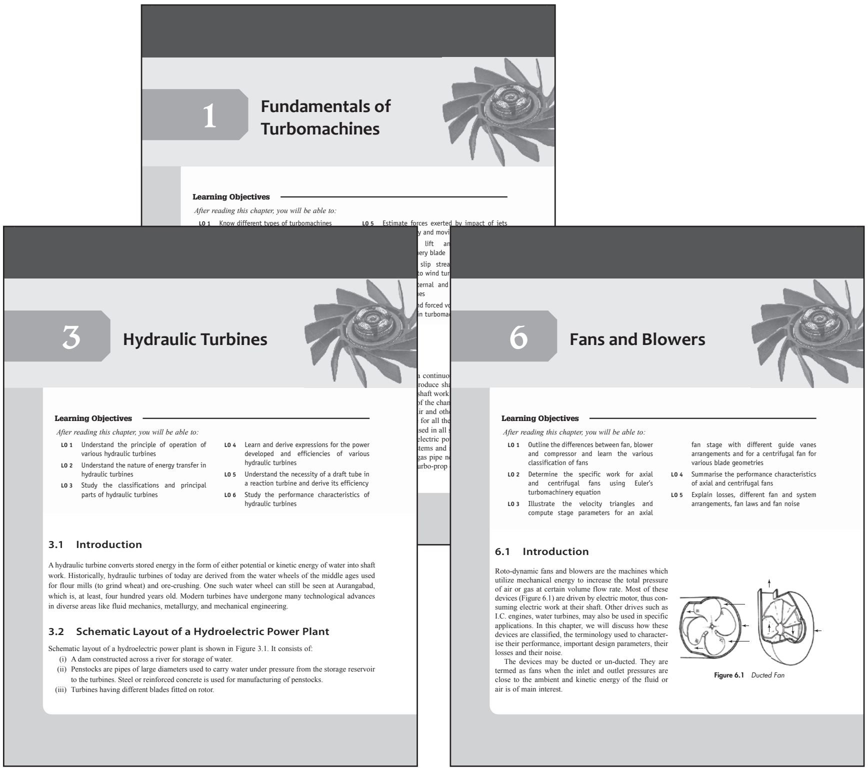
FEATURES OF



1 Fundamentals of Turbomachines

Learning Objectives

After reading this chapter, you will be able to:

3 Hydraulic Turbines

Learning Objectives

After reading this chapter, you will be able to:

LO 1	Understand the principle of operation of various hydraulic turbines	**LO 4**	Learn and derive expressions for the power developed and efficiencies of various hydraulic turbines
LO 2	Understand the nature of energy transfer in hydraulic turbines	**LO 5**	Understand the necessity of a draft tube in a reaction turbine and derive its efficiency
LO 3	Study the classifications and principal parts of hydraulic turbines	**LO 6**	Study the performance characteristics of hydraulic turbines

3.1 Introduction

A hydraulic turbine converts stored energy in the form of either potential or kinetic energy of water into shaft work. Historically, hydraulic turbines of today are derived from the water wheels of the middle ages used for flour mills (to grind wheat) and ore-crushing. One such water wheel can still be seen at Aurangabad, which is, at least, four hundred years old. Modern turbines have undergone many technological advances in diverse areas like fluid mechanics, metallurgy, and mechanical engineering.

3.2 Schematic Layout of a Hydroelectric Power Plant

Schematic layout of a hydroelectric power plant is shown in Figure 3.1. It consists of:

(i) A dam constructed across a river for storage of water.
(ii) Penstocks are pipes of large diameters used to carry water under pressure from the storage reservoir to the turbines. Steel or reinforced concrete is used for manufacturing of penstocks.
(iii) Turbines having different blades fitted on rotor.

