Chapter 5
Turbines

Part 1

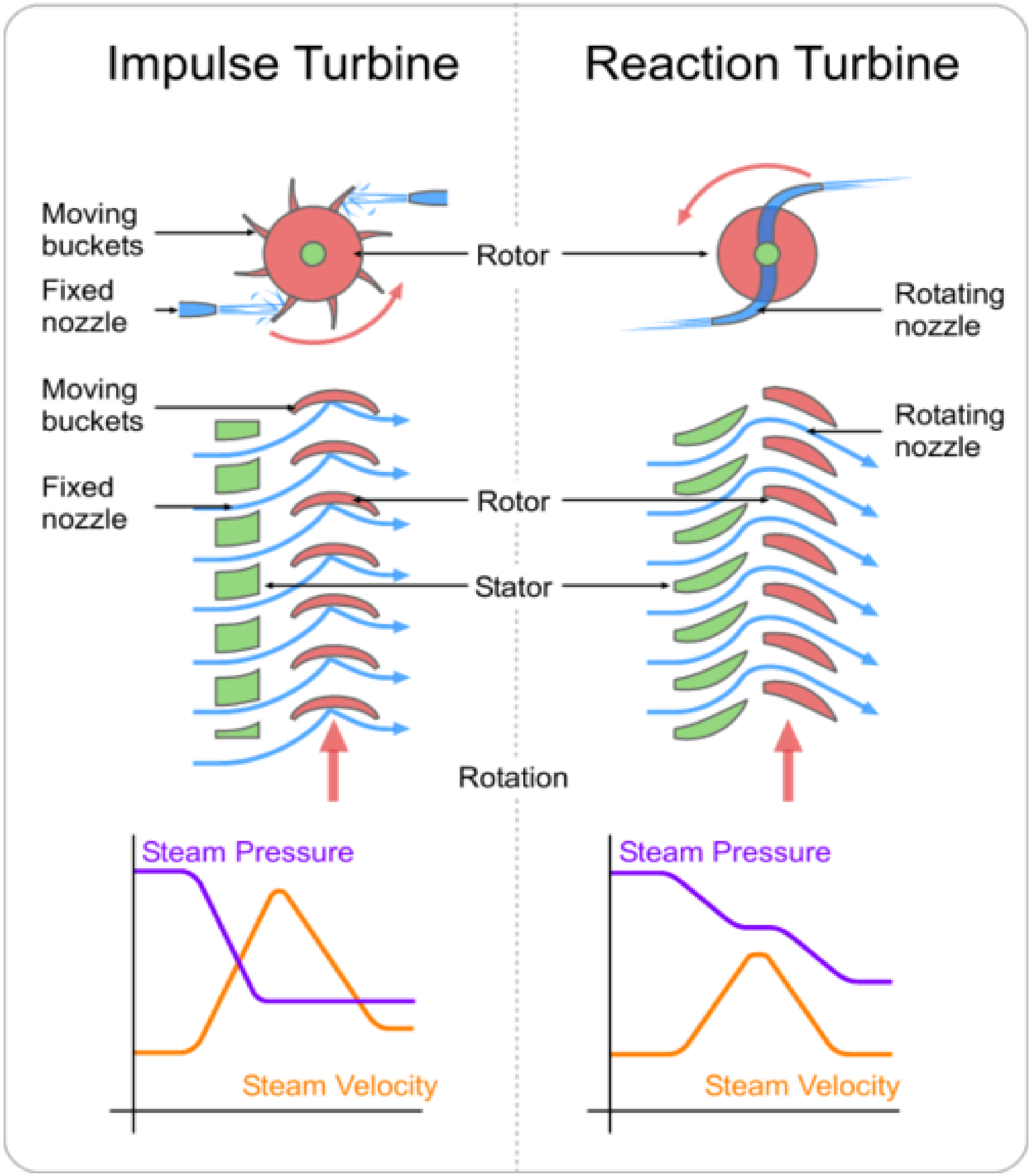
Types of Turbines

There are two major types of turbines depending on the principle of their work:

1. Impulse turbine or turbine stages, which are simple, single-rotor or multi-rotor (compounded) turbines to which impulse blades are attached. Impulse blades are usually symmetrical and have entrance and exit angles. At the entrance of the turbine where the pressure is high, the blades are normally short and have constant cross sections.

