

McGraw-Hill **HANDBOOKS**

POWER GENERATION HANDBOOK

SELECTION, APPLICATIONS,
OPERATION, AND MAINTENANCE



- Covers the latest in instrumentation and control systems
- Presents operation and maintenance tips and troubleshooting methods
- Provides calculations for gas turbine and steam power plants

PHILIP KIAMEH

CONTENTS

Preface	xv
Acknowledgments	xvii

Chapter 1. Review of Thermodynamic Principles	1.1
--	------------

The First Law of Thermodynamics	/ 1.1
Enthalpy	/ 1.2
Closed System	/ 1.4
The Cycle	/ 1.4
Property Relationships	/ 1.5
Vapor-Liquid Phase Equilibrium in a Pure Substance	/ 1.5
The Second Law of Thermodynamics	/ 1.8
The Concept of Reversibility	/ 1.9
External and Internal Irreversibilities	/ 1.9
The Concept of Entropy	/ 1.9
The Carnot Cycle	/ 1.12
References	/ 1.13

Chapter 2. Steam Power Plants	2.1
--------------------------------------	------------

The Rankine Cycle	/ 2.1
Reheat	/ 2.3
Regeneration	/ 2.5
Feedwater Heating	/ 2.6
The Internally Irreversible Rankine Cycle	/ 2.7
Open or Direct-Contact Feedwater Heaters	/ 2.8
Closed-Type Feedwater Heater with Drains Cascaded Backward	/ 2.11
Efficiency and Heat Rate	/ 2.12
Supercritical Plants	/ 2.13
Cogeneration	/ 2.16

Chapter 3. Steam Turbines and Auxiliaries	3.1
--	------------

Turbine Types	/ 3.1
Turbine Control Systems	/ 3.6
Lubrication Requirements	/ 3.6
Journal Bearings	/ 3.7
Thrust Bearings	/ 3.9
Hydraulic Control Systems	/ 3.9
Gear Drives	/ 3.10
Turning Gear	/ 3.11
Factors Affecting Lubrication	/ 3.11
Lubricating Oil Characteristics	/ 3.12
Reference	/ 3.13

Chapter 4. Turbine Governing Systems **4.1**

Governor Characteristics / 4.3
Subsidiary Functions / 4.6
Electronic Governing / 4.12
Reheater Relief Valves / 4.12
Hydraulic Fluid System / 4.18
Reference / 4.22

Chapter 5. Steam Chests and Valves **5.1**

Steam Chest Arrangements and Construction / 5.1
Steam Chest Material / 5.1
Steam Strainers / 5.3
Emergency Stop Valves / 5.3
Governor Valves / 5.3
Reference / 5.3

Chapter 6. Turbine Protective Devices **6.1**

Possible Hazards / 6.1
Protection Scheme / 6.2
Overspeed Trip / 6.4
Reference / 6.5

Chapter 7. Turbine Instrumentation **7.1**

Instrumentation Categories / 7.1
Reference / 7.2

Chapter 8. Lubrication Systems **8.1**

Lubrication Requirements and Typical Arrangements / 8.1
Oil Pumps / 8.4
Oil Tanks / 8.6
Piping / 8.9
Oil Coolers / 8.9
Oil Strainer and Filters / 8.10
Oil Purifiers and Coalescers / 8.11
Oils and Greases / 8.14
Jacking Oil Systems / 8.18
Greasing Systems / 8.18
Reference / 8.18

Chapter 9. Gland Sealing System **9.1**

Function and System Layout / 9.1
Labyrinth Seals / 9.1
System Layout / 9.3
Temperature and Pressure Control / 9.4

