pumps, centrifugal gas compressors, etc., when operating under steady conditions as regards output, offer a fairly constant resistance. Such machines are also essentially high-speed machines. Consequently the steam turbine is, from every point of view, eminently suitable as a prime mover for driving such machines.

The uniform turning moment and consequent uniform speed are also very desirable qualities for a prime mover required to drive certain textile machines.

A feature of considerable practical value is the entire absence of internal lubrication in steam turbines (excepting one or two small turbines). Two important advantages follow from this. In the first place, the exhaust steam is not contaminated with oil vapour and the condensed steam may be fed direct into the boilers without passing through filters. Furthermore, in certain industrial turbine plants where the whole or part of the turbine steam is used for some heating process, such steam is clean and may, in many cases, be used for direct heating. In the second place, there is a considerable saving in lubricating oil.

As the only parts of the turbine which require lubrication are the bearings supporting the rotor spindle, the governor shaft bearings and one or two gear wheels, and as there are no sliding parts, the amount of wear is negligible. The lubricating oil is circulated around the system, is cooled and filtered, and so may be used for long periods without replacement. Thus the cost of lubricating oil is negligible when compared with that for a steam engine of equal power.

The extensive use of electricity in the present age has brought into existence many large electricity generating stations. Economic considerations call for individual generating units of very large output. Similarly, the propulsion of vessels of large tonnage and at high speeds has called for machinery of such a power as would be quite beyond the possibilities of the reciprocating engine, steam or Diesel. These demands have been met with comparative ease by the steam turbine. The steam turbines of the ill-fated battle cruiser *Hood*, built in 1917, developed about 150,000 s.h.p. on 4 shafts and sent her 42,000 tons through the water at 31 knots. To-day, there are in central power stations turbines developing more than 100,000 kW, or nearly the total power of a modern battleship, on a single line of shaft.

2. Principle of Action of Steam Turbine. In the reciprocating steam engine, the pressure energy of the steam is utilized to overcome external resistances, and the dynamic action of the steam is negligibly small. Steam engines may be operated by using the full pressure without any expansion or drop of pressure in the cylinder. Such engines are said to work non-expansively. The steam turbine proper could not be operated in such a manner. The machine in which the pressure of steam is used for forcing round a rotating plate or similar device is a rotary engine and not a turbine.

available energy by having two or more simple velocity-compounded turbines in series on the same shaft. The total pressure drop is then effected in as many steps as there are wheels on the shaft, and hence the turbine is pressure-compounded as well as velocity-compounded. As in other types of impulse turbines, the steam is

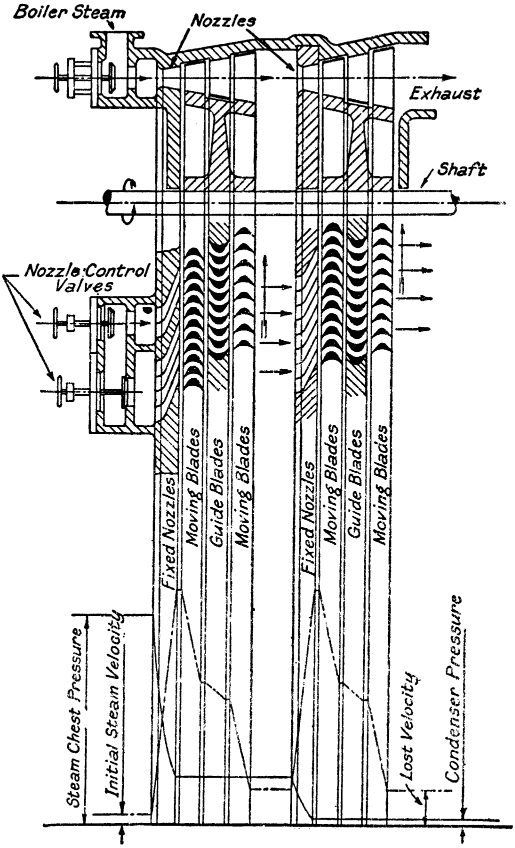

FIG. 4.—Diagrammatic Arrangement of Pressure-velocity-compounded Impulse Turbine

expanded wholly in the nozzles, and the wheels rotate in steam at constant pressure. Thus ample clearances are permissible in the radial direction, while the clearances in an axial direction should, from the point of view of efficiency, be kept as small as possible.

The middle portion of Fig. 4 is intended to show roughly how this and other types of impulse turbine may be controlled so as to give

Unless otherwise stated, the problems set in the various parts of this book and involving the use of steam tables will be solved by using these tables.