The Single-Stage Impulse Turbine

- It is also called the *de Laval turbine* after its inventor. In this type a single rotor is used to which impulse blades are attached.
- The steam is fed through one or several nozzles which do not extended completely around the circumference of the rotor, so only part of the blades are impinged at any one time.
- The pressure drop in this type occurs mainly in the nozzle and the velocity drops on the blades.


Impulse Turbine
Reaction Turbine
Moving buckets
Fixed nozzle
Rotor
Rotating nozzle
Moving buckets
Fixed nozzle
Rotor
Stator
Rotating nozzle
Rotation
Steam Pressure
Steam Velocity
Steam Pressure
Steam Velocity

$$F = \frac{\dot{m}}{g_c}(V_s - 0) = \frac{\dot{m}}{g_c}V_s \tag{5-1}$$

where F = force or impulse, lb_f or N

$\dot{m}$ = mass-flow rate of the jet, lb_m/s or kg/s

V_s = velocity in the horizontal direction, ft/s or m/s

g_c = conversion factor, 32.2 $lb_m \cdot ft/(lb_f \cdot s^2)$ or 1 $kg \cdot m/(N \cdot s^2)$

Now consider that the plate is free to move in the horizontal direction (Fig. 5-2*b*) with a velocity V_B. $V_s - V_B$ will be the velocity of the jet relative to the plate. Now the force on the plate is

$$F = \frac{\dot{m}}{g_c}(V_s - V_B) \tag{5-2}$$

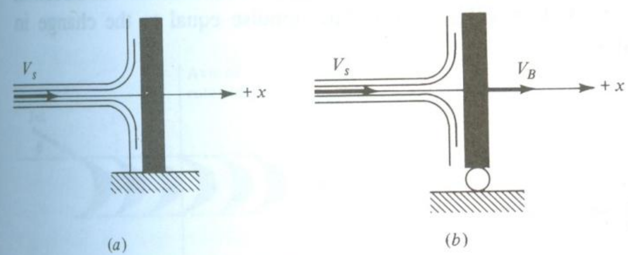


Figure 5-2 The impulse of a fluid jet on (*a*) a fixed flat plate and (*b*) a moving flat plate.

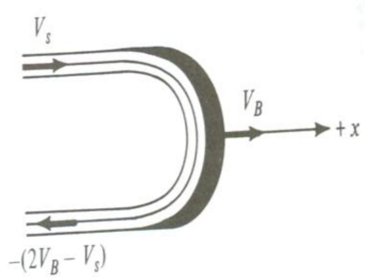


Figure 5-3 The impulse of a fluid jet on a 180° curved blade.

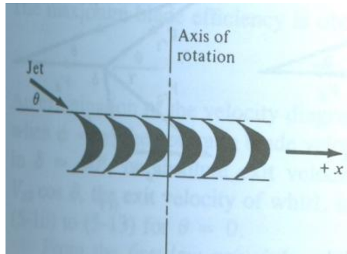


Figure 5-4 Top view of a row of impulse blades on wheel.

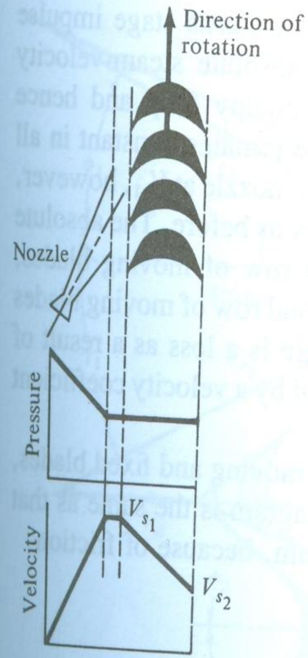


Figure 5-7 Overall steam pressure and absolute steam-velocity changes in an ideal single-stage impulse (deLaval) turbine.

Compounded-Impulse Turbine

- From the impulse principle the blade speed in a single impulse turbine is nearly half the incoming absolute steam velocity.
- In modern plants the turbine velocity is very high which is beyond the safety limits due to centrifugal stresses on the rotor material. Also high velocity results in high friction losses and thus reduction in the turbine efficiency.
- To overcome these difficulties two methods have been utilized which are called compounding or staging; 1- velocity-compounded turbine 2- pressure compounded turbine.