Gland Steam Condenser / 9.6

Reference / 9.7

Chapter 10. An Overview of Gas Turbines

10.1

Introduction / 10.1

The Brayton Cycle / 10.3

Industrial Heavy-Duty Gas Turbines / 10.5

Aircraft-Derivative Gas Turbines / 10.7

Medium-Range Gas Turbines / 10.8

Small Gas Turbines / 10.8

Major Gas Turbine Components / 10.8

Total Energy Arrangement / 10.16

Gas Turbine Applications / 10.16

Comparison of Gas Turbines with Other Prime Movers / 10.16

References / 10.16

Chapter 11. Gas Turbine Compressors

11.1

Centrifugal Compressors / 11.1

Axial-flow Compressors / 11.3

Nomenclature / 11.9

Chapter 12. Gas Turbine Combustors

12.1

Combustion Terms / 12.2

Combustion / 12.3

Combustion Chamber Design / 12.4

Combustor Design Considerations / 12.10

Air Pollution Problems / 12.10

Typical Combustor Arrangements / 12.11

Combustors for Low Emissions / 12.13

Combustors for Small Engines (Less than 3 MW) / 12.16

Industrial Chambers / 12.18

Aeroderivative Engines / 12.21

Reference / 12.22

Chapter 13. Axial-Flow Turbines

13.1

Turbine Geometry / 13.1

Impulse Turbine / 13.4

The Reaction Turbine / 13.5

Turbine Blade Cooling Methods / 13.6

Turbine Blade Cooling Designs / 13.7

Cooled-Turbine Aerodynamics / 13.11

Reference / 13.13

Chapter 14. Gas Turbine Materials

14.1

General Metallurgical Behaviors in Gas Turbines / 14.1

Gas Turbine Blade Materials / 14.7

Reference / 14.9

Chapter 15. Gas Turbine Lubrication and Fuel Systems**15.1**

- Gas Turbine Lubrication Systems / 15.1
- Cold Start Preparations / 15.1
- Fuel Systems / 15.2
- Liquid Fuels / 15.3
- Gaseous Fuels / 15.5
- Gas Fuel Systems / 15.5
- Starting / 15.5
- Intake System / 15.6
- Compressor Cleaning / 15.6

Chapter 16. Gas Turbine Bearings and Seals**16.1**

- Bearings / 16.1
- Bearing Design Principles / 16.3
- Tilting-Pad Journal Bearings / 16.6
- Bearing Materials / 16.7
- Bearing and Shaft Instabilities / 16.7
- Thrust Bearings / 16.7
- Seals / 16.11
- Seal Systems / 16.18
- Reference / 16.19

Chapter 17. Gas Turbine Instrumentation and Control Systems**17.1**

- Vibration Measurement / 17.1
- Pressure Measurement / 17.1
- Temperature Measurement / 17.3
- Control Systems / 17.4
- Start-Up Sequence / 17.6
- Fuel System / 17.8
- Baseline for Machinery / 17.8
- Data Trending / 17.9
- Compressor Aerothermal Characteristics and Compressor Surge / 17.11
- Failure Diagnostics / 17.12
- Mechanical Problem Diagnostics / 17.15
- Instrumentation and Control Systems of a Typical Modern Gas Turbine / 17.18
- Protective Systems / 17.19
- Permissives (Interlocks) / 17.20
- Liquid Fuel Supply / 17.21
- Start-Up Sequence of the Gas Turbine / 17.21
- Reference / 17.23

Chapter 18. Gas Turbine Performance Characteristics**18.1**

- Thermodynamic Principles / 18.1
- Thermodynamic Analysis / 18.1
- Factors Affecting Gas Turbine Performance / 18.2
- Air Extraction / 18.5
- Performance Enhancements / 18.6
- Peak Rating / 18.7
- Performance Degradation / 18.7

Verifying Gas Turbine Performance / 18.8
References / 18.8

Chapter 19. Gas Turbine Operating and Maintenance Considerations 19.1

Gas Turbine Design Maintenance Features / 19.1
Borescope Inspection / 19.2
Major Factors Influencing Maintenance and Equipment Life / 19.2
Combustion Inspection / 19.6
Hot-Gas-Path Inspection / 19.6
Major Inspection / 19.7

