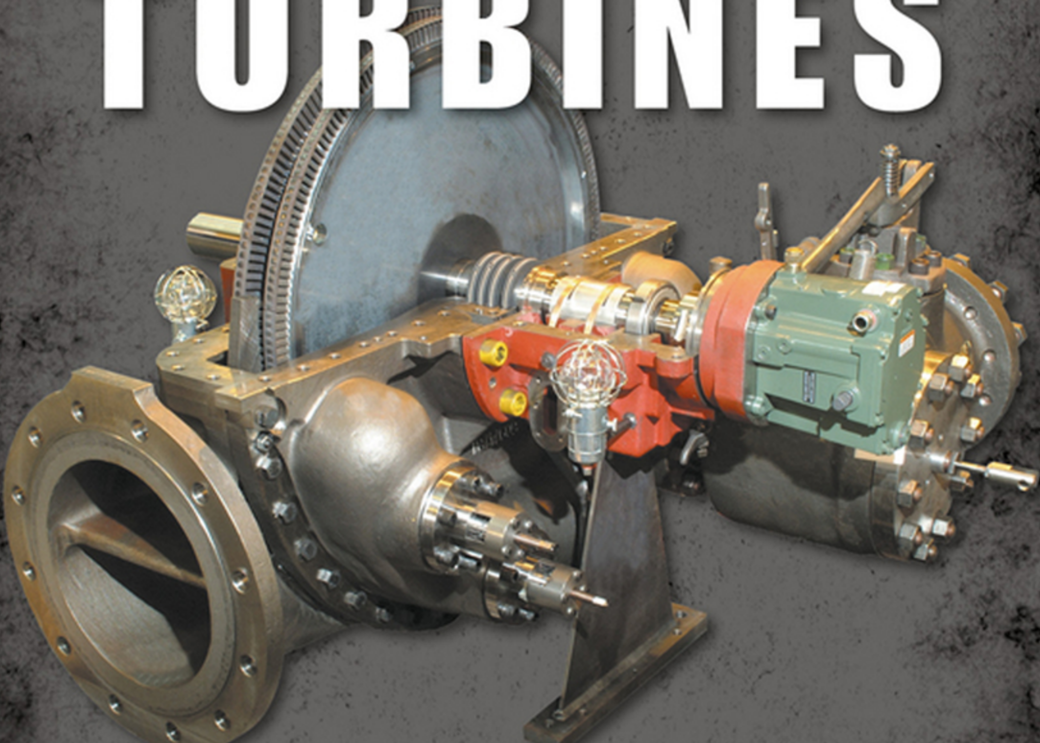
OPERATOR'S GUIDE TO

GENERAL PURPOSE STEAM TURBINES



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Operator's Guide to General Purpose Steam Turbines

An Overview of Operating Principles, Construction, Best Practices, and Troubleshooting

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We dedicate this book to our families for their constant support and encouragement.

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Preface

“We are what we repeatedly do.
Excellence, then, is not an act, but a habit.”

—Aristotle

If you operate steam turbines in your plant you are probably asking: Why do I need a whole book devoted to steam turbine operations? The short answer is because we all want our steam turbines to operate reliably and safely during their lifetimes and to avoid nasty surprises, such as massive failures, unexpected outages or injuries. Owners of steam turbines should continuously strive to protect life, limb and property and minimize the life cycle costs through the use of proven operating practices like those contained in this book. The best practices presented in this book can be used as a basis for your plant’s steam turbine reliability program and operating procedures.

The life cycle cost (LCC) of a machine is the total of the purchase, installation, repair, and operating costs incurred throughout its lifetime. As an operator the only way to affect a steam turbine LCC is by minimizing maintenance cost. This is accomplished by employing proven start-up procedures that will minimize undue stresses and erosion and by monitoring them in order to detect minor issues before they lead to costly repairs. General purpose (GP) steam turbine drivers present operators with special challenges because they tend to have a minimum of automation and instrumentation which makes their reliability dependent on the skill and knowledge of their caretakers. In other words, their reliability is dependent on the quality of human implemented procedures and human-based monitoring methods.