1- the velocity compounded impulse turbine

- It is called Curtis stage turbine.
- It is composed of three zones of blades, where the first and third zones are moving, while the middle blade stage is stationary.
- This configuration results in velocity reduction as seen in figure 5-8 and 5-9.
- Any number of rows can be used as figure 5-10. such staging usually is built with successively increasing blade angles and flatter and thinner blades toward the last row.

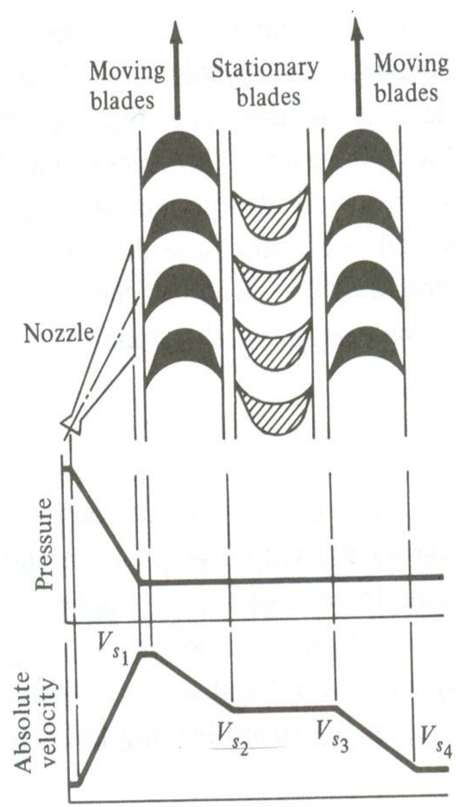


Figure 5-8 Overall steam pressure and absolute steam velocity changes in an ideal velocity-compounded impulse turbine (a Curtis stage).

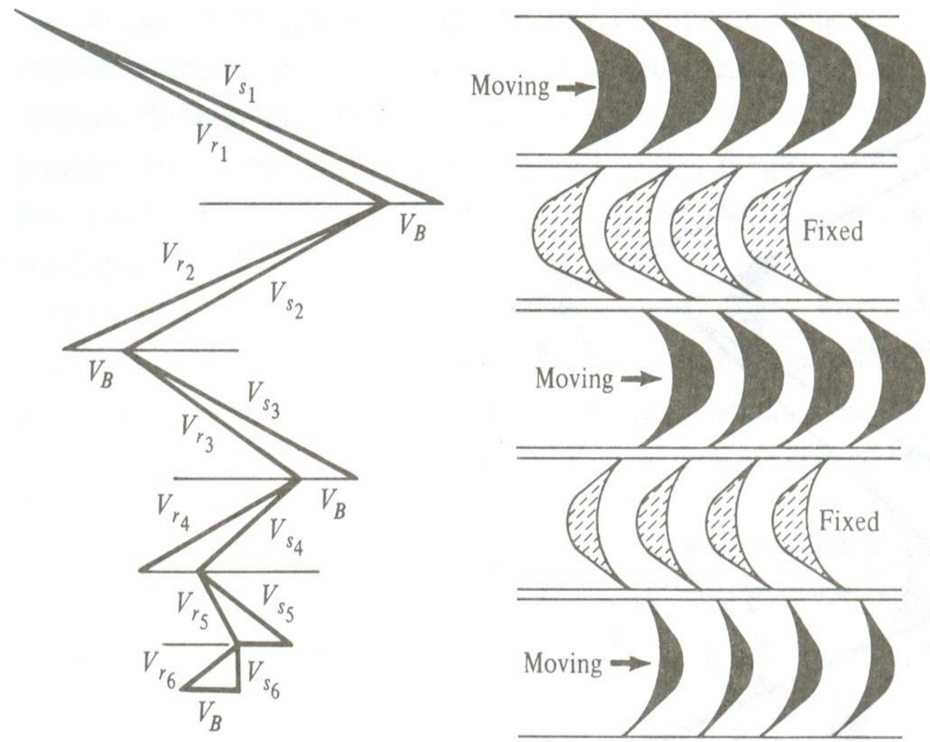


Figure 5-10 velocity diagram and blades for a velocity-compounded impulse turbine w
moving blades.