3. *Thermodynamic Properties of Steam.* By Professor J. H. Keenan and Dr. F. G. Keyes. Published by John Wiley and Sons, Inc., New York. These tables were published in 1936 and extend to 5,500 lb. per sq. in. and 1,600° F. A large Mollier chart is included in a folder.
4. *VDI-Steam Tables.* By the late Dr. Ing. We Koch. The Fourth revised and amplified edition by Professor Ernst Schmidt was published in 1956 by Springer, Berlin, and extends to a pressure of 300 atm. and 800° C. (4,267 lb. per sq. in. and 1,472° F.).
5. *Thermodynamic Properties of Water Vapour.* By the Moscow Power Engineering Institute, in 1956. These extend to a pressure of 400 kg. per sq. cm. and 750° C. (5,689 lb. per sq. in. and 1,382° F.).
6. *Properties of Steam at High Pressures—An Interim Steam Table.* Published by the American Society of Mechanical Engineers. This interim steam table is an extension of the Keenan and Keyes steam tables into the region of 5,500 to 10,000 lb. per sq. in. and 32 to 1,600° F.

12. Unit of Heat. In the centigrade system, the thermal unit is the *calorie.* If the pound is taken as the unit of mass, then the heat unit is the pound calorie; if the gramme is the unit of mass, then the corresponding heat unit is the gramme calorie, and so forth.

The calorie is then defined as the heat required to raise unit mass of pure water from a temperature t° C. to $(t + 1)$° C.

There are three such units, viz.—

(1) *The* 15° *C. gr. calorie* ($t = 15$° C.). This is equal to $4{\cdot}184 \times 10^7$ ergs. [1 erg = 1 dyne-cm.]

(2) *The* 20° *C. gr. calorie* ($t = 20$° C.). This equals $4{\cdot}180 \times 10^7$ ergs.

(3) *The mean calorie,* which is the $\frac{1}{100}$th part of the heat required to raise the temperature of 1 gr. of water from 0° C. to 100° C. According to Barnes (2), this is equal to $4{\cdot}184 \times 10^7$ ergs. Thus the mean calorie is equal to the 15° C. calorie.

Corresponding to the mean calorie, there is the *mean British Thermal Unit,* which is the $\frac{1}{180}$th part of the heat required to raise the temperature of 1 lb. of water from 32° F. to 212° F. This unit will be used throughout the book, except where otherwise stated.

Attempts have been made in recent years to express heat quantities in units which are independent of the physical properties of water. To this end the M.K.S. system, which uses the metre, kilogramme and second as the fundamental units, has been introduced. In this system the unit of force is that required to give unit mass of 1 kg. an acceleration of 1 metre per sec.^{2}; this unit is termed the Newton, and written N. Since 1 dyne gives a mass of 1 gr. an acceleration of 1 cm. per sec.^{2}, 1 N. = 10^5 dynes.

The unit of energy is the Newton-metre and is termed the joule, equivalent to 1 watt-second. In the same system of units, the steam, but as this term is sometimes (erroneously) used for another quantity which differs slightly in amount from the heat of generation, confusion is apt to arise.

$$\begin{aligned} H &= \text{Sensible heat} + \text{Latent heat} \\ &= h + L \end{aligned}$$

19. Dryness Fraction. Steam which is taken from the steam drum of a boiler normally contains a small amount of water in the form of minute suspended drops. Then again, during the expansion of steam in the nozzles or blades of the turbine a certain amount of condensation takes place. This condensation is not due

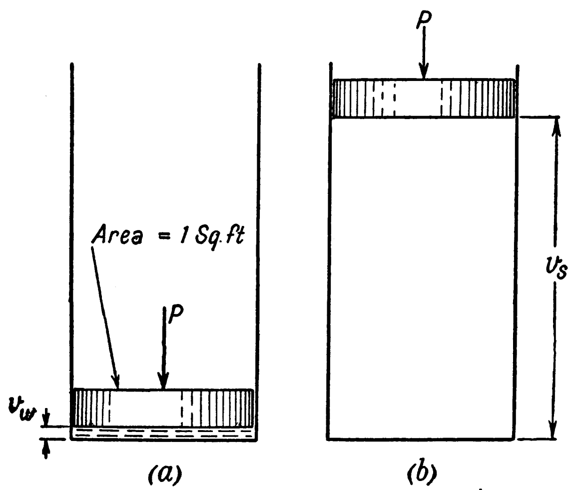

FIG. 12

to the cooling of the steam by the metal parts (since under a steady load these are at a sensibly uniform temperature) but, as will be shown later, is a natural result of the expansion. The steam condenses partially and a fine mist is formed. Such steam is said to be wet, and the mixture of dry steam and water is often referred to as "stuff." The dryness fraction x of the steam is defined as the ratio—

$$x = \frac{\text{Weight of dry steam}}{\text{Weight of stuff}}$$

The wetness fraction $1 - x$ is, similarly, the ratio of the weight of moisture to the total weight of steam and moisture.

The sensible heat of water is clearly independent of x. The heat required for the partial evaporation of 1 lb. of water is x times that required for the complete evaporation, i.e. xL.