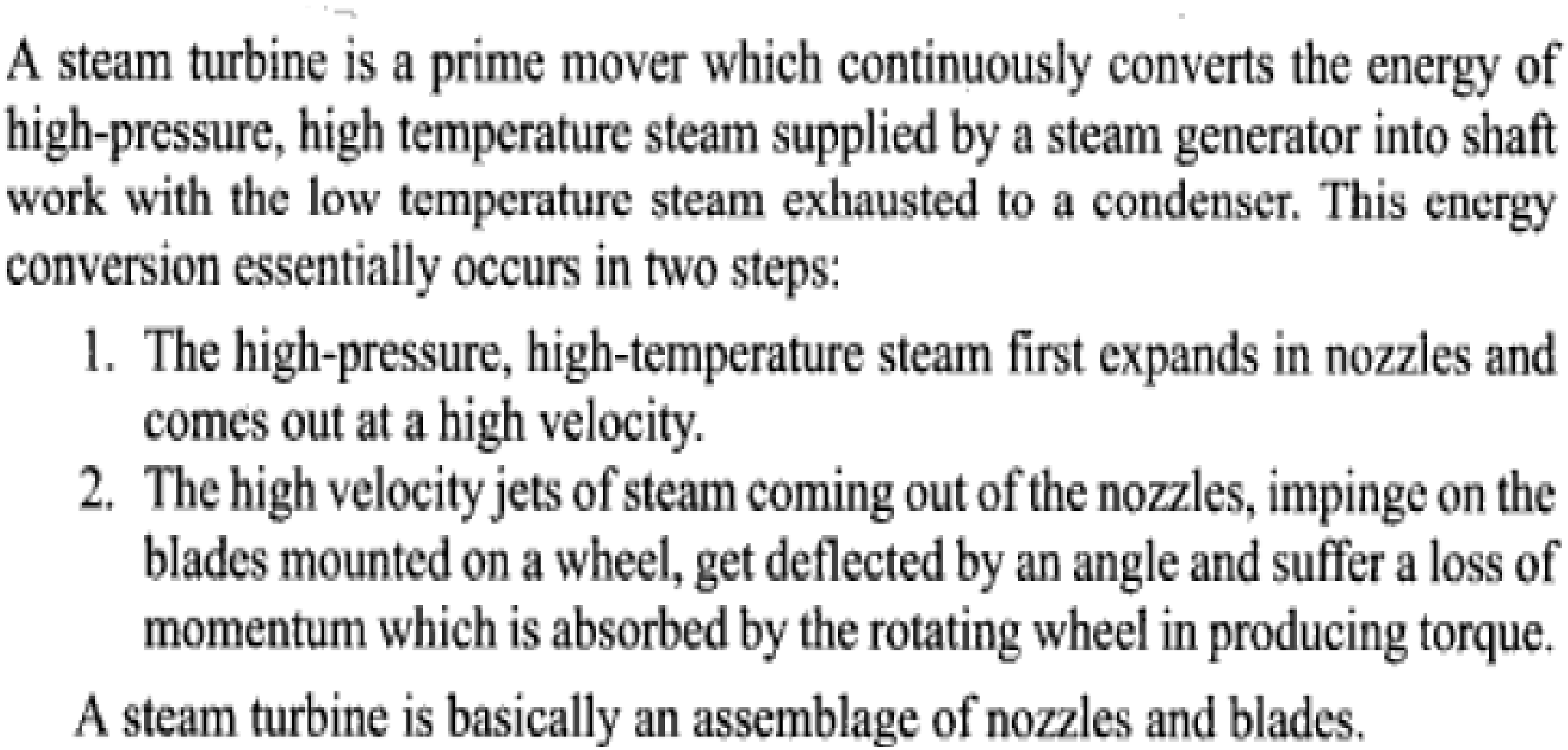
POWER PLANT ENGINEERING

MANSOOR ALI ZAHEER
Assistant Professor
Mechanical Engineering Department
University of Sargodha

Contents

- Steam Turbine (Power Plants by P.K Nag)
- Velocity and Pressure Compounding (Basic Engg. Thermodynamics by Raynor Joel)
- Turbine Governing and Control (Power Plants by P.K Nag)

What is Steam Turbine?



A steam turbine is a prime mover which continuously converts the energy of high-pressure, high temperature steam supplied by a steam generator into shaft work with the low temperature steam exhausted to a condenser. This energy conversion essentially occurs in two steps:

1. The high-pressure, high-temperature steam first expands in nozzles and comes out at a high velocity.
2. The high velocity jets of steam coming out of the nozzles, impinge on the blades mounted on a wheel, get deflected by an angle and suffer a loss of momentum which is absorbed by the rotating wheel in producing torque.

A steam turbine is basically an assemblage of nozzles and blades.

13.1 General introduction

If high-velocity steam is blown on to a curved blade, as shown in Fig. 13.1, the steam direction will be changed as it passes across the blade and it will leave as illustrated. As a result of its change of direction across the blade, the steam will impart a force to the blade. This force will be in the direction shown. Now if the blade were free, it would move off in the direction of the force. If a number of blades were fixed round the circumference of a disc and the disc were free to rotate on a shaft, steam blown across the blades, as illustrated, would cause the disc to rotate. This is the principle of the steam turbine.

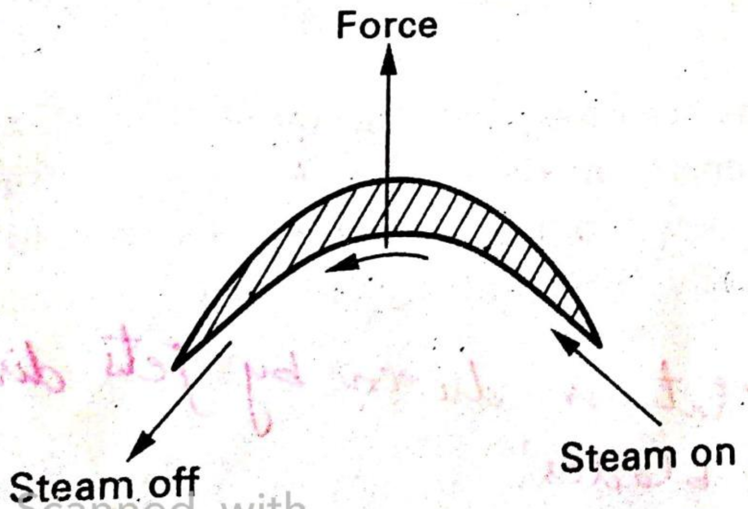


Fig. 13.1 Steam flow across a curved blade

Figure 13.2 illustrates the idea of the steam turbine. The blades are set round the circumference of the turbine disc. The tops of the blades are connected together, for rigidity, by means of the blade shroud ring. The turbine disc is free to rotate on a shaft. Set to the side of the blades, and at an angle to them, are steam nozzles. Using the nozzles, the high-pressure steam is made to give up some of its energy to produce a large increase in kinetic energy of the steam. The steam thus leaves the nozzles at a high velocity. It passes from the nozzles over the blades and thus the turbine disc rotates. Power can then be taken from the shaft. In practice, the turbine disc and the nozzles are fitted into a casing. The number of nozzles in use will be a function of the load on the turbine. The higher the load, the more steam must be used to sustain it. Thus more nozzles are put into service.

