divergent nozzle. This is the case, for instance, in the Parsons turbine, where the whole expansion is divided into many stages each of which involves only a small drop in pressure.

111. *Influence of Friction.—*We have dealt so far with the ideal case of no friction, and have taken the whole work of expansion as going to produce kinetic energy in the jet. But under real condi­tions there is a progressive dissipation of energy through friction; as expansion proceeds the steam loses part of its kinetic energy which is restored to it as heat. Thus, at every stage in the process the velocity acquired is less than it would be in frictionless adiabatic ex­pansion, but the steam is drier and its volume is greater in consequence of the restored heat. Referring to the entropy-temperature diagram (fig. 54.) the process of expansion under conditions involving friction is represented not by the adiabatic line *cd* but by some such line as *eg* lying between the adiabatic line and the saturation line *cf.* The final condition of dryness is *ag/af* instead of *ad/af.* During this expansion the effect of friction, as regards the entropy, is equivalent to the communication to the substance of a quantity of heat repre­sented by the area *pcgr.* Hence that area represents the work converted by friction into heat. The whole work done during expansion is the area *abcg,* which is more than before by the area *dcg.* The difference, namely *abeg minus pcgr,* represents what may be called the *net* heat drop when friction is allowed for: it represents what is effectively available for giving kinetic energy to the jet. This net area may. also be expressed as equal to *abcd minus pdgr.* Compared with frictionless adiabatic expansion the net loss resulting from friction is the area *pdgr.* The volume is increased in the ratio of *a g* to *ad,* and this has to be taken account of in determining the proper dimensions of the divergent nozzle.

112. Turning now to the question of utilizing the kinetic energy of steam in a steam turbine, it will be clear from the figures that have been given that if the whole heat drop is allowed to give kinetic energy to the steam in one operation, as in the De Laval nozzle, a velocity of about 4000 ft. per second has to be dealt with. To take advantage of a jet in the most efficient manner in a turbine consisting of a single wheel the velocity of the buckets against which the steam impinges should be nearly one half the velocity of the stream. But a peripheral velocity approaching 2000 ft. per second is impracticable. Apart from the difficulties which it would involve as regards gearing down to such a speed as would serve for the driving of other machines, which are to employ the power, there are no materials of con­struction fitted to withstand the forces caused by rotation at Such a speed.

Hence it is advantageous to divide the process into stages. This may be done by using more than one wheel to absorb the kinetic energy of the jet, as is done in the Curtis turbine, or by dividing the heat drop into many steps, making each of these so small that the steam never acquires an inconveniently great velocity, as is done in the Parsons turbine. Turbines which employ one or other of these two methods, or a combination of both, achieve a greater economy of steam than is practicable with a single wheel.

113. *De Laval Turbine.—*Thanks, however, to the inventions of De Laval, the single expansion single wheel type of turbine, with buckets in the rim, has been brought to a degree of effici­ency which, while considerably less than is reached in com­pound turbines, is still remarkably good. This has been done by the use of the divergent nozzle and with the help of mechani­cal devices which enable the peripheral speed to be very high, though even with the help of these devices the speed of the buckets falls considerably short of that which would be suitable to the velocity of the jet. In De Laval’s turbine the steam expands at one step from the full pressure of the supply to the pressure of the exhaust by discharge in the form of a jet from a divergent nozzle. It then acts on a ring of buckets or blades in much the same way as the jet of water acts on the buckets of a Pelton wheel or other form of pure impulse turbine. To utilize a fair fraction of the kinetic energy of the jet the blades have to run at an enormous velocity, and the speed of the shaft which carries them is so great that gearing down is resorted to before the motion is applied to useful purposes. The general arrange­ment of the steam nozzle and turbine blades is illustrated in fig. 55. The blades project from the circumference of a disk-shaped wheel and form a complete ring round it, only a few of the blades being shown in the sketch.

The increasing section of the nozzle is calculated with reference to the final pressure, according to the principles already explained. The jet impinges at one side of the wheel and escapes at the other after having had its direction of motion nearly reversed. The expansion in the nozzle is carried to atmospheric pressure, or near it, if the turbine is to be used without a condenser; but in many cases an ejector condenser is employed, and when that is done the nozzle is of a form which adapts it to expand the steam to a correspond­ingly lower pressure. It is only in the smaller sizes of these turbines that a single nozzle is used; in the larger steam turbines, as in large Pelton wheels, several nozzles are applied at intervals along the circumference of the disk. The peripheral velocity of the blades ranges from about 500 ft. per second in the smallest sizes (5 h.p.) up to nearly 1400 ft. per second in turbines of 300 h.p. In a 50 h.p. De Laval turbine the shaft which carries the turbine disk makes 16,000 revolutions per minute; in the 5 h.p. size it makes as many as 30,000 revolutions per minute. A turbine developing 300 h.p. uses a wheel 30 in. in diameter, running at over 10,000 revolutions per minute, with a peri­pheral speed of nearly 1400 ft. per second. These enormous speeds are made possible by the ingenious device of using **a** flexible shaft, which protects the bearings and foundations from the vibration which any want of balance would otherwise produce. The elasticity of the shaft is such that its period of transverse vibration is much longer than the time taken to complete a revolution. The high-speed shaft which carries the turbine disk is geared, by means of double helical wheels with teeth of specially fine pitch, to a second-motion shaft, which runs at one-tenth of the speed of the first; and from this the motion is taken, by direct coupling or otherwise, to the machine which the turbine is to drive. The wheel carrying the buckets is much thickened towards the axis to adapt it to withstand the high stresses arising from its rotation. Turbines of this class in sizes up to 300 or 400 h.p. are now in extensive use for driving dynamos, fans and centrifugal pumps. Com­pared with the Parsons turbine, De Laval’s lends itself well to work where small amounts of power are wanted, and there it achieves a higher efficiency, but in large sizes the Parsons turbine is much the more efficient of the two. Trials of a De Laval turbine used with a condenser, and developing about 63 h.p., have shown an average steam consumption at the rate of about 20 lb per brake-horse-power- hour, and even better results are reported in turbines of a larger size.

114. *Action of the Jet in De Laval,s Turbine.—*In entering the turbine the jet is inclined at an angle α to the plane of the wheel. Calling its initial velocity V1 and the velocity of the buckets *u* we have, as in fig. 56, V2 for the velocity of the steam relatively to the wheel on admis­sion. A line AB parallel to V2 therefore determines the proper angle of the blade or bucket on the entrance side if the steam is’to enter without shock. As the steam passes through the blade channel the magnitude of this relative velocity does not change, except that it is a little reduced on account of friction. The action is one of pure impulse; there is no change of pressure during the passage, and consequently no acceleration of the steam through drop in pressure after once it has left the nozzle. Hence V3, the relative velocity at exit may (neg­lecting friction) be taken as equal to V2. The direction of V3 or BC is tangent to the exit side of the bucket.