# 2.14 A Pass-out Two-stage Turbine Receives Steam At 50 Bar, 350 "C. At 1.5 Bar, The Hp Steam Exhausts

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Understanding the operation and thermodynamic principles of a pass-out two-stage turbine is essential for engineers and students involved in power generation and thermal engineering. This article delves into the detailed analysis of a pass-out two-stage turbine receiving high-pressure (HP) steam at 50 bar and 350°C, with the exhaust steam leaving at 1.5 bar. We will explore the principles governing its operation, the thermodynamic calculations involved, and the significance of various parameters in optimizing turbine performance.

## Introduction to Two-Stage Turbines

A two-stage steam turbine consists of two separate turbine sections—often called stages—that work in sequence to convert thermal energy into mechanical work more efficiently than a single-stage turbine. The primary motivation for using multiple stages is to reduce the temperature and pressure differences across each stage, thereby minimizing losses and improving efficiency.

Key features of a pass-out two-stage turbine:

- Sequential expansion: Steam expands in the high-pressure (HP) stage first, then in the low-pressure (LP) stage.
- Inter-stage cooling or reheating: In some designs, steam may be reheated between stages to improve efficiency, but in the simplest pass-out turbines, this may not be present.
- Exhaust at low pressure: The steam exhausts at a pressure (1.5 bar in this case) suitable for condensing or other downstream processes.

## Operating Conditions and Parameters

The operational parameters for this specific turbine are:

- Inlet steam conditions: 50 bar, 350°C
- Exhaust steam conditions: 1.5 bar
- Number of stages: Two (high-pressure and low-pressure stages)
- Type: Pass-out (meaning steam passes through the stages and exhausts without reheating)

Understanding these conditions is crucial for thermodynamic calculations and efficiency assessments.

# Thermodynamic Analysis of the Two-stage Turbine

The primary goal in analyzing this turbine is to determine:

- Enthalpy changes during expansion
- Work output per stage
- Overall efficiency
- Quality of the exhaust steam
- Heat transfer and losses (if applicable)

The analysis involves applying the first and second laws of thermodynamics, along with steam tables and Mollier diagrams.

## Step 1: Enthalpy at Inlet Conditions

Using steam tables for the inlet conditions:

- Pressure: 50 bar
- Temperature: 350°C

From superheated steam tables:

| Parameter | Value |
|---|---|
| Enthalpy ($h_1$) | approximately 3120 kJ/kg |
| Entropy ($s_1$) | approximately 6.7 kJ/kg·K |

(Values are approximate; consult detailed steam tables for precise data.)

## Step 2: Enthalpy at Exhaust Conditions

At the exhaust pressure of 1.5 bar, the steam may be:

- Wet or dry, depending on expansion
- Superheated, saturated, or wet

Determine the state at the exhaust:

- Pressure: 1.5 bar

From the saturated steam tables:

| Parameter | Saturation temperature at 1.5 bar | Enthalpy of saturated vapor (h_g) | Enthalpy of saturated liquid (h_f) |
|---|---|---|---|
| Temperature | approximately 111°C | h_g ≈ 2675 kJ/kg | h_f ≈ 594 kJ/kg |

The actual exhaust state depends on the expansion process. For maximum efficiency, the steam ideally leaves dry at the exhaust conditions.

## Step 3: Thermodynamic Expansion in Stages

The expansion process occurs in two steps:

1. High-pressure stage: From 50 bar, 350°C to some intermediate pressure
2. Low-pressure stage: From intermediate pressure to 1.5 bar

Assuming ideal expansion (isentropic), the process is characterized by conservation of entropy:

- Isentropic expansion: $s_2 = s_1$ in the high-pressure stage
- Similarly, for the low-pressure stage: $s_3 = s_2$

Calculations proceed by:

- Determining the enthalpy at each stage
- Calculating work done in each stage

Note: Real processes have irreversibilities; thus, actual work is less than ideal.

Calculations:

- Use steam tables or Mollier diagrams to find enthalpy at each state
- Determine the specific work output:

$$
W_{stage} = h_{in} - h_{out}
$$

where $h_{in}$ and $h_{out}$ are enthalpies at inlet and outlet of each stage.

