Steam Turbines

An Online Continuing Education Course for Engineers

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Steam Turbines

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Introduction

The invention of the reciprocating steam engine enabled man to convert the thermal energy of burning fuel to useful mechanical work, thus sparking the industrial revolution. As useful as it was, the reciprocating steam engine was still inefficient, cumbersome, had a very low power to weight ratio, and was a high maintenance piece of machinery. The development of the steam turbine was a vast improvement in all of these respects. The steam turbine led to applying many of the same principles of moving blades which ultimately led to the development of the gas turbine. All engineers should strive to learn as much as they can about the principles and features of steam and gas turbines.

The vector analyses, detailed descriptions and illlustrations are adapted and reproduced from publications of the U. S. Naval Institute, Power Magazine, and Marks Handbook for Mechanical Engineers.

Steam Turbines

Many industries use steam turbines in a variety of applications. Capacities begin at less than one HP for mechanical drives and up to 1,000,000KW for electric power generating stations. Steam conditions run from 4,500 psig and 1,200 deg F to sub-atmospheric and 100 deg F. Steam can be supplied by boilers, heat recovery steam generators, or nuclear reactors.

The expansion part of a steam cycle is where the high pressure steam from the boiler is expanded into a steam engine and the thermal energy of the steam is converted into mechanical energy, or work. A steam turbine is a type of steam engine that converts the thermal energy first to kinetic energy by expanding through nozzles or blading, and then to the rotational mechanical energy of a spinning rotor.

Classifications of Steam Turbines

Steam turbines can be classified in several different ways:

1. **By details of stage design:** Impulse or reaction.

2. **By steam supply and exhaust conditions:** Condensing, Non-condensing (back pressure), Automatic or controlled extraction, Mixed pressure (where there are two or more steam sources at different pressures), and Reheat (where steam is extracted at an intermediate stage, reheated in the boiler, and re-admitted at a lower turbine stage).

3. **By casing or shaft arrangement:** Single casing, Tandem compound (two or more casings with the shaft coupled together in line), and Cross compound (two or more shafts not in line, and possibly at different RPM).

4. **By number of exhaust stages in parallel:** Two flow, four flow, six flow.

5. **By direction of steam flow:** Axial flow, radial flow, and tangential.

6. **Single or multi-stage**

7. **By steam supply:** Superheat or saturated.

Any particular turbine may be classified by combinations of these classifications, e.g., tandemcompound, three-casing, four-flow extraction turbine.

A turbine stage consists of one set of stationary blades or nozzles and an adjacent set of moving blades or buckets. (The terms "blades" and "buckets" are nearly interchangeable. The term blade or blades will be used in this course for consistency). These stationary and rotating elements act together to allow the steam flow to do work on the rotor. The work is transmitted to the load through the shaft or shafts.

There are two basic models for steam turbine stage design: **Impulse stage** and **Reaction stage**. Even though most actual multi-stage turbines are combinations of these model stage designs, each will be described separately, because the theoretical differences are distinct.

Impulse Turbine Stage

As the steam passes through a nozzle from a high pressure pipeline to a lower pressure region, the velocity of the steam increases as the thermal energy is converted to kinetic energy. The velocity of the flow depends upon the difference in pressures between the high pressure and the low pressure regions. The weight rate of flow depends upon the velocity and the cross sectional area of the nozzle throat. This is illustrated in figure 1-2 below. The decrease in thermal energy as the steam passes through the nozzle equals the increase in kinetic energy, which is proportional to the square of the velocity.

$KE = WV^2 / 2g$

Where KE = kinetic energy in ft lb
W = weight of the steam in lb
V = velocity of the steam in ft/sec
g = 32 ft/sec

If an obstruction, such as a turbine blade, is placed in the path of the flowing steam, the steam will exert a force, or an "impulse" on the blade in an amount equal to the weight rate of flow and the velocity of the steam. As the blade moves due to this force, work is performed on the blade in an amount equal to the force times the distance the blade moves due to this force. If the blade is one of a series of such blades connected to a rotor, the rotor will spin as the continuous flow of steam impinges on each successive blade. Such a device would constitute a simple form of a turbine called an impulse turbine. This action is illustrated in figures 1-2 and 1-3 below.

