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THE PARSONS STEAM TURBINE.

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There are two underlying principles in the various steam turbines of to-day, viz , the Parsons and the De Laval, all other types being modifiations or combinations of these types, but possessing characteristic features of their own in the method of combination and their treatment of steam. These two types were as distinct in their method of utilising the heat energy of steam as their partly analogous hydraulic brethren the common water wheel or weight machine and the impulse machine of Pelton or undershot systems in their endeavours to utilise the potential and kinetic energy of water. These two systems were created about the same period. The Parsons to supply a high speed motor suitable for direct coupling to armatures of electrical generators which were then constructed for much higher peripheral speeds than the practice in reciprocating engines of that day permitted for direct coupling. Dr. De Laval's creation was the outcome of a demand for a high speed motor for cream separation, but although Dr. De Laval produced a wonderfully ingenious and compact plant which gave admirable results, he, at the same time by adopting the method of extracting the whole of the available energy of steam in one step, limited its sphere of usefulness owing to absence of constructional material of sufficient strength to withstand the periphera velocities necessary to comply with efficient steam and wheel ratios of horse powers over 300. The Parsons system really knows no limit as to size. The two types differed in this respect. The De Laval relied upon one wheel to extract the kinetic energy from the fluid, which fluid was allowed to expand upon itself in a diverging nozzle from the boiler to the condenser temperatures. This steam in a well designed nozzle naturally attained a velocity of from 3000 to 4000 feet per second, and a corresponding motor spindle speed of about 500 revolutions per second. This expanding operation was fulfilled before steam was allowed to perform external work and one firm had seen the natural limits of this type and by the addition of guide passages was able to withdraw steam after its first impact upon the vanes and again lead it to the wheel with the result that the peripheral velocity had not to comply with single step 5 steam wheel ratio of De Laval for maximum efficiencies. This method, however, still required a high speed of revolution. Parsons' type also consisted of a nozzle in which steam was allowed to expand, the inherent difference in the two types existed in the fact that the heat energy was extracted and performed external work as steam, then was actually expanding by impinging upon a series of rows of vanes or complete turbine wheels, and, unlike the De Laval, high efficiencies with comparative low peripheral velocities were possible with a low enough speed of revolution to allow of direct coupling to electrical generators, propellers, pumps or air compressors, and there was no doubt that turbo generators at present considered large will be superseded by gigantic machines and remind us that we had periodically to change our ideas of size. It was evident to engine builders, more especially marine engineers, a few years ago that the reciprocating engine was getting of unwieldy proportions and that soon the limit must be reached if a machine could not be produced which would largely reduce weight per H P. The steam turbine had solved this difficulty and alone made speeds of 25 knots in boats of the new express Cunard type possible, as the size and weight of reciprocating engines for a total H.P. of 70,000 (which had been provided for this speed) even in three units was quite beyond our conception, and when viewing the experimental launch, "Turbinia," which was 100ft. overall and had a total displacement of 44 tons, lying alongside the "Mauratania" of an overall length of 785ft.

and 33,500 gross tonnage. Considering that the "Turbinia's" first trials dated only some 11 years ago one wondered what the ultimate power of units would eventually be.