Chapter 20. Gas Turbine Emission Guidelines and Control Methods 20.1

Emissions from Gas Turbines / 20.1
General Approach for a National Emission Guideline / 20.2
No _x Emission Target Levels / 20.3
Power Output Allowance / 20.3
Heat Recovery Allowance / 20.5
Emission Levels for Other Contaminants / 20.5
Size Ranges for Emission Targets / 20.6
Peaking Units / 20.6
Emission Monitoring / 20.6
No _x Emission Control Methods / 20.7
References / 20.9

Chapter 21. Combined Cycles 21.1

The Nonideal Brayton Cycle / 21.1
Modifications of the Brayton Cycle / 21.4
Design for High Temperature / 21.9
Fuels / 21.11
Combined Cycles / 21.11
References / 21.15

Chapter 22. Selection Considerations of Combined Cycles and Cogeneration Plants 22.1

The Heat Recovery Steam Generator / 22.1
Cogeneration Steam Considerations / 22.2
Combined Cycle / 22.5
Selection and Economics of Combined Cycles / 22.5
Guidelines / 22.6

Chapter 23. Applications of Cogeneration and Combined-Cycle Plants 23.1

Guidelines for Addition of a Steam Turbine / 23.1
Scenario A—Food Processing Plant / 23.1
Scenario B—Repowering a Power Generating Plant / 23.2
Scenario C—Chemical Plant / 23.2
Scenario D—Pulp and Paper Plant / 23.3

Chapter 24. Cogeneration Application Considerations	24.1
<hr/>	
Cogeneration / 24.1	
Net Heat to Process and Fuel Chargeable to Power / 24.1	
Steam Turbines for Cogeneration / 24.2	
Gas Turbine Power Enhancement / 24.3	
Gas Turbine Exhaust Heat Recovery / 24.3	
Heat Recovery Steam Generators / 24.3	
Cycle Configurations / 24.4	
Cogeneration Opportunities / 24.5	
Chapter 25. Economic and Technical Considerations for Combined-Cycle Performance—Enhancement Options	25.1
<hr/>	
Economic Evaluation Technique / 25.1	
Output Enhancement / 25.2	
Efficiency Enhancement / 25.7	
Conclusion / 25.8	
Reference / 25.8	
Chapter 26. Fundamentals of Electrical Systems	26.1
<hr/>	
Capacitors / 26.1	
Current and Resistance / 26.4	
The Magnetic Field / 26.5	
Ampère's Law / 26.7	
Magnetic Field in a Solenoid / 26.10	
Faraday's Law of Induction / 26.10	
Lenz's Law / 26.12	
Inductance / 26.14	
Alternating Currents / 26.15	
Reference / 26.21	
Chapter 27. Introduction to Machinery Principles	27.1
<hr/>	
Electric Machines and Transformers / 27.1	
Common Terms and Principles / 27.1	
The Magnetic Field / 27.2	
Production of a Magnetic Field / 27.2	
Magnetic Behavior of Ferromagnetic Materials / 27.3	
Energy Losses in a Ferromagnetic Core / 27.5	
Faraday's Law—Induced Voltage from a Magnetic Field Changing with Time / 27.6	
Production of Induced Force on a Wire / 27.7	
Induced Voltage on a Conductor Moving in a Magnetic Field / 27.8	
Reference / 27.8	
Chapter 28. Transformers	28.1
<hr/>	
Importance of Transformers / 28.1	
Types and Construction of Transformers / 28.1	
The Ideal Transformer / 28.2	
Power in an Ideal Transformer / 28.3	
Impedance Transformation through a Transformer / 28.4	

Analysis of Circuits Containing Ideal Transformers /	28.5
Theory of Operation of Real Single-Phase Transformers /	28.9
The Voltage Ratio across a Transformer /	28.9
The Magnetizing Current in a Real Transformer /	28.11
The Equivalent Circuit of a Transformer /	28.12
The Exact Equivalent Circuit of a Real Transformer /	28.12
Approximate Equivalent Circuits of a Transformer /	28.13
References /	28.13

