with broken basalt. The rails are set on each tie in a steel chair, strongly bolted down, and are joined perpendicularly by bevelled joints 7-in. in length, held firmly together by bolts passing horizontally through the fish-plates, so that the effectiveness of a continuous rail is practically secured. The old light rails, which failed in 1901, and were taken up, have been laid down flat as guard rails, resting horizontally on special cast-iron chairs in such a way that the flat bottom flange of the rail stands vertically along the inside line of each heavy rail, and about 2-in. distant from the inner edge of its face. The track is a nearly level air-line throughout its length, except one curve of 2,000 yards radius near its southern extremity, and is up to the highest standard of modern railway construction. The motors have been improved, but the cars are the same as when first constructed. Each is 72.18 feet in length, and weighs about 200,000 lbs. avoirdupois. Of this weight 48 metric tons comprise the body and running gear, and 42.5 tons are made up by the motors, transformers, and other details of the electrical equipment. Each end of the car rests on a six-wheel bogie truck of the American type, and the motors are four in number, one attached to the front and rear axle of each truck, the middle pair of wheels in each group running free. The wheels are 49-in. in diameter, and are equipped with pneumatic brakes of the standard type. The transformers, which are hung beneath the middle section of the car, weigh 12 tons, besides which a storage battery of 631 lbs. weight supplies the current for lighting purposes.

NOTES ON THE STEAM TURBINE.*

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The turbine, the oldest type of steam engine, has always attracted more than an ordinary amount of attention, but the results of the epoch-making events of 1884 and 1889, when patents were awarded the Hon. Charles Algernon Parsons and Dr. Gustaf De Laval, respectively, have increased this interest to an almost unlimited degree. Trevithick, Pilbrow, Wilson, and possibly others, grasped the salient features of the modern turbine; but it needed modern workshop facilities with the attendant accuracy of workmanship and attention to detail, to make the turbine a commercial success. When we realize that it is not twenty years since the application was made for the first letters patent for the Parsons turbine, and that it was as late as 1891 that the first condensing turbine was produced, we cannot but wonder at the success it has achieved, and the world-wide interest it has excited. Previous to the last decade, conservative engineers in general undoubtedly looked askance at rotary engines and turbines; but it needs only a glance at the modern turbine to perceive mechanical features which must meet with approbation, and a closer examination cannot fail to call forth admiration for the ingenuity displayed and the persevering attention to detail in every part.

The modern parallel flow turbine is too well known to need a detailed description, but it will not be amiss to insert here the general principles of its chief types. They all depend for their action upon the conversion of the kinetic energy, caused by the expansion of the steam into work done on the rotating turbine shaft. In the De Laval turbine the expansion of the steam takes place in one or more nozzles before it reaches the turbine blades. In the Parsons this expansion takes place during the passage of the steam through the turbine, while in the Curtis turbine we have the application of both these principles. The De Laval, with its one row of blades, must, in order that the velocity of the steam leaving the blades be not excessive, have a very high peripheral velocity. In the Parsons and Curtis turbines, however, the employment of many rows of stationary and rotating vanes makes it possible to diminish the speed of the turbine shaft, without reducing the efficiency.

As regards the velocity of the turbine blades, it is not difficult to find the one that is most efficient. Suppose V_1 be the absolute velocity in feet per second of the steam as it strikes the vanes and V_2 the absolute velocity of the steam leaving the vanes, the greatest amount of energy that can be given to the turbine per pound of steam is $\frac{V_1^2 - V_2^2}{2g}$ foot pounds, and in order that this should be a maximum, V_2 must equal nothing. This is the case when the velocity of the vane is one-half the velocity of the impinging jet, and when the direction of the motion of the vane is parallel to that of the impinging and leaving jets.

This condition cannot be realized in steam turbines, though it may be noticed in passing that a close approximation to it is obtained in the case of the Pelton water wheel. But the velocities dealt with when working with steam are immensely greater than can ever be experienced with water. Thus, with a head of 200 feet, the velocity of the water entering the turbine could not exceed 113 feet per second. In the case of turbines of the De Laval type, however, where the steam expands in a diverging nozzle from initial pressure to condenser pressure, it is estimated that velocities of 4,000 feet or more per second must be employed. This velocity can, of course, be regulated by the form of nozzle. But for economical working, as large a proportion as possible of the heat energy of the steam must be changed into the kinetic energy of the gas, the velocity of which, since it has a large specific volume, must be very high. It is stated above, that for maximum efficiency the velocity of the vane should be one-half the velocity of the impinging jet. But a vane velocity of 2,000 feet per second would, of course, cause such centrifugal forces in the turbine wheel as no known material could safely bear. Turbines, with a single row of vanes using high pressure steam, must consequently run at a speed lower than the most efficient—a peripheral velocity of 1,000 feet per second being about the limit. The introduction of many rows of moving and stationary vanes at once overcomes this difficulty. The steam loses some of its velocity at each row, and so, on this principle, turbines have been made that run efficiently at speeds not much in excess of those of some high-speed reciprocating engines.

Figure 1 shows the working parts of a De Laval turbine, and Figure 2 is a sectional plan of the same. The steam enters the nozzle from the chamber D, where it is completely expanded, passes through the turbine bucket F to the exhaust chamber G. The important features are the diverging nozzle referred to above, the fact that there may be considerable clearance between the wheel, casing and nozzle, the flexible turbine shaft with its flexible bearing, the

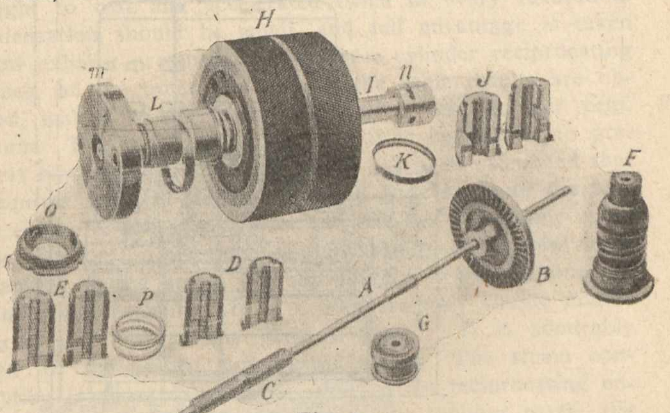

Fig. 1.

turbine wheel, made of forged nickel steel of increasing thickness from the periphery to the centre to resist centrifugal force; above all, the high velocity of the turbine wheel, and the gear wheels required to reduce this velocity usually in the ratio of about ten to one. It is interesting to notice in passing some of the forces acting on this turbine. Suppose in a 10-H.P. turbine the speed of the turbine shaft is 24,000 revolutions per minute and the diameter of the turbine wheel 4.8 inches, the torque on the flexible spindle will be about 26 lbs. inches, and the total tooth pressure approximately 50 lbs.

Figure 3 shows a longitudinal section of the Parsons turbine, as manufactured by the Westinghouse Machine Company. In this the steam enters at A, passes through the stationary to the rotating blades through the high pressure, intermediate and low pressure cylinders, exhausting at B. As stated above, because of the many rows of stationary and

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