Steam turbine

A rotor of a modern **steam turbine**, used in a power plant

A **steam turbine** is a mechanical device that extracts thermal energy from pressurized steam, and converts it into useful mechanical work.

It has completely replaced the reciprocating piston steam engine (invented by Thomas Newcomen and greatly improved by James Watt) primarily because of its greater thermal efficiency and higher power-to-weight ratio. Also, because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator — it doesn't require a linkage mechanism to convert reciprocating to rotary motion. The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency through the use of multiple stages in the expansion of the steam (as opposed to the one stage in the Watt engine), which results in a closer approach to the ideal reversible process.

History

The first steam engine was little more than a toy, the classic Aeolipile made by Heron of Alexandria. Another steam turbine device was created by Italian Giovanni Branca in year 1629. The modern steam turbine was invented by an Anglo Irishman, Charles A. Parsons, in 1884 whose first model was connected to a dynamo that generated 7.5 kW of electricity. His patent was licensed and the turbine scaled up shortly after by an American, George Westinghouse. A number of other variations of turbines have been developed that work effectively with steam. The *de Laval turbine* (invented by Gustaf de Laval) accelerated the steam to full speed before running it against a turbine blade. This was good, because the turbine is simpler, less expensive and does not need to be pressure-proof. It can operate with any pressure of steam. It is also, however, considerably less efficient. The Parson's turbine also turned out to be relatively easy to scale up. Within Parson's lifetime the generating capacity of a unit was scaled up by about 10,000 times.


Parsons turbine from the Polish destroyer *ORP Wicher II*

Types

Steam turbines are made in a variety of sizes ranging from small 1 hp (0.75 kW) units used as mechanical drives for pumps, compressors and other shaft driven equipment, to 2,000,000 hp (1,500,000 kW) turbines used to generate electricity. There are several classifications for modern steam turbines.

Steam Supply and Exhaust Conditions

These types include condensing, noncondensing, reheat, extraction and induction.

Noncondensing or backpressure turbines are most widely used for process steam applications. The exhaust pressure is controlled by a regulating valve to suit the needs of the process steam pressure. These are commonly found at refineries, pulp and paper plants, and desalination facilities where large amounts of low pressure process steam is available.

Condensing turbines are most commonly found in electrical power plants. These turbines exhaust steam in a partially saturated state, typically of a quality greater than 90%, at a pressure well below atmospheric to a condenser.

Reheat turbines are also used almost exclusively in electrical power plants. In a reheat turbine, steam flow exits from a high pressure section of the turbine and is returned back to the boiler where additional superheat is added. The steam then goes back into an intermediate pressure section of the turbine and continues its expansion.

Extracting type turbines are common in all applications. In an extracting type turbine, steam is released from various stages of the turbine, and used for industrial process needs or sent to boiler feed water heaters to improve overall cycle efficiency. Extraction flows may be controlled with a valve, or left uncontrolled. Induction turbines introduce low pressure steam at an intermediate stage to produce additional power.

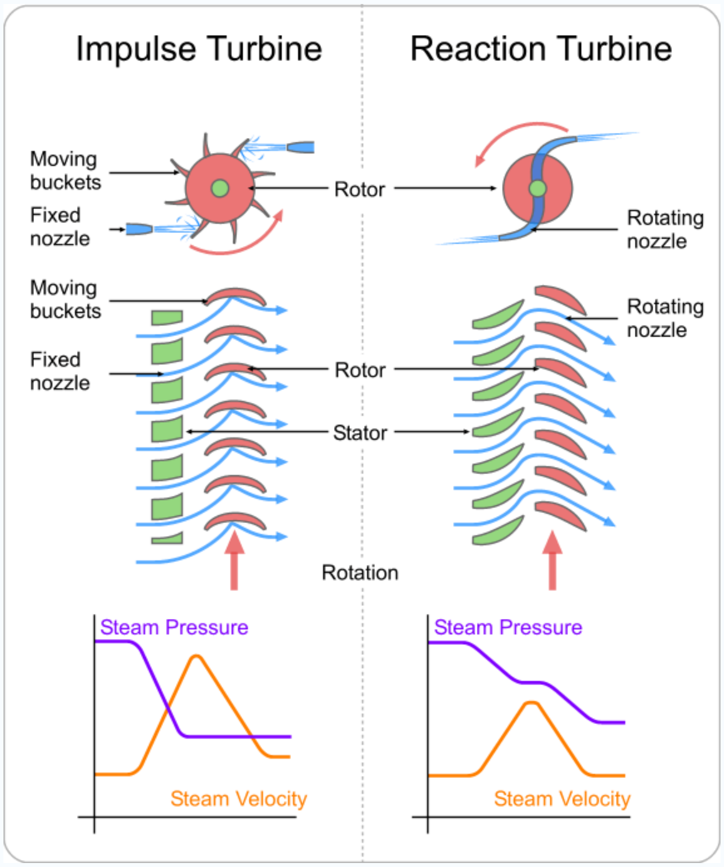
Casing or Shaft Arrangements

These arrangements include single casing, tandem compound and cross compound turbines. Single casing units are the most basic style where a single casing and shaft are coupled to a generator. Tandem compound are used where two or more casings are directly coupled together to drive a single generator. A cross compound turbine arrangement features two or more shafts not in line driving two or more generators that often operate at different speeds. A cross compound turbine is typically used for many large applications.