In the following he proposed to confine his remarks to the Parsons system. For those members who had only viewed the uninteresting exterior of a Parsons Steam Turbine, he had prepared some diagrams of the interior organs, which, it was hoped, will form a substitute. Plate XV represented a 5000 K. W. Parsons Turbine, the cylinder being in section and spindle in elevation, but no blades were inserted. The annular steam space was thus represented before its reduction in area by blades and gave the diverging nozzle. The reduction of the area due to blades amounted to two thirds with the normal blading, and a smaller amount with the special blading introduced for expansion to very low pressures, without again increasing the length of blades and cylinder diameter, to accomodate the increased volume of steam. Plate XVI represented the annular area in terms of diameter and area of nozzle for machine as described in Plate XV, the steam volume expanding some 300 fold. It would be noticed that the increase in diameter took place rather abruptly in ten steps, the last two being due to a higher pitch and a somewhat different form of blade. The increase of efficiency due to a more gradual increase in blade area was not sufficient to counteract the larger cost of manufacturing, and thus a compromise was entered upon. The steam entered by an annular belt, and was directed by the first row of stationary or guide vanes to impinge upon the spindle or rotary vanes. The steam on leaving these rotary vanes reacted with a certain force upon the outlet side of the vanes. These two operations were repeated in the case of the machine under consideration 75 times until condenser pressure was reached. By this large number of complete turbines in series, the speed of vanes was reduced to a maximum of about 300 feet per second, and with a vane ratio of ·6 to about 700ft. per second steam velocity.

In the early parallel flow turbines, steam entered at the centre flowing in two directions axially to the exhaust. Thus the spindle was balanced as blade lengths were equal in these halves, but blade tip clearance losses were large, and this system was dropped in favour of the rotary balance pistons. The end thrust on the spindle due to differences of pressure between sides ef each row was now perfectly balanced by these balance pistons of definite area according to height of blade used, and three pipes connected the balancing portion with the different pressure in turbine shown in Plate XV. The thrust block used was purely for keeping the motor spindle in one position in relation to the guide blades and other stationary parts. The turbo spindle was therefore in tension. To prevent the escape of steam past the balance pistons, the periphery of each was grooved and the cylinder was provided with projecting brass rings which entered these grooves (Plate XVI). These caulked rings were ground up by spindle until they acted as valve seats to the rotary valves on the balance piston. The thrust block was then adjusted until the moving and stationary parts of these labyrinth packing rings were a safe distance apart for running. The steam glands were on the same principle excepting a slight modification in the exhaust end gland to allow for the extra expansion of the steel spindle over the cast iron cylinder. It would thus be seen that there were no rubbing parts in the turbine, oil was supplied to the bearings under pressure of a few pounds by a rotary pump driven by vertical governor shaft from turbine spindle by worm gearing. For large sized units the ordinary white metal bearing was used, and for sizes up to 500 k.w. the tubular patent bearing was used, and to show the amount of actual wear of bearings he had been allowed, by the kind permission of the Engineer of the Imperial Lighting Station, Sydney, to take a bearing as originally supplied by Parsons from the first Steam Turbine installed in New South Wales, and which had been in constant operation for 5 years, at 16 hours per day and 7 days per week, at a speed of 4500 revolutions per minute, which equalled a total of 7¾ billions for that period. The bearing wear was imperceptible and the original tool marks could still be seen. This bearing was surrounded by three concentric tubes with a play between each of the tubes of one or two thousandth part of an inch, oil penetrates between these tubes and acted as a cushion, damping down any minute vibration from the spindle and so prevented its transmission to the bedplate. He might also mention that the interior of this turbine was inspected for the first time this year in the presence of some members of the University, and the blades and spindle were found in a perfect condition. The governing of the steam turbine was effected by a sensitive centrifugal governor, which controlled the position of a small plunger piston of steam relay mechanism, which in turn controlled the pressure by altering the position of main double beat admission valve. This small plunger was not allowed a moment's rest for possible sticking, but was kept in a state of activity by the governor clutch being slightly cam shaped or by an independent motion from worm geared shaft. The steam if saturated leaving the first row of vanes, became a heterogeneous mass, due to minute drops of condensed steam due to expansion and the performance of external work by steam; if steam be superheated the position in which it becomes charged with water molecules was delayed somewhat in its path through the turbine, but in both cases the steam was in a heterogeneous condition the greater part of its travel. This mixture of water and steam increased the surface frictional losses of the steam in its path through the turbine, and in the case of very high steam velocities being used of slightly pitting the leading edges of vanes or altering the contour and efficiency of the Laval diverging nozzle.