6 Fans and Blowers

Learning Objectives

After reading this chapter, you will be able to:

LO 1	Outline the differences between fan, blower and compressor and learn the various classification of fans	**LO 4**	Summarise the performance characteristics of axial and centrifugal fans
LO 2	Determine the specific work for axial and centrifugal fans using Euler's turbomachinery equation	**LO 5**	Explain losses, different fan and system arrangements, fan laws and fan noise
LO 3	Illustrate the velocity triangles and compute stage parameters for an axial fan stage with different guide vanes arrangements and for a centrifugal fan for various blade geometries		

6.1 Introduction

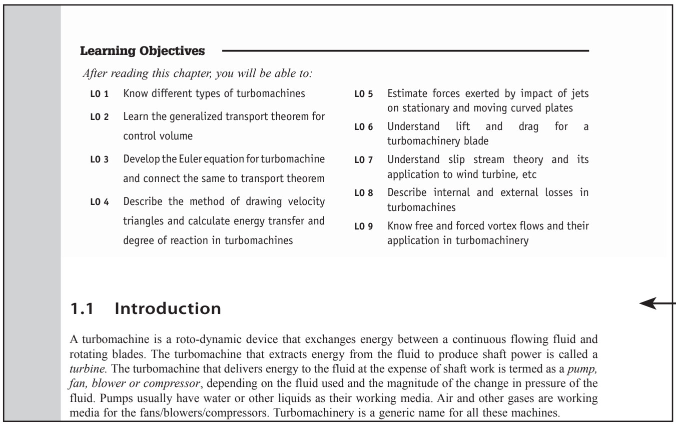
Roto-dynamic fans and blowers are the machines which utilize mechanical energy to increase the total pressure of air or gas at certain volume flow rate. Most of these devices (Figure 6.1) are driven by electric motor, thus consuming electric work at their shaft. Other drives such as I.C. engines, water turbines, may also be used in specific applications. In this chapter, we will discuss how these devices are classified, the terminology used to characterise their performance, important design parameters, their losses and their noise.

The devices may be ducted or un-ducted. They are termed as fans when the inlet and outlet pressures are close to the ambient and kinetic energy of the fluid or air is of main interest.

Figure 6.1 *Ducted Fan*

1. Module-based approach

Chapters are written to form modules when clubbed with the first chapter. For example, Chapters 1 & 3 form a module on Hydraulic Turbines; similarly, Chapters 1 & 6 form a module on Fans & Blowers. Hence, it offers utility to all including students, teachers and professionals!



Learning Objectives

After reading this chapter, you will be able to:

LO 1	Know different types of turbomachines	**LO 5**	Estimate forces exerted by impact of jets on stationary and moving curved plates
LO 2	Learn the generalized transport theorem for control volume	**LO 6**	Understand lift and drag for a turbomachinery blade
LO 3	Develop the Euler equation for turbomachine and connect the same to transport theorem	**LO 7**	Understand slip stream theory and its application to wind turbine, etc
LO 4	Describe the method of drawing velocity triangles and calculate energy transfer and degree of reaction in turbomachines	**LO 8**	Describe internal and external losses in turbomachines
		LO 9	Know free and forced vortex flows and their application in turbomachinery

