# STEAM TURBINE CONFIGURATION

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**Keywords:** Steam Turbines, Turbine Plant, Turbine Arrangement

## Contents

## Summary

Most electric power is produced by steam turbines. This is because the steam cycle is well suited to the conversion of heat to work and steam turbines can be built in a wide range of capacities up to about 1500 MW. Steam turbines are basically very simple having fixed blades to accelerate the steam and moving blades to absorb the resulting kinetic energy. The moving blades are mounted on a rotating shaft which drives an electrical generator. A characteristic of the steam turbine is the ability to produce high power outputs in a fairly compact machine though steam turbines are by no means small.

Although simple in concept, turbine design has evolved to improve the internal efficiency. Steam turbulence and fluid friction have been minimized by refinements to the steam flow path and blade profiles. Steam leakage has also been reduced by improved seal design. The large size of the turbines and the small clearances prevailing in the seals, result in a machine requiring a high degree of manufacturing precision and strict operating precautions to ensure satisfactory operation.

In particular, steam turbines must not be subjected to severe temperature transients nor uneven heating or cooling which could cause distortion of the rotor or casing. This would upset the fine balance of the rotor and the small clearances at the seals.

Periodic inspection and maintenance is required to ensure that there are no cracks which could result in failure. A turbine failure could be catastrophic and even a single blade failure can produce a missile capable of ripping through a turbine casing and penetrating adjacent equipment. To guard against this, turbines are disassembled periodically and

rigorously inspected. At the same time it may be necessary to rectify general wear on the machine. Most turbines suffer some damage to the blades due to moisture erosion in the wet steam regions near the exhaust. Generally turbine maintenance is a lengthy process and is scheduled periodically at the same time as major boiler maintenance (fossil units) or reactor refueling (nuclear units).

## 1. Design Principles

### 1.1. Introduction

Steam turbines are the largest prime movers and thus the natural choice when utilizing a steam cycle to convert heat into work and ultimately electricity. In steam turbines, steam under high pressure is accelerated in nozzle shaped stationary blades to a high velocity. The steam then impinges upon moving blades which are driven at speed and which in turn cause the rotors to rotate. Rotational speeds are 3000 rev min$^{-1}$ or 3600 rev min$^{-1}$ for 50 Hertz or 60 Hertz applications respectively or half these speeds for very large turbines used in nuclear plants. The steam velocities should be roughly double the moving blade velocity for good blade efficiency.

The blade speed in turn is determined by the geometrical size of the turbine and its rotational speed. Thus, for any given design, steam velocities are limited to fall within a certain range. These velocities are generated by a certain pressure ratio between the upstream and downstream sides of the blades. Since the overall pressure ratio across the turbine from inlet to exhaust is considerably larger than the required ratio, the turbine is divided into a number of stages each consisting of a pair of fixed and moving blades.

Each stage has the required pressure ratio to generate the appropriate steam velocity. A characteristic of all steam turbines therefore are multiple rows of alternating fixed and moving blades. A further characteristic is the progressive lengthening of the turbine blades towards the exhaust. This is due to the expansion of the steam under decreasing pressure and the need to accommodate the increased volume flow rate even though the mass flow rate may be the same and the steam velocities similar.

Since the steam turbine receives steam at high temperatures and pressures the turbine cylinders containing the rotors must be very robust but at the same time made with precision to ensure proper alignment of the fixed and moving blades for good efficiency and fine clearances between the casing and the rotor to minimize steam leakage. There are invariably two or three low pressure turbine cylinders in parallel to accommodate the increasing steam volume and to provide multiple exhausts with sufficient flow area for the exhaust steam. The length of the turbine blades at the exhaust is often a limiting design parameter.

As already explained, steam turbines are made up of a number of cylinders in series and parallel with respect to steam flow. These cylinders are generally built in a limited range of sizes by a particular manufacturer. By selecting a particular combination of sizes and arrangement of cylinders, a range of outputs can be achieved. Slight changes to the blading can be made, if necessary, to obtain the output specified by the purchaser.