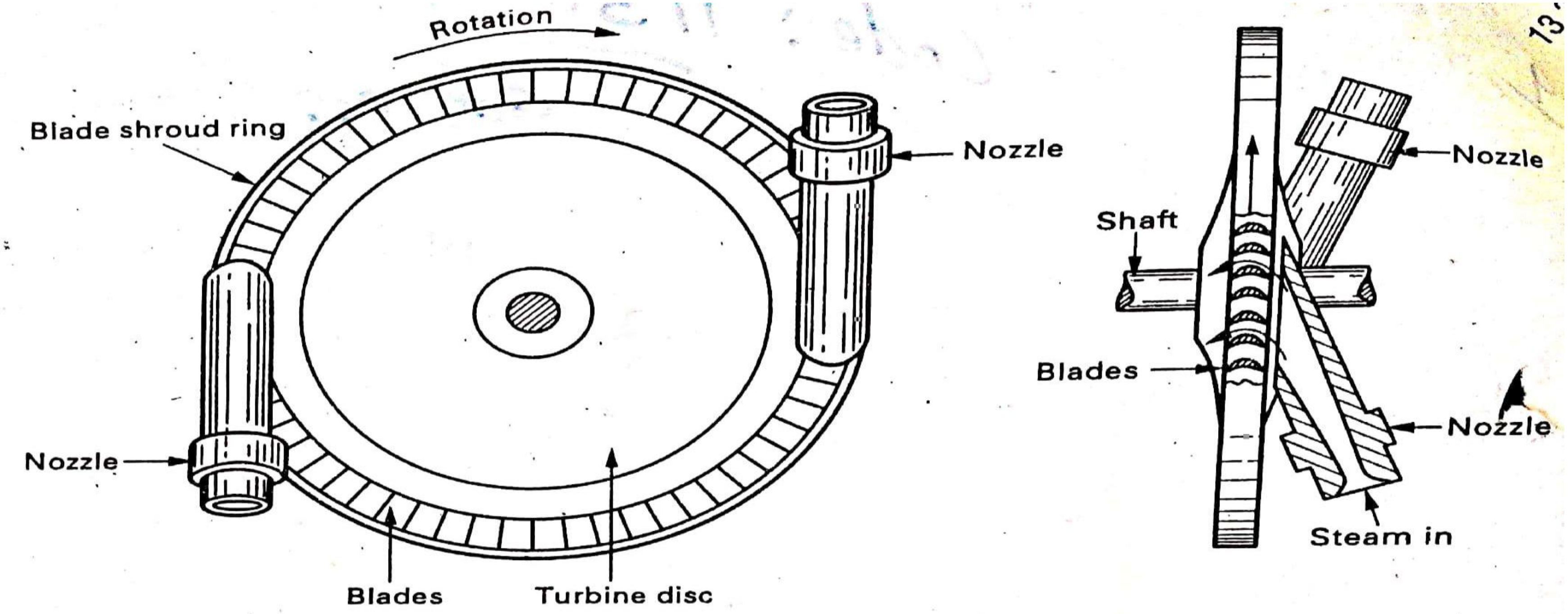


Fig. 13.2 Steam turbine: basic concept

The turbine just described is a simple turbine and was one of the first to be developed. It is called a **de Laval turbine** after its inventor.

This type of turbine usually rotates at a very high speed, some 300 to 400 rev/s. This high speed of rotation will restrict the size of the turbine disc for mechanical reasons such as centrifugal force. Thus, the de Laval turbine is of relatively small size, so it has a small power output. Also, due to the high speed of rotation, a direct drive between the turbine disc and external equipment is not generally possible. For this reason, a reduction gearbox is installed between the turbine disc and the external equipment.

A problem in steam turbine development has been to reduce the speed of rotation and at the same time to make full use of the energy in the steam, thus allowing the production of turbines of large size and high power output. Work in this direction has produced many turbine designs, but broadly they can be split into two basic types: **impulse turbines** and **reaction turbines**.

by jets direct

ction turbines.

13.2 The impulse turbine

"A turbine that is driven by jets direct against the blades".

The simple de Laval turbine is an impulse turbine. The impulse turbine has two principal characteristics: it requires nozzles and the pressure drop of the steam takes place in the nozzles. The steam enters the turbine with a high velocity; the pressure in the turbine remains constant because the whole of the pressure drop has taken place in the nozzles. And the velocity of the steam is reduced as some of the kinetic energy in the steam is used up in producing work on the turbine shaft.

If the whole pressure drop from boiler to condenser pressure takes place in a single row of nozzles, as in the de Laval turbine, then the steam velocity entering the turbine is very high. If some of this velocity is used up in a single row of turbine blading, as in the de Laval turbine, then the speed of rotation is very high. In the impulse turbine this speed may be reduced by three techniques: velocity compounding, pressure compounding and pressure–velocity compounding.

13.3 Velocity compounding

In velocity compounding (Fig. 13.3(a)) the steam is expanded in a single row of nozzles, as before. The high-velocity steam leaving the nozzles passes on to the first row of moving blades where its velocity is only partially reduced. The steam leaving the first row of moving blades passes into a row of fixed blades which are mounted in the turbine casing. This row of fixed blades serves to redirect the steam back to the direction of motion such that it is correct for entry into a second row of moving blades which are mounted on the same turbine disc as the first row of moving blades. The steam velocity is again partially reduced in the second row of moving blades. These processes are shown in Fig. 13.3(b). Graphs of pressure and velocity through the turbine are included. Once again, all the pressure drop occurs in the nozzles; the pressure in the turbine remains constant. Only part of the velocity of the steam is used up in each row of blades, so a slower turbine results. But there is no loss of output because the rows of blades are connected to the same shaft. This turbine is sometimes called a **Curtis turbine**; it is quite common in the high-pressure stage of a large turbine. If necessary, further rows of fixed and moving blades may be added.