For the reason that the available heat of steam at higher pressures than 150 to 200lbs. per square inch increased so slowly, and necessitating great expense in boiler construction, pressures much over 200lbs. per square inch were not likely to be superseded, and the path along which economy was to be sought was with high superheat and the best possible vacuum. Advantages to be derived by superheating steam were limited by the superheater, and in actual working practice superheats of 250° Fah., were not likely to be improved upon. The very scant attention condensing plant received up till recent years was, he thought, to be explained by the inability of reciprocating engines to utilise higher vacua than 25 to 27 inches of mercury, even if lower condenser pressure existed, as the steam volumes increased so rapidly over 27 inches, it was found impossible to construct low pressure cylinder pistons and steam passages of large powers to conform with the augmented volume. Other reasons there were, such as leaking cylinder glands, and distance from the low pressure cylinder to condenser, but a study of the pressure volume curve for low pressure steam would, he thought, be sufficient reason to damp any designer's ardour in attempting to work at lower exhaust pressures of 2lbs. absolute.

Since Professor Ewing, in 1892, tested a 150 K.W. turbo set exhausting into condenser at 1lb. absolute pressure, and which tests resulted in a steam consumption of only 27lbs. per K.W. hour, the distinct tendency had been to improve condensing plants. Few of the mechanical hindrances inherent with the reciprocating engine existed in the steam turbine to prevent higher vacua being utilised. Steam glands were not subjected to any mechanical friction and resulting wear, and had only the atmospheric pressure to contend with, they were made air tight by the exhaust steam from steam relay governor mechanism, and the slightest discharge of steam from these glands insure that the pressure therein was sufficient to absolutely seal the condenser from entrance of air by this route. The condenser could also be placed in close proximity to the turbine with a short exhaust pipe with fewer steam joints liable to air leaks.

The curve, Plate XVII., demonstrated the relation between final pressure in inches of mercury, and percentage of heat efficiency of perfect steam engine working between temperatures, the initial pressure being 100lbs. per square inch. On the knee of this curve turbine engineers were safely installed, and the advance made towards the theoretical possible, was marked since the advent of this steam turbine, but as a mechanical check was encountered in the reciprocating engine practice at about 26in. of vacuum, a check more of a physical nature was met with at a vacuum of 29·8in. (barometer 30in.), with the present type of condenser, and until some refrigerative condenser replaced the present form, our ideal thermal efficiency would remain below 40 per cent. at this initial pressure.

Mr. Parsons, with a view of further extracting air from condensers, introduced an apparatus which he termed a vacuum augmentor, and which acted very much in the same way as a steam exhauster, or the exhaust steam in a loco funnel, extracting nearly all the residual air from the condenser, which an air pump of ordinary dimensions was unable to deal with. This residual air with accompanying vapour was compressed by a steam jet in a contracted pipe to one-fourth of their volume, and delivered to an auxiliary condenser having a cooling surface of about 2% of main condenser, and was then dealt with by an ordinary sized air pump. A water seal was interposed in the main, or wet air pump suction pipe, so that the slightly compressed air was unable to return to the main condenser. The suction pipe from the condenser for the augmentor steam jet was elevated, and hooded in the interior of the condenser. The suction pipe to the air pump was also provided with a spigot, which extended a sufficient distance above the bottom of the condenser, to raise the condensed steam high enough to submerge 3 or 4 rows of condenser tubes, and which tubes cooled the condensed steam to about circulating water temperature before it overflows and reached the air pump, and to a certain extent acted as a cold water jacket upon the air pump keeping the air volume lower. The steam consumption of the ejector jet was about 1% of the total steam used by the turbine at full load, but the observed total nett. reduction in steam consumption was about 8%, the condenser quantity of circulating water, velocity of air pumps remaining the same.

These figures being the result of actual tests upon a 1500 K.W. set, and a vacuum of 29in., mercury barometer 30in., was now common practice with condenser and air pumps of ordinary proportions.