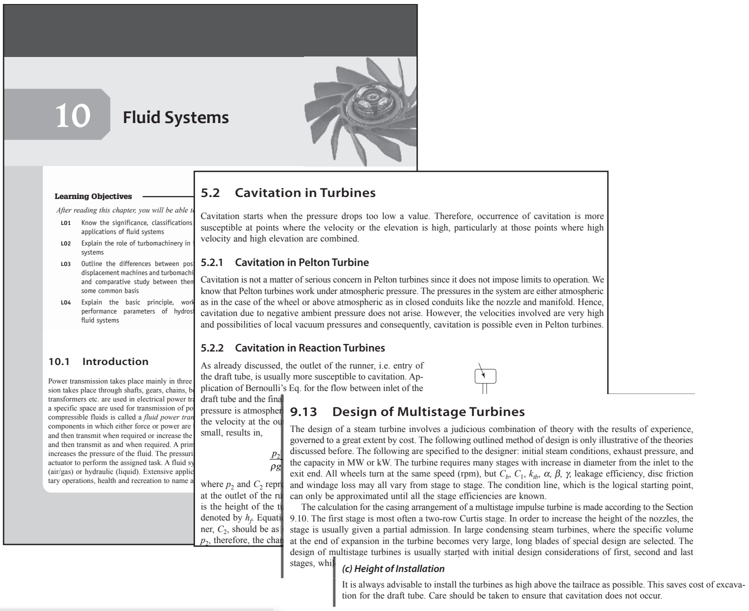
1.1 Introduction

A turbomachine is a roto-dynamic device that exchanges energy between a continuous flowing fluid and rotating blades. The turbomachine that extracts energy from the fluid to produce shaft power is called a *turbine.* The turbomachine that delivers energy to the fluid at the expense of shaft work is termed as a *pump, fan, blower or compressor*, depending on the fluid used and the magnitude of the change in pressure of the fluid. Pumps usually have water or other liquids as their working media. Air and other gases are working media for the fans/blowers/compressors. Turbomachinery is a generic name for all these machines.

2. Outcome-based Learning

All chapters begin with Learning Objectives based on Bloom's Taxonomy, highlighting the learning outcome of the content covered.

THE BOOK



10 Fluid Systems

Learning Objectives

After reading this chapter, you will be able t

LO1 Know the significance, classifications
applications of fluid systems

LO2 Explain the role of turbomachinery in
systems

LO3 Outline the differences between pos
displacement machines and turbomachi
and comparative study between them
some common basis

LO4 Explain the basic principle, work
performance parameters of hydrost
fluid systems

10.1 Introduction

Power transmission takes place mainly in three
sion takes place through shafts, gears, chains, b
transformers etc. are used in electrical power tr
a specific space are used for transmission of po
compressible fluids is called a *fluid power tran*
components in which either force or power are
and then transmit when required or increase the
and then transmit as and when required. A prim
increases the pressure of the fluid. The pressuri
actuator to perform the assigned task. A fluid sy
(air/gas) or hydraulic (liquid). Extensive applic
tary operations, health and recreation to name a

5.2 Cavitation in Turbines

Cavitation starts when the pressure drops too low a value. Therefore, occurrence of cavitation is more susceptible at points where the velocity or the elevation is high, particularly at those points where high velocity and high elevation are combined.

5.2.1 Cavitation in Pelton Turbine

Cavitation is not a matter of serious concern in Pelton turbines since it does not impose limits to operation. We know that Pelton turbines work under atmospheric pressure. The pressures in the system are either atmospheric as in the case of the wheel or above atmospheric as in closed conduits like the nozzle and manifold. Hence, cavitation due to negative ambient pressure does not arise. However, the velocities involved are very high and possibilities of local vacuum pressures and consequently, cavitation is possible even in Pelton turbines.

5.2.2 Cavitation in Reaction Turbines

As already discussed, the outlet of the runner, i.e. entry of the draft tube, is usually more susceptible to cavitation. Application of Bernoulli's Eq. for the flow between inlet of the
draft tube and the fina
pressure is atmospher
the velocity at the ou
small, results in,

$\frac{p_2}{\rho g}$

where p_2 and C_2 repr
at the outlet of the ru
is the height of the t
denoted by h_f. Equati
ner, C_2, should be as
p_2, therefore, the cha

9.13 Design of Multistage Turbines

The design of a steam turbine involves a judicious combination of theory with the results of experience, governed to a great extent by cost. The following outlined method of design is only illustrative of the theories discussed before. The following are specified to the designer: initial steam conditions, exhaust pressure, and the capacity in MW or kW. The turbine requires many stages with increase in diameter from the inlet to the exit end. All wheels turn at the same speed (rpm), but C_b, C_1, k_{tb}, α, β, γ, leakage efficiency, disc friction and windage loss may all vary from stage to stage. The condition line, which is the logical starting point, can only be approximated until all the stage efficiencies are known.