When installed and operated properly, GP steam turbines are reliable and tend to be forgotten, "out of sight, out of mind". But these sleeping giants can create major headaches if ignored. Three real steam turbine undesirable consequences that immediately come to mind are:

- *Injury and secondary damage due to an overspeed failure.* An overspeed failure on a large steam or gas turbine is one of the most frightening of industrial accidents. A huge amount of thermal, chemical, and mechanical energy is contained within a large steam turbine when it is in service. If the rotational speed of the steam turbine ever exceeds its safe operating limits, the main shaft and impeller wheels can be pulled apart by centrifugal force, releasing a tremendous amount of energy. In the worst case, the disintegrating parts can break through the turbine housing and fling hot, fast-moving shards of metal in all directions. The results of such a failure are always very costly due to the peripheral equipment damage and can sometimes be fatal to personnel in the area.

- *The high cost of an extensive overhaul due to an undetected component failure.* The cost of a major steam turbine repair can run ten or more times that of a garden variety centrifugal pump repair. If an early failure is not detected, it will usually result in a more costly failure. For example, a simple packing leak can result in oil contamination, which can lead to a bearing failure, which can lead to major rotor damage. Repair cost can rapidly escalate if the chain of failure events is not stopped early, i.e., in the primary stage.
- *Costly production losses due an extended outage if the driven pump or compressor train is unspared.* The value of lost production can quickly exceed repair costs. Extending the mean time between repairs though the implementation of best practices will in turn reduce production downtime and dramatically increase overall profits.

A major goal of this book is to provide readers with detailed operating procedure aimed at reducing these risks to minimal levels. Start-ups are complicated by the fact that operators must deal with numerous scenarios, such as:

1. Overspeed trip testing
2. Starting up a proven steam turbine driver after an outage
3. Shutting down a steam turbine driving a centrifugal pump or centrifugal compressor
4. Commissioning a newly installed steam turbine
5. Starting up after a major steam turbine repair

It is not enough to simply have a set of procedures in the control room for reference. To be effective, operating procedures must be clearly written down, taught, and practiced—until they become habit. Operators must be fully committed to following the prescribed steam turbine operating procedure every time and carefully monitoring them in the field in order to detect signs of early failures before serious damage is done. To support this commitment this book will:

- Provide operators with a broad exposure to the principles of steam turbine design and operations
- Explain common failure modes and how they can be prevented or mitigated and

- Provide proven operating procedures that can protect your steam turbines from costly and dangerous failures.

The authors hope the reader will find the contents of this book to be useful and applicable in their present assignment. We also hope the ideas and suggestions provided here compel you to commit yourself to operational excellence.

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1

Introduction to Steam Turbines

1.1 Why Do We Use Steam Turbines?

Steam turbine drivers are prime movers that convert the thermal energy present in steam into mechanical energy through the rotation of a shaft. Industrial steam turbines fit into one of two general categories: generator drives and mechanical drives. Generator drives include all turbines driving either synchronous or induction generators for power generation. In this book, we will cover primarily steam turbines used in the petrochemical industry as mechanical drives for centrifugal pumps and centrifugal compressors. In mechanical drives, the rotational energy is transmitted to a process machine that in turn

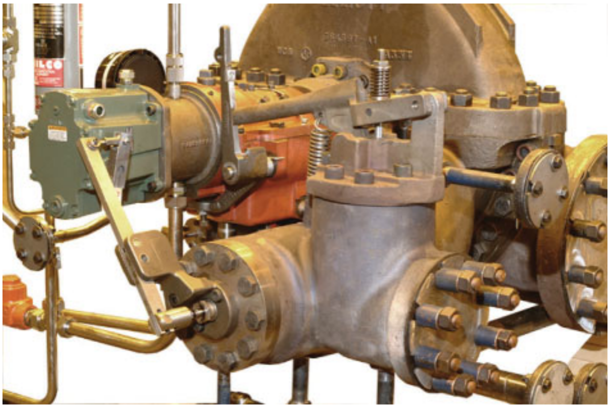

Figure 1.1 General purpose steam turbine. (Courtesy of Elliott Group)

converts it into fluid energy required to provide flow for a given process.