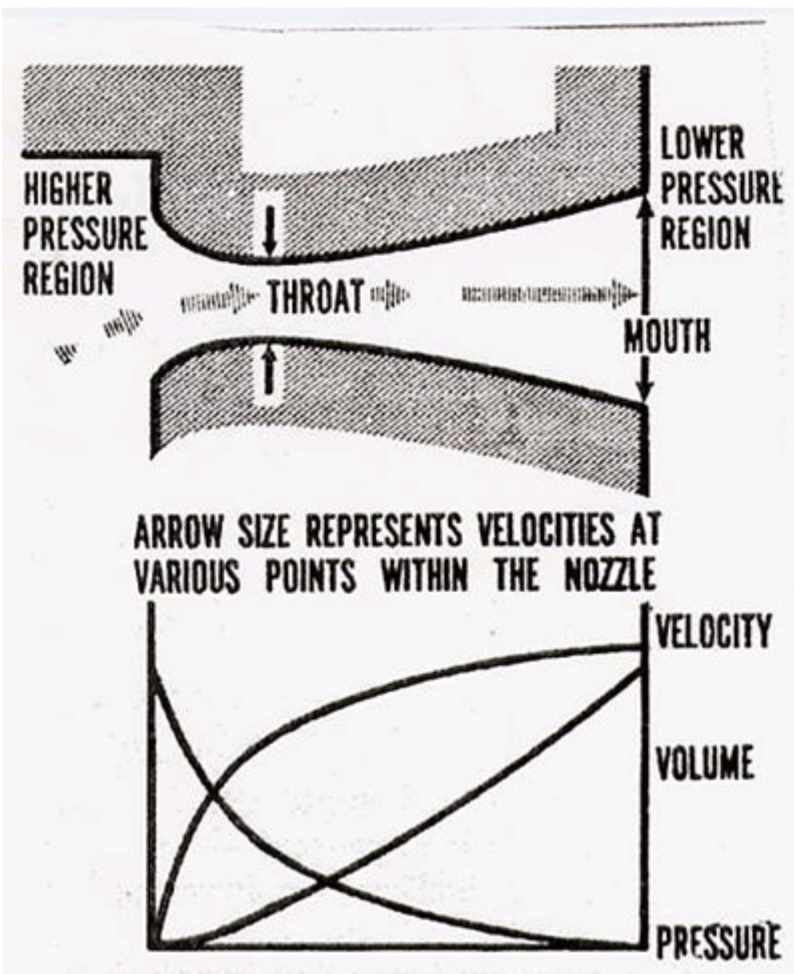

FIG. 1-2. Convergent-Divergent Nozzle.

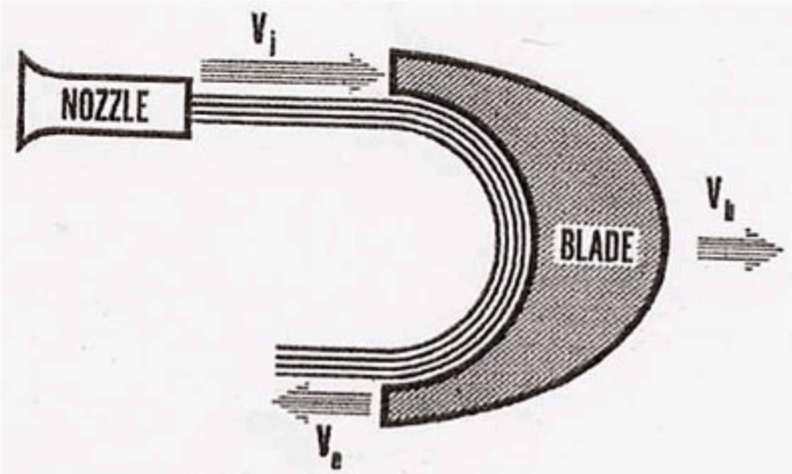

FIG. 1-3. Curved Impulse Blade.