# Efficiency and Performance Metrics

The efficiency of the turbine is a measure of how well it converts thermal energy into mechanical work.

Thermal efficiency (η):

\[

$$
\eta = \frac{\text{Work output}}{\text{Heat supplied}}
$$

For a two-stage turbine:

$$
\eta_{total} = \frac{W_{HP} + W_{LP}}{Q_{in}}
$$

where:

- $W_{HP}$: work done in the high-pressure stage
- $W_{LP}$: work done in the low-pressure stage
- $Q_{in}$: heat supplied at the inlet (from the boiler)

Factors Affecting Efficiency:

- Pressure ratio: Higher ratios generally improve efficiency but can also cause increased irreversibility
- Temperature difference: Larger temperature differences lead to higher work output
- Blade design: Optimal blade profiles reduce losses
- Isentropic efficiency: Real turbines are less than 100% efficient due to friction and turbulence

# Exhaust Steam Characteristics and Uses

At the exit at 1.5 bar:

- The steam may be wet or dry depending on the expansion process
- If wet, moisture content can damage blades, so blade erosion considerations are important
- The exhaust steam can be used for:

- Feedwater heating
- Reheating in a regenerative cycle
- Condensation and power generation

Importance of Exhaust Conditions:

- Ensuring the steam leaves dry reduces blade erosion
- Proper condenser design is necessary to handle the low-pressure exhaust

# Applications of Two-Stage Turbines

Two-stage turbines are prevalent in:

- Power plants (thermal, nuclear, and combined cycle)
- Mechanical drive applications
- Marine propulsion systems

Their ability to efficiently handle large pressure drops makes them suitable for high-capacity applications.

## Advantages of Two-Stage Over Single-Stage Turbines

- Better efficiency due to smaller pressure drops per stage
- Reduced blade stresses
- Improved control over expansion process
- Flexibility in operation and maintenance

## Design Considerations for Pass-out Two-Stage Turbines

Designing an efficient two-stage turbine involves:

- Selecting optimal inlet and exhaust pressures
- Balancing blade velocities for minimal losses
- Ensuring thermal stresses are within limits
- Managing moisture and erosion at low-pressure exhaust

## Conclusion

A pass-out two-stage turbine receiving steam at 50 bar and 350°C with an exhaust at 1.5 bar exemplifies the complex interplay of thermodynamics, mechanical design, and operational efficiency. Proper analysis of inlet and exhaust conditions, along with stage-wise expansion calculations, enables engineers to optimize turbine performance. Understanding these principles is fundamental for designing efficient power generation systems, improving energy use, and reducing operational costs.

In summary:

- High inlet pressure and temperature facilitate maximum work extraction
- Multi-stage expansion reduces irreversibility and improves efficiency
- Exhaust conditions influence downstream processes and turbine longevity
- Thermodynamic calculations guide design and operational decisions

By mastering these concepts, engineers can enhance turbine performance, contribute to sustainable energy solutions, and advance power plant technologies.

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Keywords: Two-stage turbine, steam expansion, thermodynamic analysis, turbine efficiency, high-pressure steam, exhaust conditions, power generation, steam tables, isentropic process, moisture content.

# Frequently Asked Questions

## What are the main stages involved in a pass-out two-stage turbine operating with steam at 50 bar and 350°C?

The main stages include the high-pressure (HP) stage where steam expands from 50 bar and 350°C down to an intermediate pressure, followed by the low-pressure (LP) stage where the steam expands further to 1.5 bar, exhausting as HP steam.

## How does the pressure drop from 50 bar to 1.5 bar affect the turbine's efficiency?

The pressure drop allows for energy extraction through expansion; however, large pressure drops can lead to increased irreversibilities and reduced efficiency if not properly managed with blade design and staging.

## What is the typical work output of a pass-out two-stage turbine receiving steam at 50 bar and 350°C?

The work output depends on steam conditions and turbine design, but generally, two-stage turbines are designed to maximize energy extraction, producing significant power suitable for industrial or power generation applications.

## Why is the exhaust pressure set at 1.5 bar in this turbine design?

Exhausting at 1.5 bar allows the turbine to extract maximum useful work while maintaining a manageable condenser or downstream process pressure, balancing efficiency with practical operational constraints.