Chapter 29. Transformer Components and Maintenance

29.1

Classification of Transformers /	29.1
Main Components of a Power Transformer /	29.2
Transformer Core /	29.7
Windings /	29.7
Nitrogen Demand System /	29.8
Conservator Tank with Air Cell /	29.8
Current Transformers /	29.8
Bushings /	29.9
Tap Changers /	29.9
Insulation /	29.9
Forces /	29.11
Cause of Transformer Failures /	29.11
Transformer Oil /	29.13
Testing Transformer Insulating Oil /	29.14
Causes of Deterioration /	29.15
The Myers Index Number /	29.17
The Transformer Oil Classification System /	29.18
Methods of Dealing with Bad Oil /	29.19
Gas-in-oil /	29.21
Gas Relay and Collection Systems /	29.21
Relief Devices /	29.24
Interconnection with the Grid /	29.24
References /	29.27

Chapter 30. AC Machine Fundamentals

30.1

The Rotating Magnetic Field /	30.1
Proof of the Rotating Magnetic Flux Concept /	30.3
The Relationship between Electrical Frequency and the Speed of Magnetic Field Rotation /	30.3
Reversing the Direction of the Magnetic Field Rotation /	30.6
Induced Voltage in AC Machines /	30.6
The Induced Voltage in a Coil on a Two-Pole Stator /	30.6
The Induced Voltage in a Three-Phase Set of Coils /	30.8
The RMS Voltage in a Three-Phase Stator /	30.8
The Induced Torque in an AC Machine /	30.9
Winding Insulation in AC Machines /	30.10
AC Machine Power Flows and Losses /	30.10
Reference /	30.12

Chapter 31. Synchronous Generators

31.1

Synchronous Generator Construction /	31.1
The Speed of Rotation of a Synchronous Generator /	31.4
The Internal Generated Voltage of a Synchronous Generator /	31.5

The Equivalent Circuit of a Synchronous Generator /	31.5
The Phasor Diagram of a Synchronous Generator /	31.10
Power and Torque in Synchronous Generators /	31.11
The Synchronous Generator Operating Alone /	31.13
The Effect of Load Changes on a Synchronous Generator Operating Alone /	31.13
Parallel Operation of AC Generators /	31.15
The Conditions Required for Paralleling /	31.15
The General Procedure for Paralleling Generators /	31.17
Frequency-Power and Voltage-Reactive Power Characteristics of a Synchronous Generator /	31.19
Operation of Generators in Parallel with Large Power Systems /	31.21
Synchronous Generator Ratings /	31.25
Synchronous Generator Capability Curves /	31.27
Short-Time Operation and Service Factor /	31.29
Reference /	31.30

Chapter 32. Generator Components, Auxiliaries, and Excitation

32.1

The Rotor /	32.1
Rotor Winding /	32.1
Rotor End Rings /	32.6
Wedges and Dampers /	32.8
Slip Rings, Brush Gear, and Shaft Grounding /	32.9
Fans /	32.9
Rotor Threading and Alignment /	32.9
Vibration /	32.11
Bearings and Seals /	32.12
Size and Weight /	32.14
Turbine-Generator Components—The Stator /	32.14
Cooling Systems /	32.28
Shaft Seals and Seal Oil System /	32.30
Stator Winding Water Cooling System /	32.32
Other Cooling Systems /	32.34
Excitation /	32.36
Brushless Excitation Systems /	32.42
The Voltage Regulator /	32.42
Excitation Control /	32.46
The Power System Stabilizer /	32.46
Characteristics of Generator Exciter Power System (GEP) /	32.48
Excitation System Analysis /	32.48
Generator Operation /	32.48
Reference /	32.51

Chapter 33. Generator Testing, Inspection, and Maintenance

33.1

Generator Operational Checks (Surveillance and Monitoring) /	33.1
Major Overhaul (Every 8 to 10 Years) /	33.1
Appendix A: Generator Diagnostic Testing /	33.2
Appendix B: Mechanical Tests /	33.19

Frequently Asked Questions

A.1