2- **The pressure compound impulse turbine**

- It is called *Rateau turbine*.
- The idea of this turbine to overcome the high velocity in the single stage and the pressure drop in the nozzle is by dividing up the total enthalpy equally among many single-stage impulse turbines in series. Thus the inlet steam velocities to each stage are equal and due to a reduced Δh as shown in figure 5-11.
- The pressure compounded impulse turbine has the advantages of reduced blade velocity, reduced steam velocity (friction) and equal work among the stages.
- The disadvantages are the pressure drop across the fixed rows of nozzles, which requires leak-tight diaphragms and large number of stages.
- Pressure compounded turbines are ordinarily used for large turbines where efficiency is more important than capital cost.

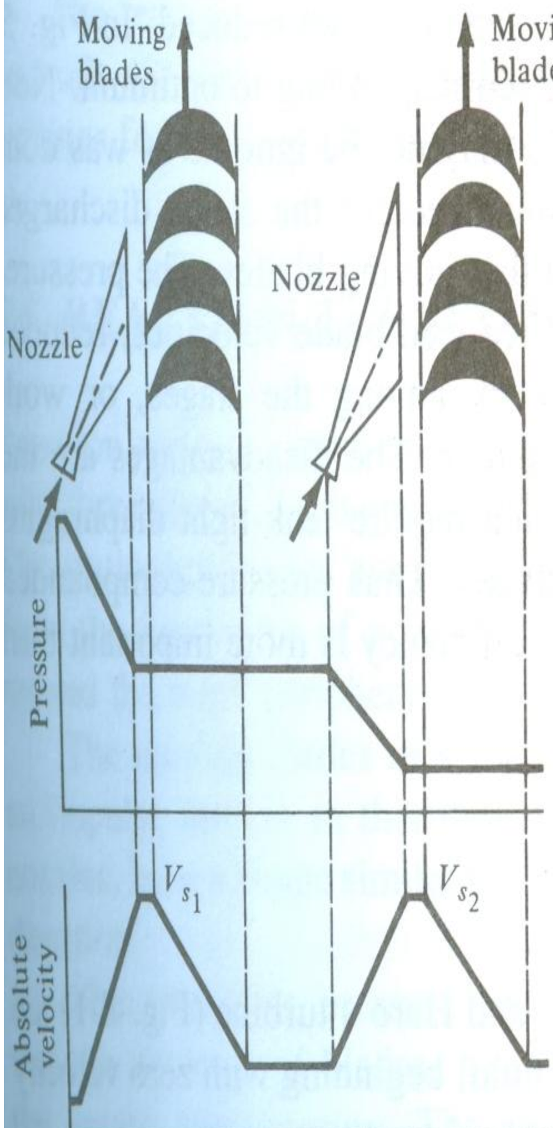


Figure 5-11 A two-stage pressure-compounded impulse turbine (Rateau).