Modern turbines are very similar in design. Evolution of design by different manufacturers has been towards common goals, namely high efficiency, good reliability and low cost. Developments by one manufacturer have tended to have been followed by other manufacturers and it is only in minor design features that differences exist except in cases where unique features have been patented. The general descriptions which follow are therefore applicable to all large steam turbines.

## 1.2. Configuration

Large turbines used in fossil fuel plants normally have a high pressure (HP) cylinder, an intermediate pressure (IP) cylinder and multiple low pressure (LP) cylinders. Turbines of equivalent output in nuclear plants normally have a high pressure (HP) cylinder and multiple low pressure (LP) cylinders due to the lower incoming steam conditions. The HP turbine in a nuclear plant is in fact very similar in construction to the IP turbine in a fossil fuel plant.

Most turbine cylinders are double flow receiving steam in the centre of the cylinder and discharging at the ends. This balances thrust and equalizes temperature gradients. At the lower end of the size range the flow of steam passed by the turbine may not warrant double flows in the HP and IP cylinders.

Single flow HP and IP cylinders may then be installed with their flows in opposite directions to minimize the net thrust in the coupled turbine shaft. Intermediate sized turbines may employ a combined high pressure and intermediate pressure (HP-IP) cylinder with fewer or smaller LP cylinders.

This HP-IP cylinder would have the high pressure and intermediate pressure flows in opposite directions creating a double flow arrangement. Small turbines for power generation may have only a single flow HP turbine and one double flow LP turbine. The resultant thrust from the single flow cylinder would be accommodated by a suitably sized thrust bearing.

The range in size from "small" to "large" is extremely wide and many different combinations are possible within this range. Large turbines could be characterized as having power outputs of about 1000 MW, intermediate size turbines of about 300 MW and small turbines of about 100 MW. Most turbines are tandem compound where all turbine cylinders are linked by one shaft to drive a single generator.

Some turbines have however been built as cross compound units where the cylinders are arranged on two shafts to drive twin generators.

The principle of operation of a turbine is that steam is directed by rings of fixed blades to impinge upon rings of moving blades. The force imparted to the moving blades by the steam drives the turbine to produce power. A pair of fixed and moving blades is known as a stage and several stages are employed in any cylinder.

Thus each cylinder has a series of fixed and moving blades arranged alternately over its length. The fixed blades are fitted to the stationary casing while the moving blades are attached to the revolving rotor.

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## Biographical Sketch

**Robin Chaplin** obtained a B.Sc. and M.Sc. in mechanical engineering from University of Cape Town in 1965 and 1968 respectively. Between these two periods of study he spent two years gaining experience in the operation and maintenance of coal fired power plants in South Africa. He subsequently spent a further year gaining experience on research and prototype nuclear reactors in South Africa and the United Kingdom and obtained M.Sc. in nuclear engineering from Imperial College of London University in 1971. On returning and taking up a position in the head office of Eskom he spent some twelve years initially in project management and then as head of steam turbine specialists. During this period he was involved with the construction of Ruacana Hydro Power Station in Namibia and Koeberg Nuclear Power Station in South Africa being responsible for the underground mechanical equipment and civil structures and for the mechanical balance-of-plant equipment at the respective plants. Continuing his interests in power plant modeling and simulation he obtained a Ph.D. in mechanical engineering from Queen's University in Canada in 1986 and was subsequently appointed as Chair in Power Plant Engineering at the University of New Brunswick. Here he teaches thermodynamics and fluid mechanics and specialized courses in nuclear and power plant engineering in the Department of Chemical Engineering. An important function is involvement in the plant operator and shift supervisor training programs at Point Lepreau Nuclear Generating Station. This includes the development of material and the teaching of courses in both nuclear and non-nuclear aspects of the program.