitting.** The steam supply must have double block and bleed valves to prevent steam leaks to the turbine.
   - **assembly errors** - related to any of the above problems can cause excessive wear or the failure of turbine parts and the loss of the use of the turbine. Close attention must be given to the assembly and maintenance of the turbine and its lubrication system.
   - **loss of overspeed shutdown systems - Overspeeding** of a turbine can result in catastrophic failure of the machine. Deposits have caused the stem of both the governor and the trip valve to stick when there was a loss of load. Of course destructive overspeeding results from loss of load.

7. Hazards
Time: 10 minutes

Explain that there are hazards associated with normal and abnormal turbine operations. These hazards could impact the personal safety of the Process Technician, the equipment, plant operations, and/or the environment.

DISPLAY SLIDE #5	***OR***	Write slide contents on the flipchart or whiteboard.

1. **Personal Safety**:
   - Describe the potential hazards associated with normal and abnormal operations.
     - ♦ noise
     - ♦ burns from contact with hot equipment or blowing high pressure steam
     - ♦ contact with moving parts such as governor arms, rotating shafts, trip/throttle valves
     - ♦ oil spray from leaks, as well as oil fires from spill contact with high temperature steam.
   - Identify typical personal protective equipment used during normal and abnormal turbine operations.
     - ♦ Protective equipment should include long sleeves and gloves, hearing protection and safety glasses.
   - Identify additional safety precautions the Process Technician may be required to take for routine/preventive maintenance.

2. **Equipment Operations**
   - Explain the types of equipment operation hazards associated with turbines during normal and abnormal operations.
     - ♦ In normal operation care should be exercised so as not to damage oil tubing or governors when handling heavy tools and equipment.
     - ♦ Normal condition of operation in most installations will be excessive noise when personnel are in close contact.
     - ♦ In abnormal operation, there will be danger of relief valve discharge (from steam header overpressure), oil spills, and oil fires.
     - ♦ The danger of turbine overspeed and destruct upon failure of overspeed protection is present, as is the danger of high pressure steam leaks from pipeline breaks and valve packing.
     - ♦ In the case of gas turbines, fuel gas or oil is present and presents fire and explosion danger. Proximity to intake manifold to the gas turbine compressor should be avoided.

3. **Process Technician's role for Safe Operations**
   - Describe how sentinel safety valves are used to provide warnings on equipment operation.
   - Explain how sentinel safety valves are different from relief valves, which are used to provide protection.
     - ♦ The process technician should be alert to abnormal sounds, which can signal steam leaks, bearing problems.
     - ♦ Watch for excessive vibration in the equipment.
     - ♦ Watch for and report surging or hunting of turbine speed, oil leaks, steam issuing from oil reservoir, or any abnormal steam emission.
     - ♦ Watch for maintenance of proper oil reservoir levels, proper oil pressures and temperatures. Operating technicians should visit the installation frequently searching for unusual conditions but do not spend unnecessary time next to the equipment.
   - For startup activity safety, technicians must be fully familiar with startup procedures:
     - ♦ Warming up steam lines and equipment to prevent water damage
     - ♦ Placing machines on slow-roll to maintain heat
     - ♦ Proper commissioning of oil systems, and in the case of gas turbines, fuel systems
     - ♦ In gas turbines with co-generation boilers, the boiler equipment must be ready to run
     - ♦ Low pressure steam headers must be prepared to receive letdown steam and the boiler system must be ready to increase load as the turbine is started
     - ♦ While the turbine is down, the plant steam level letdown valves are open, holding the plant header pressures steady. As the turbine starts up, these letdown valves must close off to maintain the plant header pressures steady
     - ♦ The technician also must be intimately familiar with the driven equipment as the turbine is started up, so that needs of each item are met

4. **Environmental Impact**. Discuss the potential problems associated with environmental topics, such as seal leaks.
   - lubrication oil leaks
   - noise pollution from relief valve discharges and leaks
   - equipment and steam pipeline warm-up for startup

8. Summary and Wrap-Up

Time: 10 minutes

1. Use learning objectives and the following discussion questions to review/summarize content presented during this session:
   - Why are critical speeds important considerations during a turbine startup?
   - Why is it important to monitor turbine vibration?
   - What happens if bearing temperatures are too high?
   - What is a safety hazard associated with performing maintenance on a turbine?

2. Encourage questions from students on any concepts they do not understand.

3. Assign homework: Complete the Turbine Review Sheet (see Appendix). Read text pages on motors and engines.