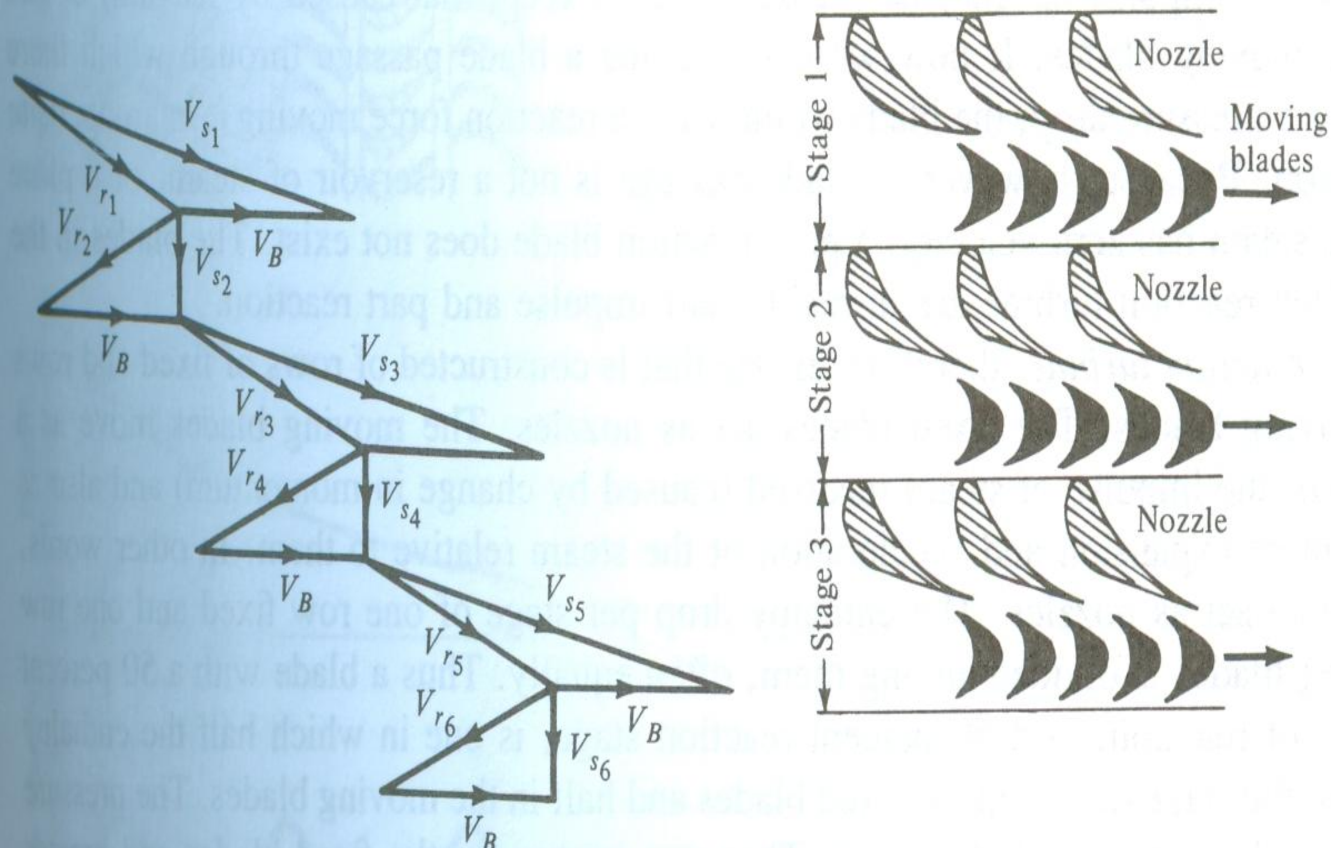


Figure 5-12 Velocity diagrams and nozzles and blades for a three-stage pressure-compounded impulse (Rateau) turbine.

Reaction Turbine

- Reaction turbines are invited by C.A Parsons. It has three stages, each composed of a row of fixed blades and row of moving blades.
- The stationary blades are designed in such a fashion that the passages between them form the flow areas of nozzles, so they become nozzles with full steam admission around the rotor periphery.
- The moving blades of a reaction turbine are differ from the impulse turbine blades in that they are not symmetrical and act partly as nozzles.
- The pressure drops through all rows of blades. The pressure change gets greater as the steam pressure gets higher.
- The absolute steam velocity changes within each stage and repeats from stage and repeats from stage to stage.

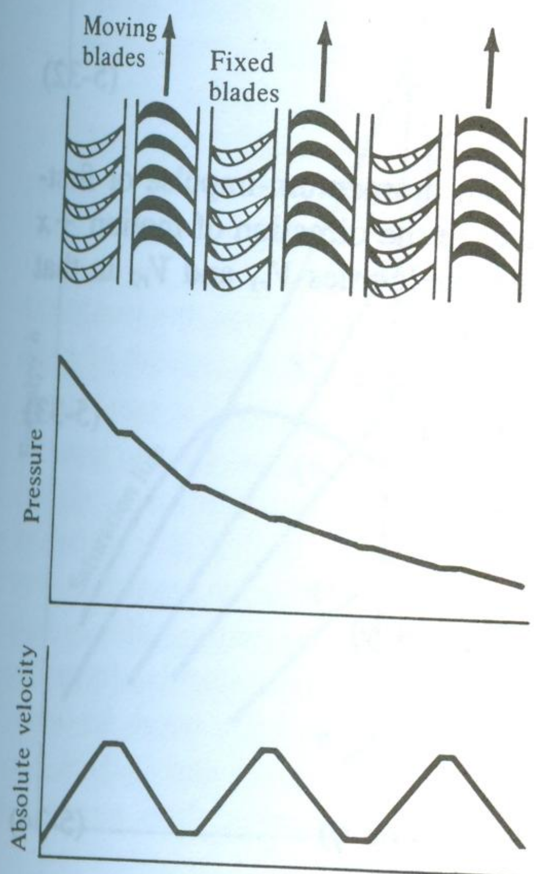


Figure 5-13 Three stages of reaction turbine with overall steam pressures and absolute velocities.