Heat energy → Steam energy → Rotational energy → Fluid energy

1.2 How Steam Turbines Work

Steam turbines are relatively simple machines that use high-velocity steam jets to drive a bladed wheel that is attached to a rotating shaft. Figure 1.2 depicts an impulse-type steam turbine in its most basic form: A steam nozzle and a bucketed, rotating wheel.

In this design, high-pressure steam is accelerated to a high velocity in the stationary nozzle and then directed onto a set of blades or buckets attached to a wheel. As the steam jet impacts the buckets, it is deflected and then leaves the scene. The change in

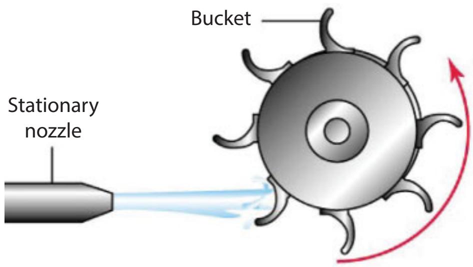

Figure 1.2 Basic impulse steam turbine.

momentum involved in the steam's deflection generates a force that turns the wheel in the direction opposite of the incoming steam jet. If the wheel is affixed to a shaft and supported by a set of bearings, rotational power can be transmitted via the output shaft.

To produce useful work in a safe and reliable manner, an impulse-type steam turbine, at a minimum, must contain:

1. A bladed wheel that is attached to a shaft.
2. A set of stationary steam nozzles capable of accelerating high-pressure steam to create high velocity jets. (See the steam nozzle in Figure 1.3.)
3. A pressure-containing casing.
4. Seals that can control steam leakage from traveling down the shaft. (See carbon packing end seals in Figure 1.3.)
5. A governor system capable of controlling rotating speed within design specifications. (Speed governor in Figure 1.3.)

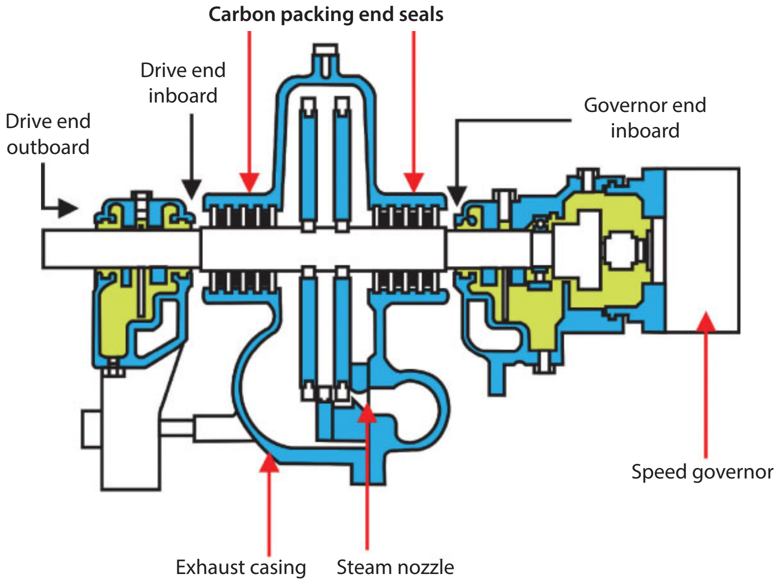

Figure 1.3 Cross section of an impulse steam turbine.

Governor systems fall into two main categories: hydraulic and electronic.

6. A coupling that can transmit power from the steam turbine to an adjacent centrifugal machine.

Steam turbines can be rated anywhere from a few horsepower to around a million horsepower. They can be configured to drive generators to produce electricity, or mechanical machines such as fans, compressors, and pumps. Steam turbines can be designed to operate with a vertical or horizontal rotor, but are most often applied with horizontal rotors.