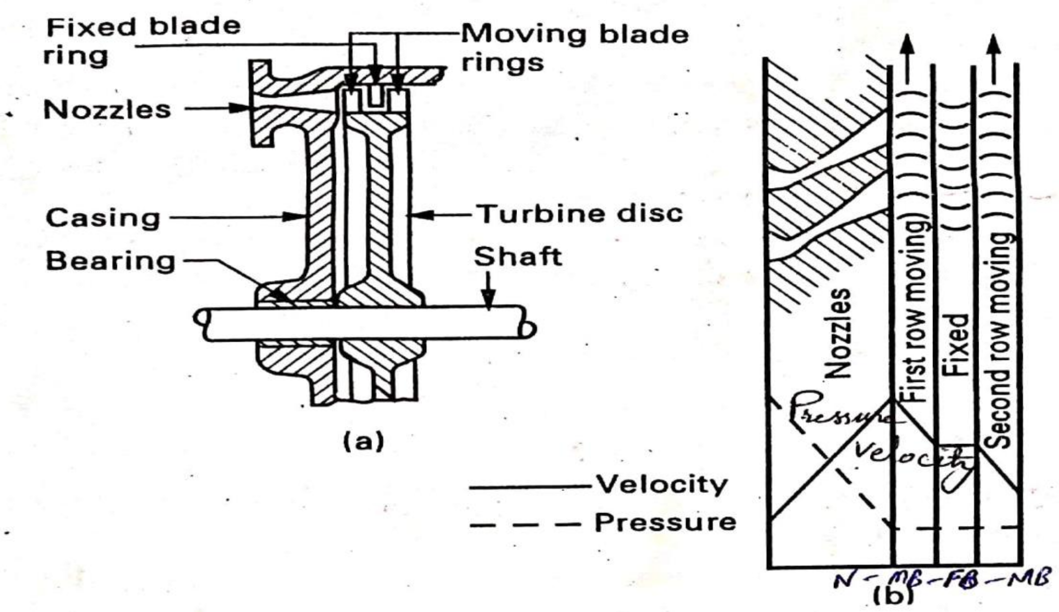


Fig. 13.3 Velocity compounding: (a) turbine and (b) graphs

13.4 Pressure compounding

In pressure compounding (Fig. 13.4(a)) the steam enters a row of nozzles where its pressure is only partially reduced and its velocity is increased. The high-velocity steam passes from the nozzles on to a row of moving blades where its velocity is reduced.

The steam then passes into a second row of nozzles where its pressure is again partially reduced and its velocity is again increased. This high-velocity steam passes from the nozzles on to a second row of moving blades where its velocity is again reduced. The steam then passes into a third row of nozzles and so on.

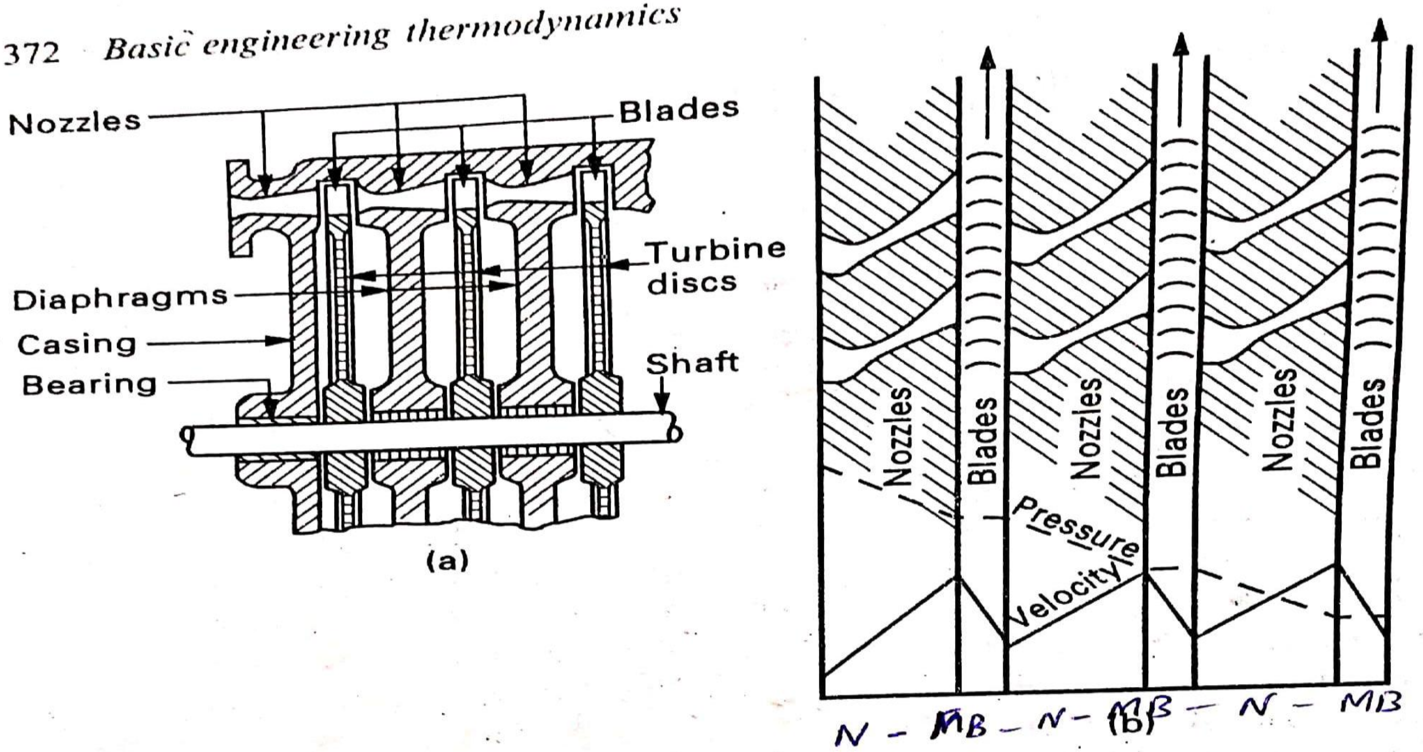


Fig. 13.4 Pressure compounding: (a) turbine and (b) graphs

Three stages of such a turbine are shown in Fig. 13.4(b). Once again, all the pressure drop occurs in the nozzles; the pressure remains constant in each turbine stage.