In order to obtain the maximum amount of work from the steam, all of its kinetic energy must be converted to work. In other words, the steam must leave the blade with zero absolute velocity. Assuming a frictionless blade, the velocity of the steam relative to the blade must be the same entering as leaving, but reversed in direction. Also, the blade velocity must be one half of the entering steam velocity. (Refer to figure 1-3).

There are actually two different forces acting on the blade. The first is the force of the steam jet striking the blade, as described. The second is the reactive force due to the change in direction of the steam flow between the entrance and exit from the blade.

In actual turbines, it is impractical to utilize the full advantage of complete reversal of the steam. In a conventional impulse stage, the blades project radially from the wheel and the nozzles are placed so that the steam flow is at an angle to the plane of rotation. (Shown in figure 1-4).

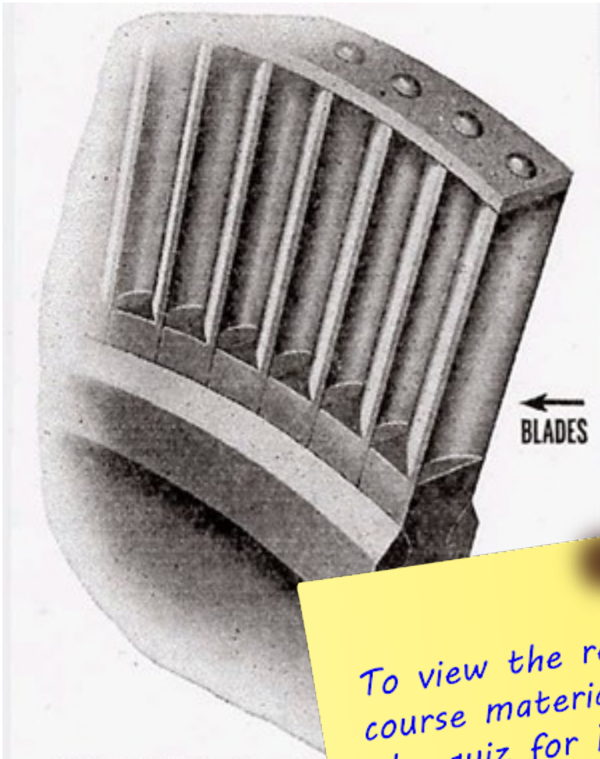

FIG. 1-4 (a). Section of Im
with Blad

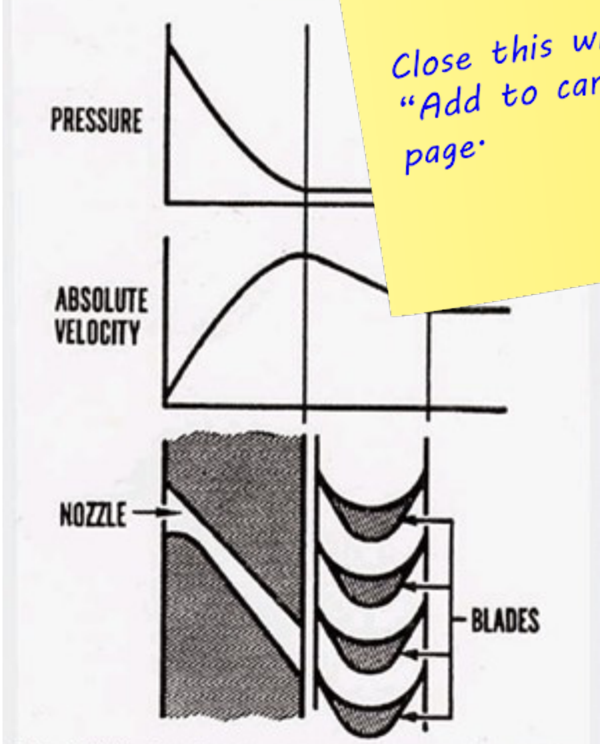

FIG. 1-4(b). Section Showing Nozzle Position in Impulse Turbine, and Pressure and Absolute Velocity Changes.

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