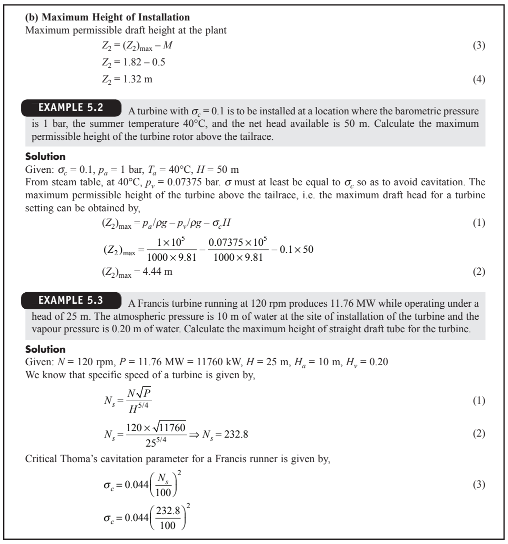
The calculation for the casing arrangement of a multistage impulse turbine is made according to the Section 9.10. The first stage is most often a two-row Curtis stage. In order to increase the height of the nozzles, the stage is usually given a partial admission. In large condensing steam turbines, where the specific volume at the end of expansion in the turbine becomes very large, long blades of special design are selected. The design of multistage turbines is usually started with initial design considerations of first, second and last stages, whi

(c) Height of Installation

It is always advisable to install the turbines as high above the tailrace as possible. This saves cost of excavation for the draft tube. Care should be taken to ensure that cavitation does not occur.

3. Coverage

One-stop solution to all curricula requirements – dedicated chapter on Fluid Systems, which is generally a part of 'Fluid Mechanics' titles. Also, the text covers topics with industrial applications such as Cavitation, Pumps and Turbines Designs, Installation of Turbines etc.



(b) Maximum Height of Installation

Maximum permissible draft height at the plant

$$Z_2 = (Z_2)_{\max} - M \tag{3}$$

$$Z_2 = 1.82 - 0.5$$

$$Z_2 = 1.32 \text{ m} \tag{4}$$

EXAMPLE 5.2 A turbine with $\sigma_c = 0.1$ is to be installed at a location where the barometric pressure is 1 bar, the summer temperature 40°C, and the net head available is 50 m. Calculate the maximum permissible height of the turbine rotor above the tailrace.

Solution

Given: $\sigma_c = 0.1$, $p_a = 1$ bar, $T_a = 40°\text{C}$, $H = 50$ m

From steam table, at 40°C, $p_v = 0.07375$ bar. σ must at least be equal to σ_c so as to avoid cavitation. The maximum permissible height of the turbine above the tailrace, i.e. the maximum draft head for a turbine setting can be obtained by,

$$(Z_2)_{\max} = p_a/\rho g - p_v/\rho g - \sigma_c H \tag{1}$$

$$(Z_2)_{\max} = \frac{1 \times 10^5}{1000 \times 9.81} - \frac{0.07375 \times 10^5}{1000 \times 9.81} - 0.1 \times 50$$

$$(Z_2)_{\max} = 4.44 \text{ m} \tag{2}$$

EXAMPLE 5.3 A Francis turbine running at 120 rpm produces 11.76 MW while operating under a head of 25 m. The atmospheric pressure is 10 m of water at the site of installation of the turbine and the vapour pressure is 0.20 m of water. Calculate the maximum height of straight draft tube for the turbine.