The quantity of circulating water at similar temperatures necessary to maintain these high vacua, naturally was in excess of that needed for a vacuum of 26 inches or thereabouts, and with ordinary temperatures of circulating water, such as was available with river and harbour suctions, the ratio of circulating water to the amount of steam condensed was about 50 to 55 per cent., and the percentage of total power generated, used with motor driven air and circulating pumps, taking an average of a large number of stations worked out at about 2 per cent., which in many cases was even a smaller percentage than that frequently consumed by stations of equal proximity to water supply, but using a much poorer vacuum.

The temperature due to vacuum approached within a few degrees of circulating water outlet temperature. This curve, Plate XVIII., as already pointed out, gave the theoretical gain with high vacua, and to supplement this with actual test figures it was found that between 25in. and 26in., or 26in. and 27in. vacuum there was a saving in steam consumption of a turbine at full load of about 4 per cent. If the vacuum be increased from 27in. to 28in. the reduction amounted to 5 per cent., and between 28in. and 29in., another reduction of about 7 per cent., or in other words a reduction of 2½° Fahr. at exhaust of turbo equalled a reduction in consumption of 1 per cent. These figures were plotted in Plate XIX. in terms of vacuum in inches and percentage gain.

An example of high vacua obtained by the Parsons condensing plant with the aid of the vacuum augmentor was to be found at the Carville Station of the Newcastle Electric Supply Co., where a vacuum of 95·8 per cent., and 97 per cent. of the barometer was regularly maintained at full and half loading of 4000 K.W. sets. 10 to 12lbs. of steam were condensed per square foot of cooling surface per hour, and to improve the cooling efficiency large wedge-shaped portions were left vacant of tubes which penetrated the interior nest of tubes. While speaking of the Carville Power House where turbines alone are used, it is interesting to note that a record steam economy has resulted from recent tests of the 4000 K.W. sets installed there of 13lbs. of steam per K.W. hour equal to about 8lbs per I.H.P. per hour. The works costs per unit generated at this station for the year ending December 31st, 1904, was also interesting reading, showing what could be actually be accomplished with that much abused quantity steam. Engine-room and boiler-house wages, .02226; coal, .0784; water, oil and stores, 00445; general repairs and main. tenance, .0161. A total of .12123 of a penny per unit generated-

Mr. Parsons in 1894 took out patents for low pressure turbines which would receive their heat supply from high pressure engines exhaust expanding steam from about atmospheric pressure to that of condenser. It was apparently impossible to get satisfactory results from winding engines, running condensing, and that appaling waste of heat, which was always manifested with this type of plant exhausting to the atmosphere, it was now possible to utilise by generating electricity if circulating water be available in sufficient quantities, expansion being carried down to ½lb absolute in some cases. That portion of Parsons turbine was the more efficient which presented to the steam the larger blade area compared with clearance area. By clearance area he meant the annular space between tips of the blades and the stationary cylinder. This mechanical clearance was practically the same for all lengths of blades or for high and low pressure stages. It would, therefore, be seen that the low pressure portion of the turbine was the most efficient and for this reason very good efficiencies result from this type of plant. The increments in steam economy for high vacua with the turbine already given were largely increased in the case of exhaust steam turbines, and the following savings had been noted under test with a turbine supplied with steam at atmospheric pressure, barometer 30 inches by increasing the vacuum from :—

26in. to 27in.	a saving equalling	12%
27in. to 28in.	,, ,,	$14\frac{1}{2}$%
28in. to $28\frac{1}{2}$in.	,, ,,	$9\frac{1}{2}$%

making a total saving of 36% of steam for 2·5 extra inches of vacuum at turbo exhaust, or roughly 1% gain in economy per degree decrease. The first turbines on this principle were installed on H.M.S. "Velox" in 1903, where two sets of small reciprocating engines exhausted into main turbines at cruising speeds. These engines were disconnected when higher speeds were required. Several turbo generators supplied to Messrs. Guinness's Brewery, Dublin, exhausted at about 10lbs. above atmospheric pressure direct into the vats, a sufficient proof of the purity of the condensed steam. At periodic times this exhaust was more than the vats could utilise, when, instead of exhausting to the atmosphere, they exhausted to a condenser at a pressure of $1\frac{1}{2}$lbs absolute through a 250 K.W. Parsons turbine taking only 34·4lbs. of steam per K.W. hour, giving an efficiency by Rankine's cycle of 58%.