Turbine Arrangements

Combination Turbines

- In the past it was either reaction or impulse turbines.
- Now different turbines arrangements are taking place especially for large and medium size turbines.
- Some common arrangements are:

1. Curtis stage (two-row velocity-compounded impulse) followed by series of Rateau (pressure-compounded impulse) stages.
2. De laval (single-stage impulse) followed by a Rateau or reaction turbine.
3. Combination of a Curtis stage followed by a large number of reaction stages.

- The advantages of having the impulse stages prior to the reaction stages are:

1. The impulse is more suited to the high pressure admission, because there is no virtually no pressure drop in the moving blades.
2. After impulse stage, pressure is sufficiently low that the more efficent reaction stages can be used

- Governing stage or control stage: the nozzles are arranged in groups, each receiving steam through a valve that is actuated by the governor. The valves open in succession as demand by the turbine load.

Turbine Configurations

- Modern turbines are made of multiple sections, also called cylinders, in both tandem (on one axis) or cross-compound (on two parallel axes).
- The sections may be HP, LP and IP.
- The presence of several LP sections reduces the blade lengths.
- Configurations are also affected by admission requierments

Table 5-2 Turbine-generator configurations*

Fossil	Fossil	Nuclear
TC-2F LSB 26, 30 and 33.5 in Two casings 3600 r/min HI-IP LP G 125–400 MW	TC-6F LSB 26, 30 and 33.5 in Five casings 3600 r/min HP IP LP LP LP G 550–1000 MW	TC-4F LSB 38 and 43 in Three casings 1800 r/min HP LP LP G 450–1000 MW
TC-4F LSB 26, 30 and 33.5 in Three casings 3600 r/min HP-IP LP LP G 250–650 MW	TC-6F LSB 30 and 33.5 in Five casings 3600 r/min (double reheat) HP-IP IP LP LP LP G 450–725 MW	TC-6F LSB 38 and 43 in Four casings 1800 r/min HP LP LP LP G 600–1100 MW
TC-4F LSB 26, 30 and 33.5 in Four casings 3600 r/min HP IP LP LP G 550–850 MW LP LP G	CC-4F LSB 38 and 43 in Four casings 3600/1800 r/min HP IP G 3600 r/min LP LP G 1800 r/min 600–1250 MW	

* Data provided by the General Electric Company. TC = tandem compound, CC = cross compound, F = number of flow ducts to condenser, LSB = last-stage blade.