Solution

Given: $N = 120$ rpm, $P = 11.76$ MW $= 11760$ kW, $H = 25$ m, $H_a = 10$ m, $H_v = 0.20$

We know that specific speed of a turbine is given by,

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} \tag{1}$$

$$N_s = \frac{120 \times \sqrt{11760}}{25^{5/4}} \Rightarrow N_s = 232.8 \tag{2}$$

Critical Thoma's cavitation parameter for a Francis runner is given by,

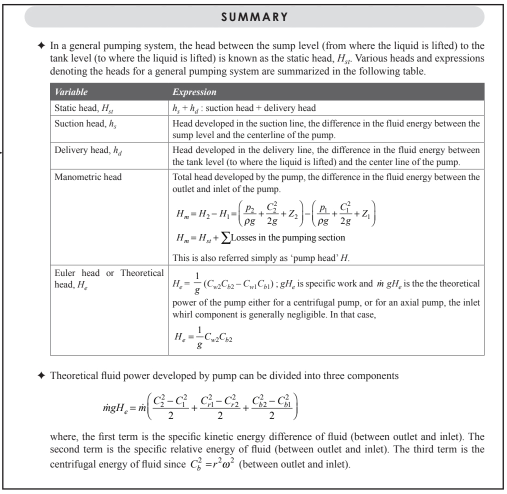
$$\sigma_c = 0.044\left(\frac{N_s}{100}\right)^2 \tag{3}$$

$$\sigma_c = 0.044\left(\frac{232.8}{100}\right)^2$$

4. Solved Examples

Ample number of examples with solutions presented as per relevant topics.

FEATURES OF



SUMMARY

✦ In a general pumping system, the head between the sump level (from where the liquid is lifted) to the tank level (to where the liquid is lifted) is known as the static head, H_{st}. Various heads and expressions denoting the heads for a general pumping system are summarized in the following table.

Variable	*Expression*
Static head, H_{st}	$h_s + h_d$: suction head + delivery head
Suction head, h_s	Head developed in the suction line, the difference in the fluid energy between the sump level and the centerline of the pump.
Delivery head, h_d	Head developed in the delivery line, the difference in the fluid energy between the tank level (to where the liquid is lifted) and the center line of the pump.
Manometric head	Total head developed by the pump, the difference in the fluid energy between the outlet and inlet of the pump. $H_m = H_2 - H_1 = \left(\frac{p_2}{\rho g} + \frac{C_2^2}{2g} + Z_2\right) - \left(\frac{p_1}{\rho g} + \frac{C_1^2}{2g} + Z_1\right)$ $H_m = H_{st} + \sum \text{Losses in the pumping section}$ This is also referred simply as 'pump head' H.
Euler head or Theoretical head, H_e	$H_e = \frac{1}{g}(C_{w2}C_{b2} - C_{w1}C_{b1})$; gH_e is specific work and $\dot{m}\, gH_e$ is the the theoretical power of the pump either for a centrifugal pump, or for an axial pump, the inlet whirl component is generally negligible. In that case, $H_e = \frac{1}{g}C_{w2}C_{b2}$

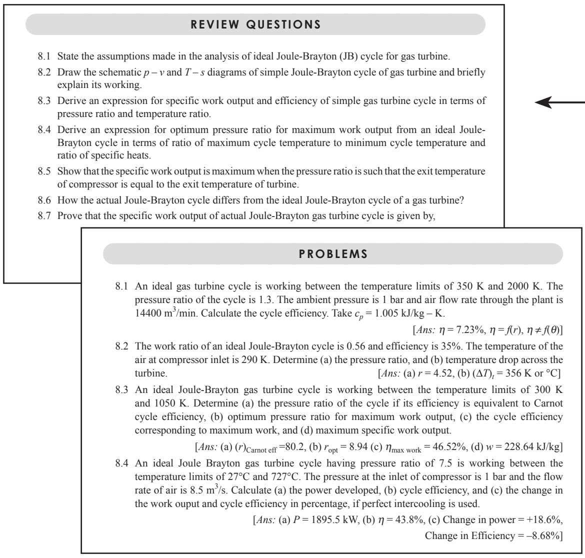
✦ Theoretical fluid power developed by pump can be divided into three components

$$\dot{m}gH_e = \dot{m}\left(\frac{C_2^2 - C_1^2}{2} + \frac{C_{r1}^2 - C_{r2}^2}{2} + \frac{C_{b2}^2 - C_{b1}^2}{2}\right)$$

where, the first term is the specific kinetic energy difference of fluid (between outlet and inlet). The second term is the specific relative energy of fluid (between outlet and inlet). The third term is the centrifugal energy of fluid since $C_b^2 = r^2\omega^2$ (between outlet and inlet).