Another instance was at Messrs. John Brown's Works, Sheffield, in which case steam from a non-condensing blowing engine exhausted into a 300 K.W. generator. These turbines were provided with a steam cylinder not unlike a Parsons blower with a few rows of long blades of the ordinary steam turbine section. Continuous current dynamos capable of being driven by the early high-speed Parsons Turbines necessitated a large amount of experimental work and to a great extent the driver and the driven had gone hand in hand if that be possible. They had gradually increased in size from 10 H.P. turbine or machine (Plate XV) at a speed of 18,000 revolutions per minute, and with an armature diameter of 3in. (this machine was now in the South Kensington Museum), to sizes of 3000 H.P. continuous current plants with tandem dynamo running at 1000 revolutions per minute at Manchester and elsewhere.

The main difficulty encountered with direct current generators was commutation at variable loads, the cross magnetising field effect being abnormally large and plane of commutation or position of brushes for sparkless collection having a much larger range than with slow speed generators, and when traction loading became common some means of automatically moving brushes for alteration in load became necessary. This was accomplished by a steam actuated brush rocker on the following principle :—The initial pressure in turbine being proportional to the load and the load being proportional to the disturbing magnetising effects, it therefore followed that the initial pressure was proportional to the cross magnetising effect of the armature current upon the field. A steam cylinder fitted with piston and connected to the initial stage of the turbine by a pipe was arranged to work against a spiral spring, a connecting rod connected the piston to the brush rocker, and it would thus be seen that the spring and pressure on the piston decided the position of the brushes practically instantaneously with any change of load. This method was used for a number of years with complete success. Another method which dispensed with the mechanical device was to provide a stationary compensating series winding round the armature which would counteract the distorting effects of the armature current upon the field. This electrical method had of late years been adopted entirely, and possessed the advantages of actually overcoming the trouble within the dynamo itself. Fixed brushes for all loads and overloads resulted and simplified the brush gear very considerably. The number of series turns in the compensating winding were in excess of armature turns, which, in addition to annuling the distortion of the field provided a sufficient counter E.M.F. between the coils of the armature to balance the self induction of commutation and thus increased the output to a certain extent. With alternators, design is comparatively easy and has now reached great sizes, an instance of which is the recent order of the N.S.W. Government for two 5000 K.W. sets capable of working at 6000 K.W. continuously and a very large reserve for overloading. These plants would run at a speed of 750 revolutions, having four poles for the 25 cycle system. In the recent proposed power scheme for the electrical supply of London, single sets were designed of 10,000 K.W.'s normal duty and capable of working at 20,000 K.W. or approximately 28,000 I.H.P. from a single shaft.

The latest adaption of the turbine was to air compression for blowing purposes in smelting operations. The first installed of large size being at the Farnley Iron Works, Leeds, some five years ago. The usual Parsons turbine was coupled direct to a turbo blower, which was a reversal of the steam turbine with certain modifications, and consisted of a number of fans in series mounted on a laminated shaft enclosed by a cast iron cylinder, and projecting from which and placed between each row of fans were the guide or air extracting vanes, which guided the air in a longitudinal direction from each moving row in the most economical manner, delivering it to succeeding row for further increment in velocity and pressure. This operation proceeds until the desired pressure is reached, each row contributing a certain fraction to the final pressure, or about half a pound. Plate XX. illustrated the departure in blade section upon the steam turbine, the blades being of very similar section as the normal Parsons' blading, but the curvature was taken out of the working face and was made of wire drawn steel. In speaking of blades, he might remark that the evolution of Parsons' present blading was an interesting example of the gradual attainment towards perfection of a vane which would transfer the velocity of steam to the turbine spindle with the minimum of friction and eddies, and maximum of strength.