## What are the typical blade and rotor considerations for a two-stage turbine operating under these conditions?

Blade and rotor designs must accommodate high inlet pressures and temperatures, ensure minimal losses, and facilitate smooth expansion, often involving staged blade arrangements, cooling methods, and materials resistant to thermal stresses.

## How is the enthalpy change in each stage calculated for this turbine?

The enthalpy change is determined using steam tables or Mollier diagrams for the given inlet and outlet pressures and temperatures, calculating the difference in enthalpy between the inlet and outlet of each stage.

## What are the typical efficiencies associated with a pass-out two-stage turbine of this type?

Typical efficiencies can range from 85% to 90%, depending on design, operating conditions, and maintenance, with higher efficiencies achieved through optimized blade design and thermal management.

## What role does steam temperature play in the performance of the turbine at 350°C?

Higher inlet steam temperature increases the specific enthalpy and work output, improving the turbine's efficiency; 350°C is considered high temperature, contributing to better energy conversion but also requiring materials capable of withstanding thermal stresses.

## What are the common applications for a pass-out two-stage turbine receiving steam at these conditions?

Such turbines are commonly used in power plants for electricity generation, in industrial processes requiring mechanical power, and in combined-cycle power systems for efficient energy utilization.

# Additional Resources

2.14 A Pass-out Two-stage Turbine Receives Steam At 50 Bar, 350°C. At 1.5 Bar, The Hp Steam Exhausts

In the world of thermal power generation, turbines remain the heart of efficiency and performance. Among various types, the pass-out two-stage turbine stands out for its ability to harness high-pressure steam efficiently through staged expansion. This article delves into the intricacies of such a turbine system, focusing on its operating parameters, thermodynamic considerations, and implications for power plant design and operation.

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# Understanding the Basic Concept of a Pass-out

# Two-stage Turbine

A pass-out two-stage turbine is a type of steam turbine that operates through two successive expansion stages, often separated by a stage of moisture separation or reheating, depending on the design. The primary goal is to extract maximum work from high-pressure steam while minimizing losses associated with moisture formation and blade erosion.

Key features include:

- Two expansion stages: The steam expands in a high-pressure (HP) rotor and then in a low-pressure (LP) rotor.
- Intermediate extraction: Some turbines might have bleed points for feedwater heating or other processes.
- Pass-out configuration: The steam passes through the turbine blades, imparting energy, and then exits at a lower pressure, ready for condensation or further use.

This configuration is widely employed in power plants where high initial steam pressure and temperature are available, ensuring optimal energy conversion.

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# Operating Conditions and Parameters

The specific parameters provided for this turbine are:

- Steam inlet conditions: 50 bar pressure, 350°C temperature
- Steam exhaust conditions: 1.5 bar pressure

Understanding how these conditions influence turbine operation is fundamental for efficiency analysis and design.

High-Pressure Inlet Conditions

At 50 bar and 350°C, the steam enters the turbine with substantial thermal energy. These conditions are typical for Rankine cycle power plants, where superheated steam is generated in boilers.

Implications:

- Thermal energy availability: The high temperature and pressure enable significant work extraction.
- Material considerations: Components must withstand high temperatures and pressures, requiring advanced metallurgy.
- Thermodynamic efficiency: Higher inlet conditions generally enhance efficiency, provided the expansion process is optimized.

Exhaust Conditions

Exiting at 1.5 bar, the steam has undergone a substantial pressure drop, converting much of its thermal energy into mechanical work.

Key points:

- Pressure drop: From 50 bar to 1.5 bar involves a significant expansion ratio.
- Potential moisture formation: As the steam expands and cools, moisture may form, impacting blade erosion and efficiency.
- Condensation considerations: The low-pressure exhaust allows for efficient condensation in the condenser, completing the cycle.

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# Thermodynamic Analysis of the Expansion Process

The core function of the turbine is to convert thermal energy into mechanical work via expansion of steam. This process can be analyzed using principles of thermodynamics, particularly the Rankine cycle and isentropic expansion assumptions.

Isentropic Expansion and Work Output

Assuming ideal conditions:

- The expansion in each stage approximates an isentropic process (constant entropy).
- The actual process involves some irreversibility, but the ideal provides a benchmark.