Summary

Chapter-end Summary for a quick and precise recapitulation of the topics covered



REVIEW QUESTIONS

8.1 State the assumptions made in the analysis of ideal Joule-Brayton (JB) cycle for gas turbine.
8.2 Draw the schematic $p - v$ and $T - s$ diagrams of simple Joule-Brayton cycle of gas turbine and briefly explain its working.
8.3 Derive an expression for specific work output and efficiency of simple gas turbine cycle in terms of pressure ratio and temperature ratio.
8.4 Derive an expression for optimum pressure ratio for maximum work output from an ideal Joule-Brayton cycle in terms of ratio of maximum cycle temperature to minimum cycle temperature and ratio of specific heats.
8.5 Show that the specific work output is maximum when the pressure ratio is such that the exit temperature of compressor is equal to the exit temperature of turbine.
8.6 How the actual Joule-Brayton cycle differs from the ideal Joule-Brayton cycle of a gas turbine?
8.7 Prove that the specific work output of actual Joule-Brayton gas turbine cycle is given by,

PROBLEMS

8.1 An ideal gas turbine cycle is working between the temperature limits of 350 K and 2000 K. The pressure ratio of the cycle is 1.3. The ambient pressure is 1 bar and air flow rate through the plant is 14400 m^3/min. Calculate the cycle efficiency. Take $c_p = 1.005$ kJ/kg – K.
[*Ans:* $\eta = 7.23\%$, $\eta = f(r)$, $\eta \neq f(\theta)$]
8.2 The work ratio of an ideal Joule-Brayton cycle is 0.56 and efficiency is 35%. The temperature of the air at compressor inlet is 290 K. Determine (a) the pressure ratio, and (b) temperature drop across the turbine. [*Ans:* (a) $r = 4.52$, (b) $(\Delta T)_t = 356$ K or °C]
8.3 An ideal Joule-Brayton gas turbine cycle is working between the temperature limits of 300 K and 1050 K. Determine (a) the pressure ratio of the cycle if its efficiency is equivalent to Carnot cycle efficiency, (b) optimum pressure ratio for maximum work output, (c) the cycle efficiency corresponding to maximum work, and (d) maximum specific work output.
[*Ans:* (a) $(r)_{\text{Carnot eff}} = 80.2$, (b) $r_{\text{opt}} = 8.94$ (c) $\eta_{\text{max work}} = 46.52\%$, (d) $w = 228.64$ kJ/kg]
8.4 An ideal Joule Brayton gas turbine cycle having pressure ratio of 7.5 is working between the temperature limits of 27°C and 727°C. The pressure at the inlet of compressor is 1 bar and the flow rate of air is 8.5 m^3/s. Calculate (a) the power developed, (b) cycle efficiency, and (c) the change in the work ouput and cycle efficiency in percentage, if perfect intercooling is used.
[*Ans:* (a) $P = 1895.5$ kW, (b) $\eta = 43.8\%$, (c) Change in power = +18.6%,
Change in Efficiency = –8.68%]

Problems and Review Questions

- **Problems:** Chapter-end exercise problems for practice, with answers
- **Review Questions:** Given at the end of chapter to assess clarity of concepts