Since only part of the pressure drop occurs in each stage, the steam velocities will not be as high, so the turbine will run slower. But all stages are coupled to the same shaft, so there is no loss of output. This type of turbine is sometimes referred to as a **Rateau turbine**.

13.5 Pressure–velocity compounding

Pressure–velocity compounding (Fig. 13.5(a)) combines the techniques of pressure compounding and velocity compounding.

Steam is partially expanded in a row of nozzles where its velocity is increased. The steam then enters a few rows of velocity compounding (two rows are illustrated). From this stage the steam enters a second row of nozzles where its velocity is again increased. This is followed by another few rows of velocity compounding and so on. The processes are illustrated in Fig. 13.5(b). Once again, all the pressure drop takes place in the nozzles.

The turbine discs are shown with increasing diameters because all multi-stage turbines will generally increase in diameter from inlet to exhaust. The reason for this is as follows. As the pressure of steam falls, the specific volume increases. For continuity of mass flow, a greater area will be required to pass the steam. This can be accommodated either by increasing the diameter of the turbine discs or by increasing the height of the blades. Increasing the height of the turbine blades will ultimately be limited by their strength; eventually a disc diameter increase will be necessary.

$P \propto \frac{1}{V}$

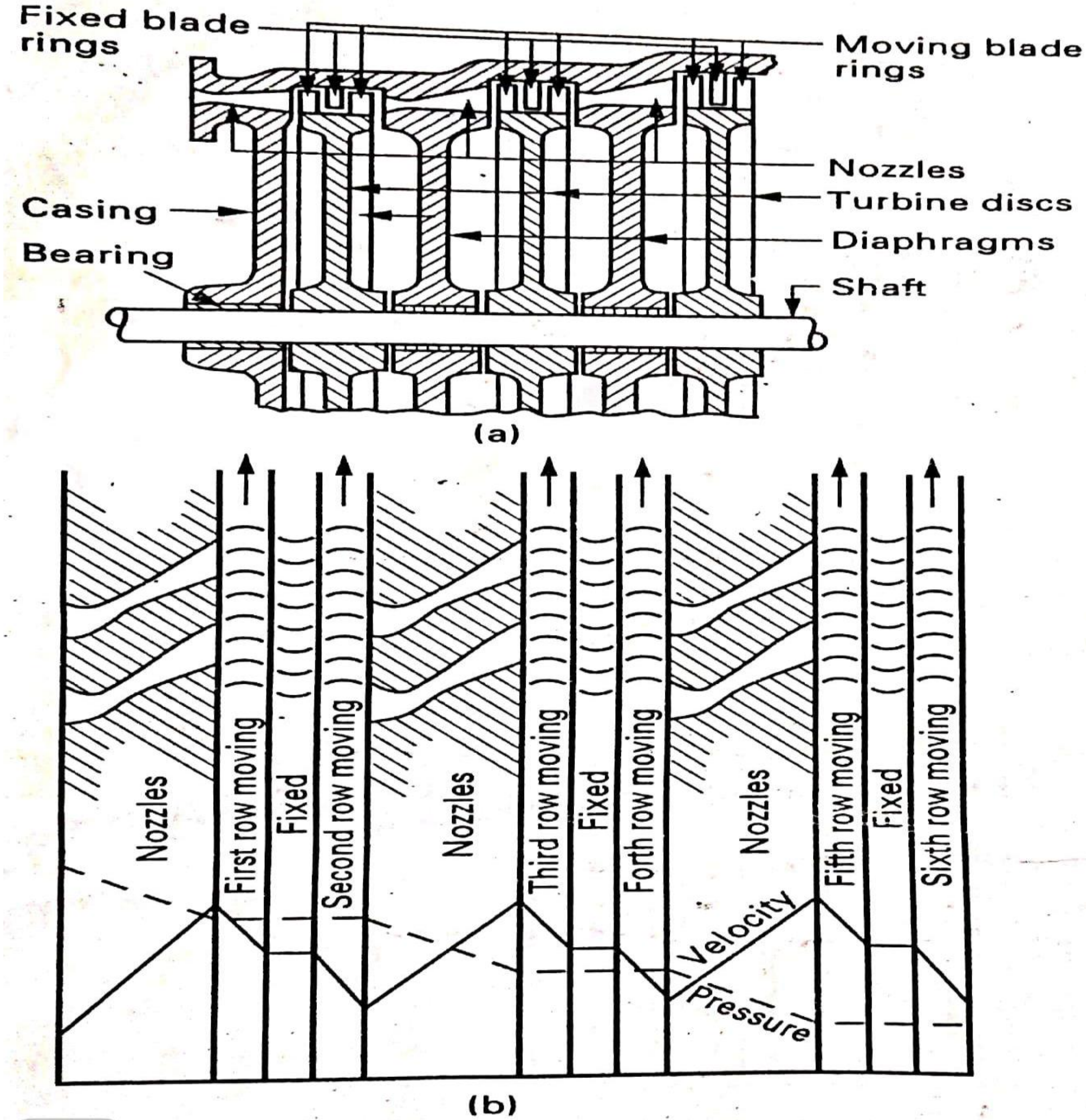


Fig. 13.5 Pressure–velocity compounding: (a) turbine and (b) graphs

ed. The
strated).
is again
d so on.
p takes

lti-stage
ason for
ses. For
This can
s or by, Fixed
ades will & moving
will be Blades

Fixed Blades
as nozzles

ṁ = AV → velocity

A further point which will contribute to the increase in diameter is the velocity of the steam. If there is a general depreciation of velocity through the turbine then, once again, a greater area will be required to pass the steam in order to preserve the mass flow.

"A turbine in which working fluid is accelerated by expansion in both the static nozzles and rotor blades. Torque is produced by momentum changes in rotor and by reaction from fluid accelerating out of rotor."

13.6 The reaction turbine

The construction of a reaction turbine (Fig. 13.6(a)) is somewhat different from that of the impulse turbine. Essentially the reaction turbine consists of rows of blades mounted on a drum. These drum blades are separated by rows of fixed blades mounted in the casing.

Unlike the impulse turbine, the reaction turbine has no nozzles as such. The fixed

"A turbine with blades arranged to develop torque from gradual decrease of steam pressure from inlet to exhaust."