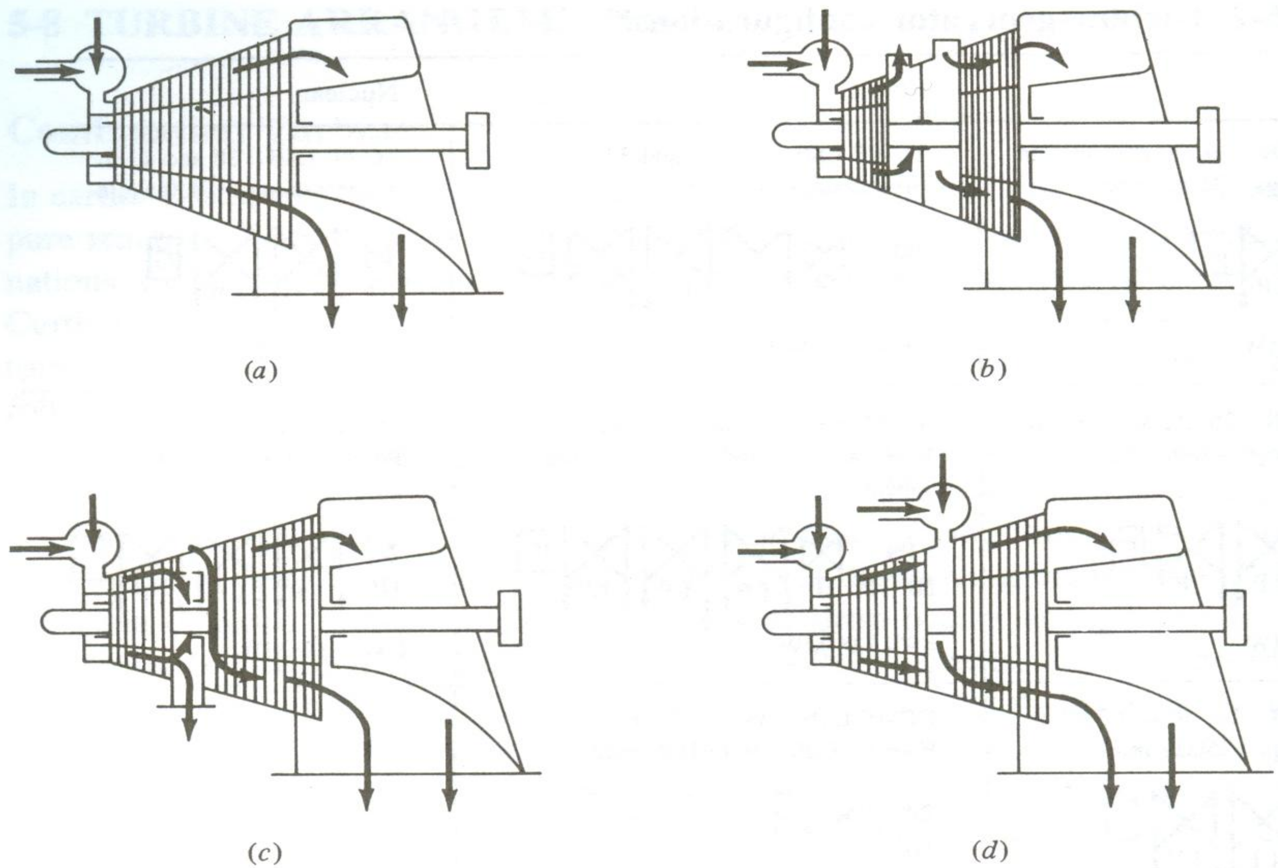


Figure 5-24 Turbine arrangements as affected by different steam paths: (*a*) straight through; (*b*) single reheat; (*c*) extraction; (*d*) induction.

Turbine Rotors

The rotor is the heart of the turbine. Current designs are shown in Fig. 5-27. Figure 5-27*a* and *b* shows two versions of a rotor produced from a *single forging*. Figure 5-27*c* shows a *composite construction* produced by shrinking rotor discs on a central shaft. Figure 5-27*d* shows a *drum-type rotor* composed of separate rotor discs that are welded together. This last design is receiving acceptance for the very large units being built today, 500 to 1000 MW and larger, which would otherwise be extremely heavy and uneconomical and would pose severe mechanical problems..

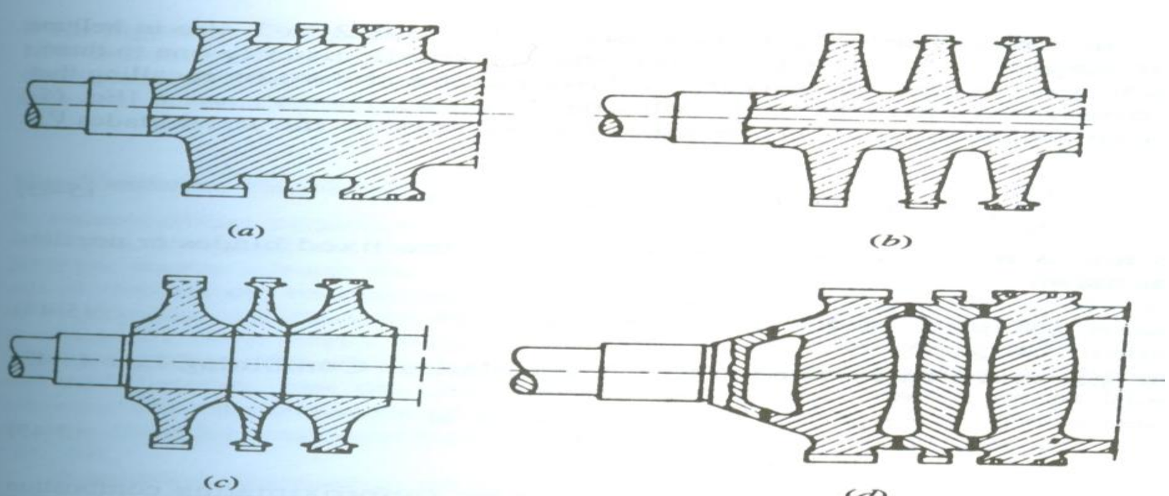


Figure 5-27 Different turbine rotor designs.