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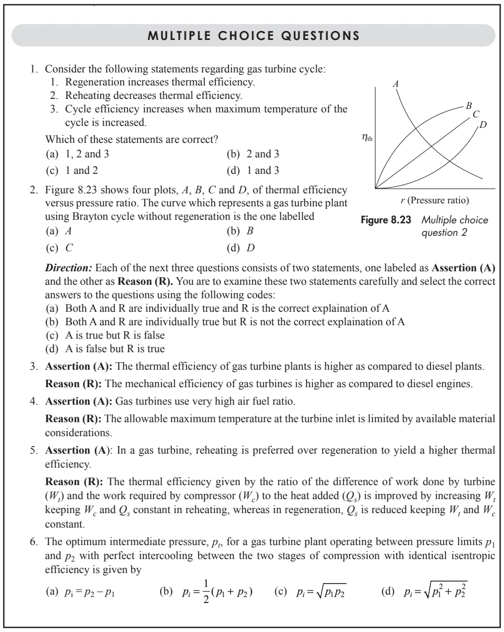


MULTIPLE CHOICE QUESTIONS

1. Consider the following statements regarding gas turbine cycle:
   1. Regeneration increases thermal efficiency.
   2. Reheating decreases thermal efficiency.
   3. Cycle efficiency increases when maximum temperature of the cycle is increased.

   Which of these statements are correct?

   (a) 1, 2 and 3 (b) 2 and 3
   (c) 1 and 2 (d) 1 and 3
2. Figure 8.23 shows four plots, *A*, *B*, *C* and *D*, of thermal efficiency versus pressure ratio. The curve which represents a gas turbine plant using Brayton cycle without regeneration is the one labelled

   (a) *A* (b) *B*
   (c) *C* (d) *D*

Figure 8.23 *Multiple choice question 2*

Direction: Each of the next three questions consists of two statements, one labeled as **Assertion (A)** and the other as **Reason (R).** You are to examine these two statements carefully and select the correct answers to the questions using the following codes:
(a) Both A and R are individually true and R is the correct explaination of A
(b) Both A and R are individually true but R is not the correct explaination of A
(c) A is true but R is false
(d) A is false but R is true

3. **Assertion (A):** The thermal efficiency of gas turbine plants is higher as compared to diesel plants.

   Reason (R): The mechanical efficiency of gas turbines is higher as compared to diesel engines.
4. **Assertion (A):** Gas turbines use very high air fuel ratio.

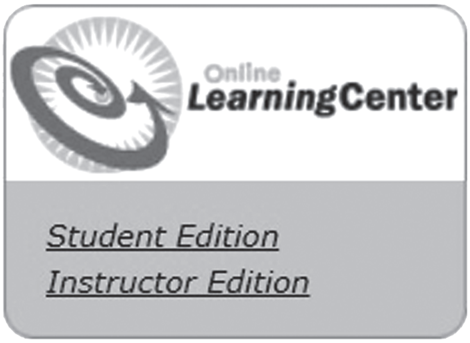
   Reason (R): The allowable maximum temperature at the turbine inlet is limited by available material considerations.
5. **Assertion (A)**: In a gas turbine, reheating is preferred over regeneration to yield a higher thermal efficiency.

   Reason (R): The thermal efficiency given by the ratio of the difference of work done by turbine (W_t) and the work required by compressor (W_c) to the heat added (Q_s) is improved by increasing W_t keeping W_c and Q_s constant in reheating, whereas in regeneration, Q_s is reduced keeping W_t and W_c constant.
6. The optimum intermediate pressure, p_t, for a gas turbine plant operating between pressure limits p_1 and p_2 with perfect intercooling between the two stages of compression with identical isentropic efficiency is given by

   (a) $p_i = p_2 - p_1$ (b) $p_i = \frac{1}{2}(p_1 + p_2)$ (c) $p_i = \sqrt{p_1 p_2}$ (d) $p_i = \sqrt{p_1^2 + p_2^2}$

Multiple Choice Questions

500+ Objective-type questions picked from previous years' GATE, IES and Public Sector Undertaking entrance examinations



Online Learning Center*

Visit **http://www.mhhe.com/dubey/turbomachinery** to access the following:

Instructor resources

- Lecture PPTs
- Solutions Manual

Student resources

- Test bank
- Chapter summary flowcharts

* For any queries/feedback related to OLC, please write to us at support.india@mheducation.com