Principle of Operation and Design

An ideal steam turbine is considered to be an isentropic process, or constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine. No steam turbine is truly “isentropic”, however, with typical isentropic efficiencies ranging from 20%-90% based on the application of the turbine. The interior of a turbine is comprised of several sets of blades, or “buckets” as they are more commonly referred to. One set of stationary blades is connected to the casing and one set of rotating blades is connected to the shaft. The sets intermesh with certain minimum clearances, with the size and configuration of sets varying to efficiently exploit the expansion of steam at each stage.

Turbine Efficiency



Schematic diagram outlining the difference between an impulse and a reaction turbine

To maximize turbine efficiency, the steam is expanded, generating work, in a number of stages. These stages are characterized by how the energy is extracted from them and are known as *impulse* or *reaction* turbines. Most modern steam turbines are a combination of the reaction and impulse design. Typically, higher pressure sections are impulse type and lower pressure stages are reaction type.

Impulse Turbines

An **impulse turbine** has fixed nozzles that orient the steam flow into high speed jets. These jets contain significant kinetic energy, which the rotor blades, shaped like buckets, convert into shaft rotation as the steam jet changes direction. A pressure drop occurs across only the stationary blades, with a net increase in steam velocity across the stage.

Reaction Turbines

In the **reaction turbine**, the rotor blades themselves are arranged to form convergent nozzles. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor. Steam is directed onto the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor. The steam then changes direction and increases its speed relative to the speed of the blades. A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

Operation and Maintenance

When warming up a steam turbine for use, the main steam stop valves (after the boiler) have a bypass line to allow superheated steam to slowly bypass the valve and proceed to heat up the lines in the system along with the steam turbine. Also a turning gear is engaged when there is no steam to the turbine to slowly rotate the turbine to ensure even heating to prevent uneven expansion. After first rotating the turbine by steam the turning gear is disengaged and the astern blades are normally used since they are more robust and not as critical.

Problems with turbines are now rare and maintenance requirements are relatively small. Any imbalance of the rotor can lead to vibration, which in extreme cases can lead to a blade letting go and punching straight through the casing. It is, however, essential that the turbine be turned with dry steam. If water gets into the steam and is blasted onto the blades (moisture carryover) rapid impingement and erosion of the blades can occur, possibly leading to imbalance and catastrophic failure. Also, water entering the blades will likely result in the destruction of the thrust bearing for the turbine shaft. To prevent this, along with controls and baffles in the boilers to ensure high quality steam, condensate drains are installed in the steam piping leading to the turbine.

Speed regulation

The control of a turbine with a governor is essential, as turbines need to be run up slowly, to prevent damage while some applications (such as the generation of alternating current electricity) require precise speed control. Uncontrolled acceleration of the turbine rotor can lead to an overspeed trip, which causes the nozzle valves that control the flow of steam to the turbine to close. If this fails then the turbine may continue accelerating until it breaks apart, often spectacularly. Turbines are expensive to make, requiring precision manufacture and special quality materials.

Direct drive

Electrical power stations use large steam turbines driving electric generators to produce most of the world's electricity. These centralised stations are of two types: fossil fuel power plants and nuclear power plants. The turbines used for electric power generation are directly coupled to their generators. As the generators must rotate at constant synchronous speeds according to the frequency of the electric power system, the most common speeds are 3000 r/min for 50Hz systems, and 3600 r/min for 60Hz systems. Some large nuclear sets rotate at half those speeds, and have a 4-pole generator rather than the more common 2-pole one.

Speed reduction

Another use of steam turbines is in ships, where their small size, low maintenance, light weight, and low vibration are compelling advantages. (Steam turbine locomotives were also tested, but with limited success.) A steam turbine is only efficient when operating in the thousands of RPM range while application of the power in propulsion applications may be only in the hundreds of RPM and so requiring that expensive and precise reduction gears must be used. This purchase cost is offset by much lower fuel and maintenance requirements and the small size of a turbine when compared to a reciprocating engine having an equivalent power.