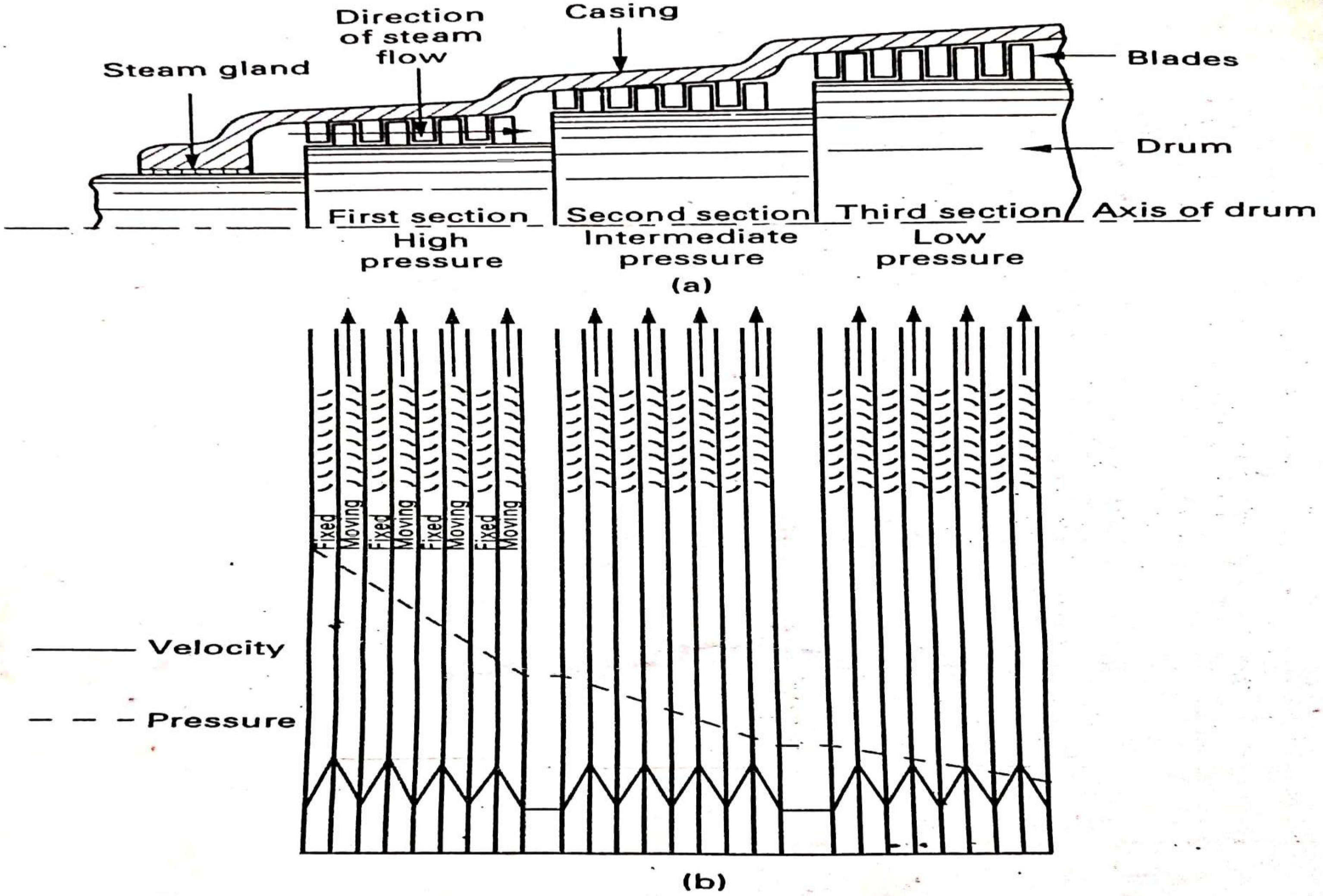


Fig. 13.6 Reaction turbine: (a) turbine and (b) graphs

blades act both as nozzles in which the velocity of the steam is increased and also as the means by which the steam is correctly directed onto the moving blades.

Full admission

And unlike the impulse turbine, the steam in the reaction turbine enters the whole blade annulus, a condition called **full admission.**

Why it called reaction turbine?

The steam also expands in the moving blades of a reaction turbine with consequent pressure drop and velocity increase. This expansion in the moving blades of a reaction turbine gives an extra reaction to the moving blades, beyond that obtainable in an impulse turbine, other things being equal. It gives the turbine its name, the reaction turbine.

A characteristic of the reaction turbine is that the pressure drop occurs continuously through the turbine. This is unlike the impulse turbine, where the pressure drop takes place in the nozzles only, not in the turbine.

Changes in pressure and velocity through a reaction turbine are illustrated in Fig. 13.6(b). Three sections are shown. Each section increases in diameter as the pressure of the steam decreases, mainly due to increase in specific volume. The steam velocity in a reaction turbine is not very high, so the speed of the turbine is relatively low.

Stage

Enthalpy drop

In a reaction turbine, a stage is made up of a row of fixed blades followed by a row of moving blades. Steam acceleration usually occurs in rows of fixed blades and rows of moving blades, so the steam passages between blades, both fixed and moving, are nozzle-shaped. Therefore there is an enthalpy drop in the steam during its passage through the blades; this produces the acceleration. The extent to which the enthalpy drop occurs in the moving blades is called the **degree of reaction.**

Degree of reaction:-

50% reaction

A common arrangement is to have 50 per cent of the enthalpy drop occurring in the moving blades, so the stage is said to have 50 per cent reaction. In the extreme cases, if no enthalpy drop occurs in the moving blades, it must all have occurred in the fixed blades, which is the necessary condition for an impulse turbine. Furthermore, if all the enthalpy drop occurred in the moving blades, the turbine would have 100 per cent reaction. ~~Section 13.13 will illustrate the effect of the acceleration of the steam in the moving blade row.~~

100% reaction

in the low pressure sections of a reaction

Low pressure section

the moving blade row.