The work done (W) during the expansion can be calculated based on enthalpy differences between inlet and outlet states:

$$W = h_{inlet} - h_{exhaust}$$

where:

- $h_{inlet}$ = enthalpy at 50 bar, 350°C
- $h_{exhaust}$ = enthalpy at 1.5 bar after expansion

Using steam tables or Mollier diagrams, these values can be determined for precise calculations.

Effect of Staging

Dividing the expansion into two stages offers several benefits:

- Reduction of moisture content: By controlling expansion in stages, moisture formation at blade tips is minimized.
- Improved efficiency: Staged expansion allows for better control over entropy generation.
- Inter-stage extraction: Sometimes, bleed steam is taken for heating or process needs,

adding to efficiency.

Performance Metrics

- Isentropic enthalpy drop: The difference between inlet and exhaust enthalpy.
- Isentropic efficiency ($\eta_{t}$): Comparing actual work output to ideal, calculated via:

$$\eta_{t} = \frac{W_{actual}}{W_{ideal}}$$

where actual values account for real irreversibilities.

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# Blade Design and Material Considerations

The high inlet temperature and pressure impose stringent requirements on turbine blade design:

- Material selection: Superalloys capable of withstanding high temperatures and corrosion.
- Blade cooling: Techniques like film cooling may be employed to maintain blade integrity.
- Aerodynamic shaping: To maximize efficiency and minimize losses.

Blade design also focuses on:

- Reducing blade erosion: By controlling moisture content.
- Minimizing aerodynamic losses: Through optimized blade profiles.

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# Efficiency and Losses in the Turbine

While theoretical models provide ideal efficiency estimates, real turbines experience various losses:

- Mechanical losses: Bearing friction, seal leakage.
- Aerodynamic losses: Blade tip leakage, flow separation.
- Thermal losses: Heat transfer to surroundings.
- Moisture-related losses: Blade erosion due to moisture droplets.

Efforts to mitigate these include:

- Advanced blade materials
- Precise manufacturing tolerances
- Moisture separation stages

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# Impact on Power Plant Performance

The performance of a pass-out two-stage turbine directly influences the overall efficiency of a thermal power plant. Key considerations include:

Power Output

- Determined by the mass flow rate of steam and the enthalpy drop.
- Higher inlet conditions (pressure and temperature) lead to greater power generation.

Efficiency Optimization

- Balancing inlet conditions, expansion ratios, and blade design.
- Employing regenerative feedwater heating to utilize extracted steam for preheating, improving cycle efficiency.

Environmental Impact

- Efficient turbines reduce fuel consumption per unit of electricity generated.
- Lower emissions due to improved thermodynamic performance.

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# Operational Challenges and Maintenance

Operating a high-pressure, two-stage turbine involves addressing several challenges:

- Blade erosion: Moisture droplets cause blade damage, requiring regular inspection.
- Thermal stresses: High-temperature operation demands careful thermal management.
- Vibration and fatigue: Mechanical stresses necessitate robust design and monitoring.
- Efficiency degradation: Over time due to wear and tear, necessitating maintenance schedules.

Regular maintenance, advanced monitoring, and employing modern materials are essential to sustain optimal performance.

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# Conclusion: The Significance of High-Pressure Steam Turbines

The pass-out two-stage turbine receiving steam at 50 bar and 350°C exemplifies the advances in thermal power technology. Its ability to extract maximum energy from high-pressure steam, coupled with staged expansion to mitigate moisture-related issues, enhances efficiency and reliability. As power demands grow and environmental considerations tighten, such turbines will continue to play a pivotal role in sustainable electricity generation.

The detailed understanding of thermodynamic principles, blade design, and operational management is crucial for engineers and operators aiming to optimize turbine performance. In essence, the evolution of these turbines reflects a broader commitment to harnessing energy efficiently while balancing operational longevity and environmental responsibility.

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In summary, the pass-out two-stage turbine operating with inlet steam at 50 bar and 350°C and exhausting at 1.5 bar embodies a sophisticated blend of thermodynamics, material science, and engineering design. Its effective utilization in power plants underscores its importance in modern energy systems, promising continued innovation and efficiency improvements in the years ahead.

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