1.2.1 Steam Generation

Steam is either generated in a boiler or in a heat recovery steam generator by transferring the heat from combustion gases into water. When water absorbs enough heat, it changes phase from liquid to steam. In some boilers, a super-heater further increases the energy content of the steam. Under pressure, the steam then flows from the boiler or steam generator and into the distribution system.

1.2.2 Waste Heat Utilization

Waste heat conversion is the process of capturing heat discarded by an existing industrial process and using that heat to generate low-pressure steam. Energy-intensive industrial processes—such as those occurring at refineries, steel mills, glass furnaces, and cement kilns—all release hot exhaust thermal energy in the form of hot liquid streams that can be captured using waste heat boilers (see Figure 1.4).

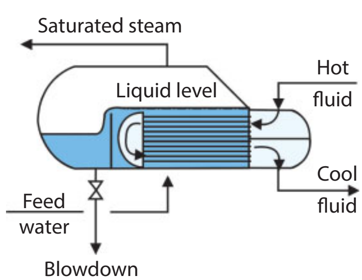

Figure 1.4 Waste heat boiler.

Figure 1.5 Steam drum.

The steam from waste heat boilers can be utilized for heating purposes or to power steam turbines.

Steam systems all tend to have the following elements:

- Boiler—A process subsystem that uses a fired fuel or waste heat to turn condensate into high-pressure steam. Steam is typically collected in a steam drum (see Figure 1.5)
- Steam Turbine—A rotating machine that converts high-pressure steam energy into shaft power
- Process Waste Heat Recovery or Condenser—A part of the process that recovers sufficient lower pressure steam heat to condense all the steam back to condensate

- Boiler Feedwater Pump—A liquid pump that raises condensate pressure back to boil pressure so that it can be returned to the steam boiler

1.2.3 The Rankine Cycle

The Rankine cycle is the thermodynamic basis for most industrial steam turbine systems. It consists of a heat source (boiler) that converts water to high-pressure steam. In the steam cycle, water is first pumped up to elevated pressure and sent to a boiler. Once in the boiler, liquid water is then heated to the boiling temperature corresponding to the system pressure until it boils, i.e., transforms from a liquid into water vapor. In most cases, the steam is superheated, meaning it is heated to a temperature above that required for boiling. The pressurized steam is: (a) transmitted via piping to a multistage turbine, where it is (b) expanded to lower pressure and then (c) exhausted either to a condenser at vacuum conditions or into an intermediate temperature steam distribution system. Intermediate pressure steam is often used for other process applications at a nearby site. The condensate from the condenser or from the industrial steam utilization system is returned to the feedwater pump for continuation of the cycle.

Primary components of a boiler/steam turbine system are shown in Figure 1.6.

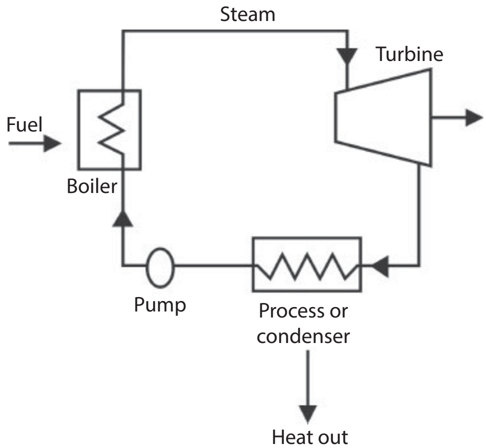

Figure 1.6 Components of a boiler/steam turbine system.

1.3 Properties of Steam

Water can exist in three forms, ice, liquid and gas. If heat energy is added to water, its temperature will rise until it reaches the point where it can no longer exist as a liquid. We call this temperature the "saturation" point, where with any further addition of heat energy, some of the water will boil off as gaseous water, called steam. This evaporation effect requires relatively large amounts of energy per pound of water to convert the state of water into its gaseous state. As heat continues to be added to saturated water, the water and the steam remain at the same temperature, as long as liquid water is present in the boiler.

The temperature at which water boils, also called boiling point or saturation temperature, increases as the pressure in the vapor space above the water