A further point to note is that in the low-pressure sections of a reaction turbine the steam volume becomes very large. This greatly increased volume of steam becomes difficult to handle by increasing the blade height or drum diameter in a single turbine section. On large turbines, therefore, the low-pressure section is often made **double-flow**. In this case, the steam enters the centre of the section and divides to flow in opposite directions along the shaft axis. This is illustrated in Fig. 13.7.

also as

e whole

sequent

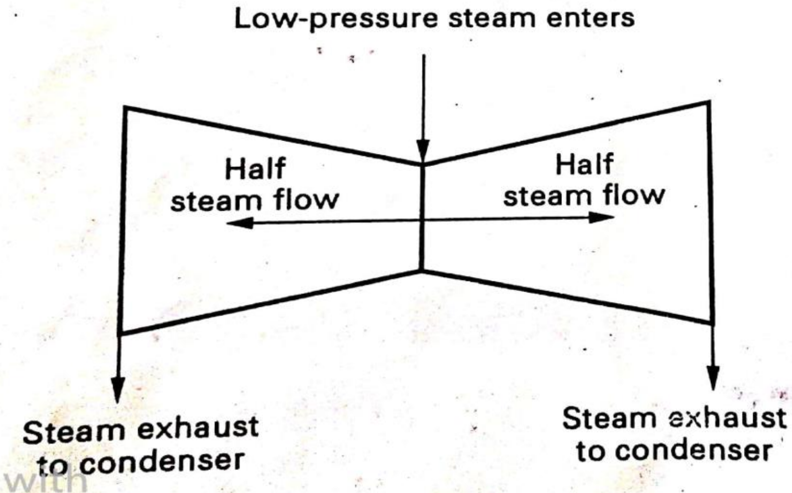


Fig. 13.7 Double-flow low-pressure turbine

In this way each half-section of the low-pressure turbine deals with only half the steam; its general dimensions are thereby reduced. This method also helps to balance end-thrusts which may appear along the turbine shaft. End-thrusts will occur along the turbine shaft due to pressure differences across the reaction turbine blading.

7.3.8 Turbine Governing and Control

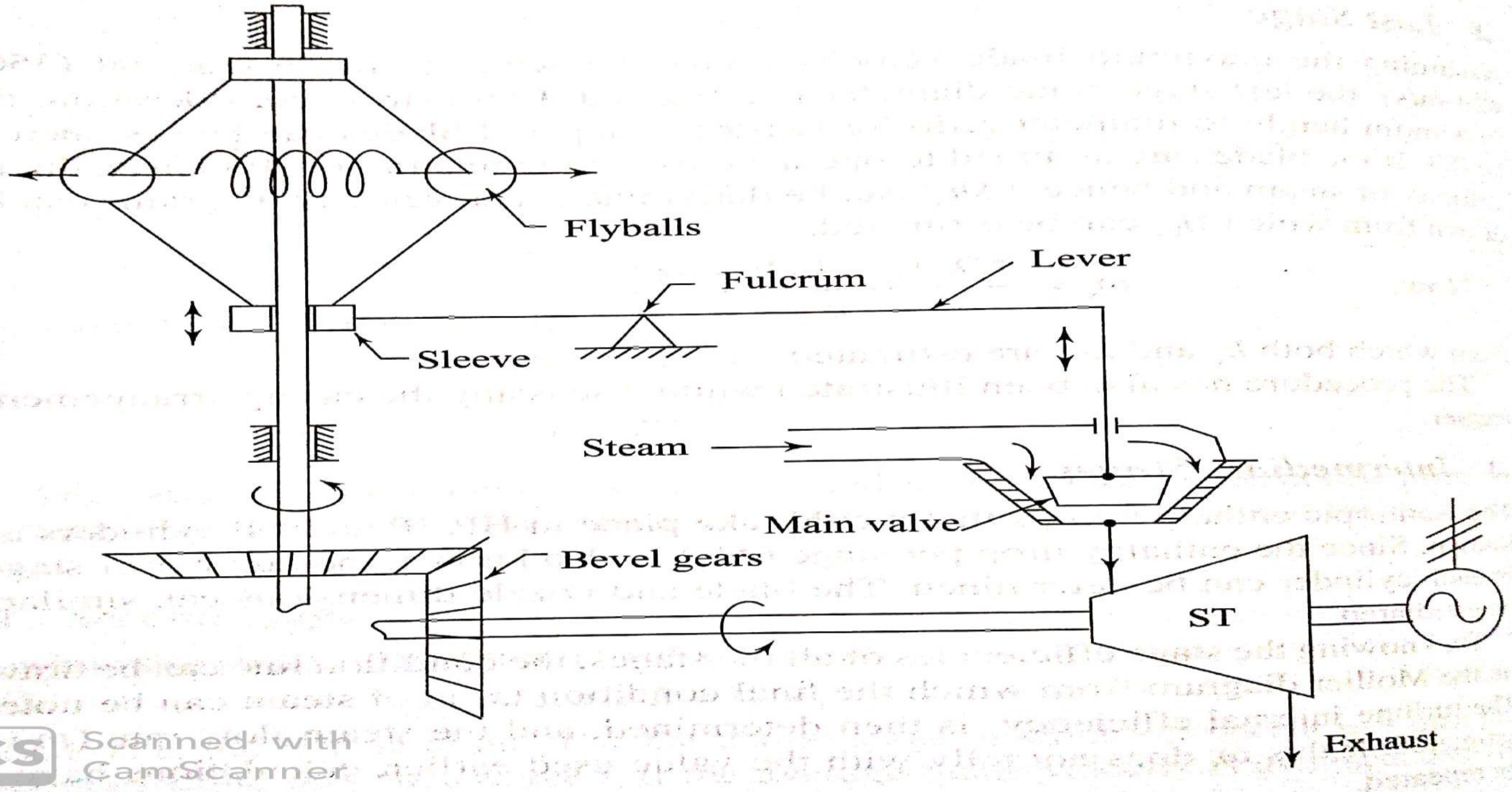
The function of a governor is to maintain the shaft speed constant as the load varies.

The simplest type of governor is the centrifugal flyball type (Fig. 7.50). The power available at the shaft is equal to $2\pi TN/60$, where T is torque and N is the rpm. As load (or torque) decreases, speed increases. Consequently, with the increase of centrifugal force, the flyballs fly apart and raise the sleeve which, operating through a lever and a fulcrum, actuates the main valve to close and reduce the mass flow of steam admitted to the turbine.

An oil-operated servo system in addition may be used to enhance the sensitivity of the governor (Fig. 7.51). The governor force is amplified to move a light and almost frictionless pilot valve which controls the flow of high pressure oil to a piston. The piston powered by the oil can thus operate the governor valve as desired. The steady-state speed regulation R_s is given by

$$R_s = \frac{N_o - N}{N_r} \times 100 \tag{7.98}$$

where N_o = speed at no load,
N = speed at rated load, and
N_r = rated speed.