The present vane sections were similar to nature's best production for a submerged substance, which was to offer the least resistance in fluid friction and was of fish section. Machine divided blading had of late years come prominently forward and it was interesting to note that over seven years ago Mr. Parsons took out patents for this class of blading, and shortly after fitted two moderate sized machines with this system. These machines had given every satisfaction from their prolonged test, and the edges of each vane being milled to a knife edge, and in the event of a foul occurring with the stationary cylinder, owing to clumsy manipulation in starting the plant, or from other possible causes, the surface presented to the cylinder casing was of minimum area and not sufficient to cause a serious vibration of the spindle between bearings. The lacing strip was of the simplest form and secured by silver solder to each blade, long blades having two or more of these strips. The volume of air inhaled in this type of blower depended upon length of blade or annular area in which blades revolved, speed of revolution, and pressure against which the blast was being delivered.

The annular area was decreased to comply with compressed volume, and blades were therefore shorter at the delivery end of the machine. The spindle had also a rotating balance piston as in the steam turbine, to neutralise the end thrust generated by the final pressure upon the vane annulars, and supplied with the usual labyrinth packing grooves for gland. The motion being purely a rotary one, the air was delivered in a perfectly steady and continuous blast, and obviated the necessity of air receivers. The most dreaded occurrence of blast furnace working—a hanging or choked furnace—was practically overcome with this type of plant, by its being possible to speed up from the normal to that corresponding to a pressure of an extra 50% which promptly cleared the obstruction. The power necessary to drive these turbo blowers varied as the cube of speed, and thus to attain an extra pressure of about 50%, with an increased volume delivered, necessitated with the plants supplied to Messrs. Sandford, an increase of only 500 revolutions per minute. The engine was designed to suit the average working requirements of the furnace, and if the resistance to air flow diminished, more air was at once automatically delivered into it without the possibility of any increase in speed which was controlled by an ordinary centrifugal governor. On the other hand an increase in the resistance of the furnace would, with constant speed, decrease the volume of air delivered, and the turbine was then speeded up until the hanging had been blown free. Our inability to indicate the power of steam turbine and blower was not altogether an unmixed evil, as it had resulted in a much clearer definition of efficiency and steam consumptions.

The heat consumed for any power from the steam turbine generator had always been given in terms of lbs. of steam per K.W. hours, thus dispensing with the sometimes misleading terms of brake and indicated I.H.P., and gave a clear overall statement of heat consumed per actual electrical H.P. delivered from the generator. This system of guaranteeing an electrical generator was now universal. In the case of turbine blowers, steam consumptions were always quoted in terms of actual adiabatic air horse power, in air delivered at the blower outlet, and these advantages were appreciated as much in air compression as in electric generation. He might also mention that cards were not necessary as far as valve setting was concerned in the steam turbine, as the ratio of expansion was fixed by the designer for all times by the steam passage in the turbine, and it was only necessary to provide the initial, and exhaust pressure for which the machine was primarily designed to attain its maximum efficiency. In intermediate loading of a steam turbine plant, the regulating valve acted as a reducing valve, the lower pressure steam resulting upon the smaller quantity passing through turbine accommodated itself to a large extent to suit the annular areas for the higher pressures and quantities at full load, at which load the machines were generally designed to be most economical. The turbo blower installed at the Farnley Iron Works was a striking example of the ancient and modern, the reciprocating set only running at 18 revolutions per minute, and the turbine set at 5200 in the same period. With this large difference in speed, the comparative dimensions of the two sets were not astonishing. The reciprocating engine set drove the blower in tandem, its total length being 75ft. x 12ft. wide, and when running at the above