Animation

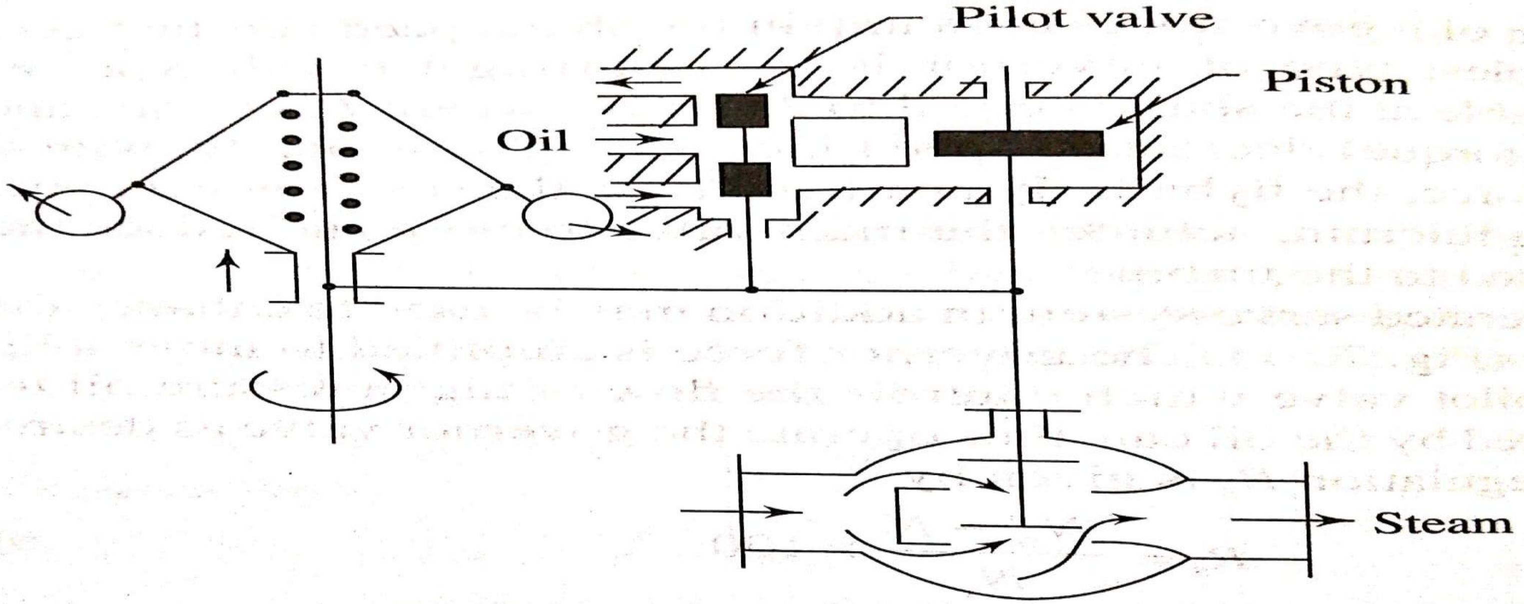
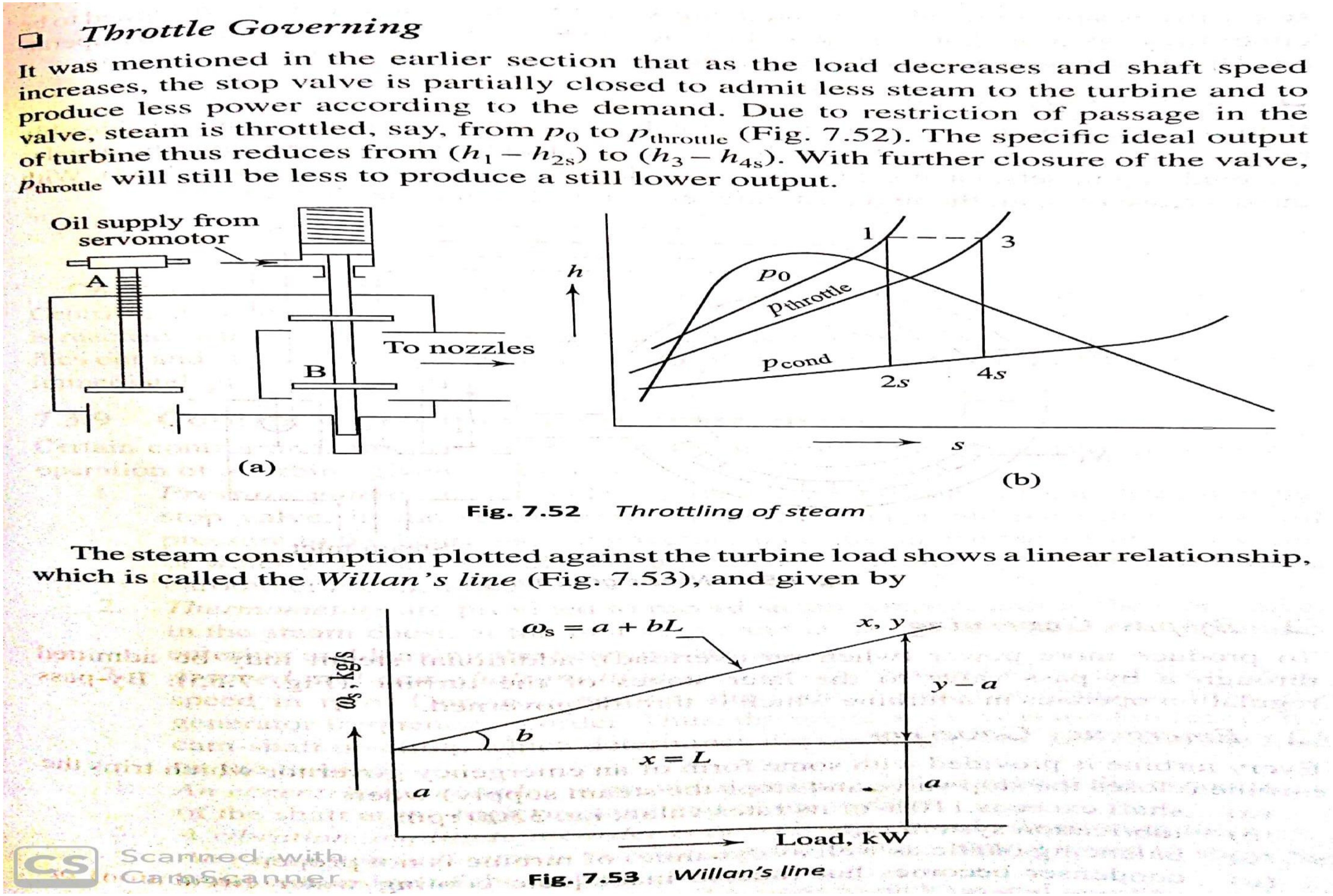


Fig. 7.51 *Centrifugal governor with hydraulic power amplifier*

Usually, the speed change from full load to no load is limited to 3–4% of the speed at rated load. If the rated speed is 3000 rpm, the speed at full load would be 3060 rpm and that at no load would be 2940 rpm. Therefore, in this case

$$R_s = \frac{3060 - 2940}{3000} \times 100 = 4\%$$



❑ *Throttle Governing*

It was mentioned in the earlier section that as the load decreases and shaft speed increases, the stop valve is partially closed to admit less steam to the turbine and to produce less power according to the demand. Due to restriction of passage in the valve, steam is throttled, say, from p_0 to p_{throttle} (Fig. 7.52). The specific ideal output of turbine thus reduces from $(h_1 - h_{2s})$ to $(h_3 - h_{4s})$. With further closure of the valve, p_{throttle} will still be less to produce a still lower output.

Fig. 7.52 *Throttling of steam*

The steam consumption plotted against the turbine load shows a linear relationship, which is called the *Willan's line* (Fig. 7.53), and given by

Fig. 7.53 *Willan's line*

Animation

$$\omega_s = a + bL \tag{7.99}$$

where $a =$ no load steam consumption, kg/s;
$b =$ steam rate (or specific steam consumption), kg/kWs; and
$L =$ load, kW.

The throttle and stop valves are located in the steam supply line to the turbine. The stop valve is a hydraulically operated quick opening and shutting valve designed to be either fully open or shut. For small turbines, the stop valve may be manually operated. The throttle valve is used to regulate steam flow during starting or stopping.

❑ *Nozzle Governing*

If throttle governing is done at low loads, the turbine efficiency is considerably reduced. The nozzle control may then be a better method of governing. The nozzles are made up in sets, each set being controlled by a separate valve (Fig. 7.54). With the decrease of load, the required number of nozzles may be shut off.

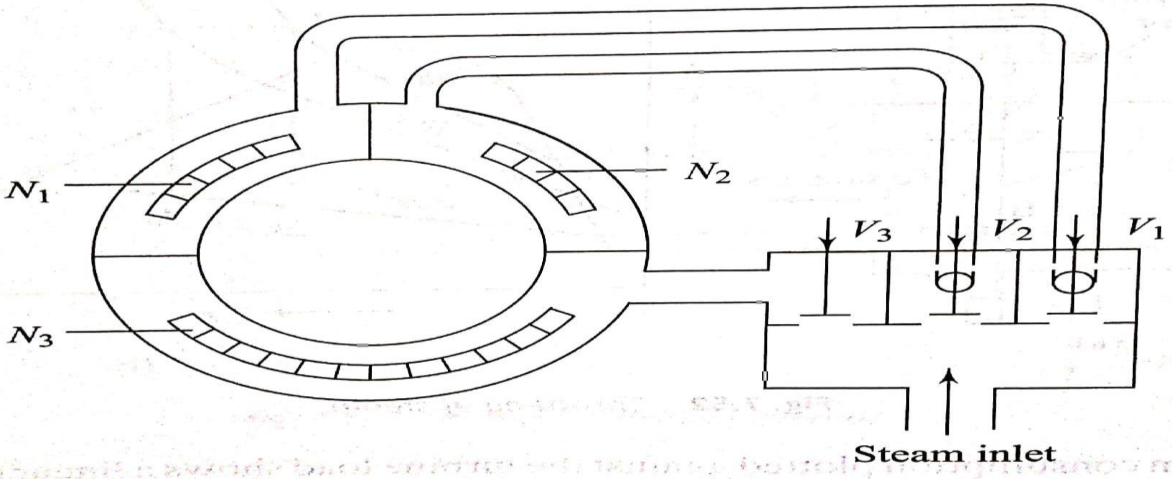


Fig. 7.54 *Nozzle governing*

❑ *By-pass Governing*

To produce more power (when on overload), additional steam may be admitted through a by-pass valve to the later stages of the turbine (Fig. 7.55). By-pass regulation operates in a turbine which is throttle governed.

- Nozzle Governor
- Bypass Governor

❑ *Emergency Governor*

Every turbine is provided with some form of an emergency governor which trips the turbine (closes the stop valve and stops the steam supply) when

(a) shaft exceeds 110% of its rates value, i.e. 3300 rpm
(b) lubrication system fails
(c) balancing (static as well as dynamic) of turbine is not proper
(d) condenser becomes hot (due to inadequate cooling water circulation) or vacuum is less.

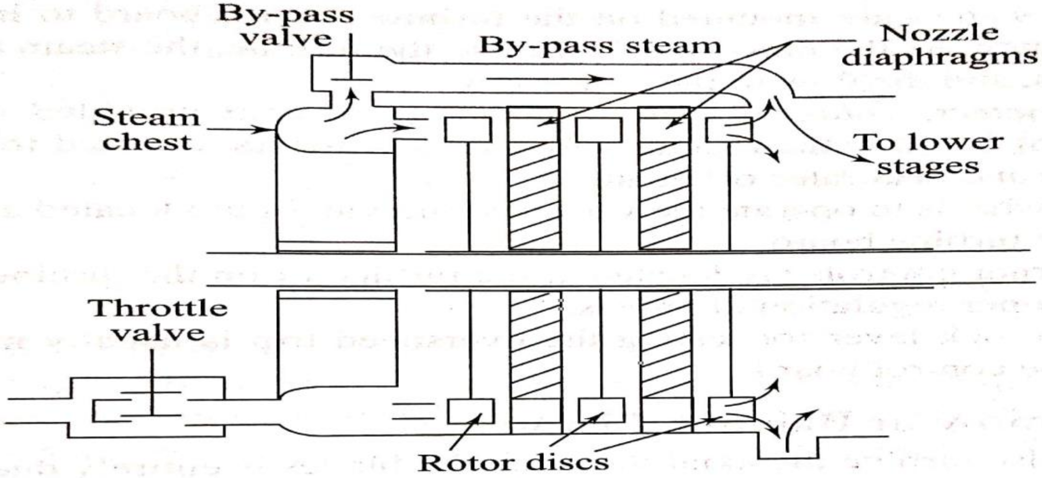


Fig. 7.55 *By-pass governing*

One common type of overspeed trip employs a pin or weight on the turbine shaft. Centrifugal force acting on the pin is opposed by a spring until about 10% overspeed is reached, whereupon, the centrifugal force overcomes the spring force and the pin flies out and strikes a trigger which, in turn, releases a spring to close the stop valve immediately.