speed delivered 9200 cubic feet of air per minute at a pressure of from 2 to $2\frac{3}{4}$lbs. to the square inch. The turbine set was only 15ft. 3in. long and about 4ft. wide, and when running at 5200 revolutions per minute, delivered 11,356 cubic feet of free air per minute at a pressure of 3lbs. It would thus be seen that this blower was without air valves of any description, and included the many advantages of the Parsons' turbine in general construction, flexibility of possible loading, and economy in working expenses. No internal lubrication is required, and the saving in this one item was very marked in several machines of the same duty as the one installed at Lithgow, namely, 20,000 cubic feet of air at 10lbs. pressure; only half a gallon of oil was used per week to make up for small leakages, and evaporation in bearing oil supply. This represented the complete weekly bill for stores, or about 1/9 against £15 to £20 for a reciprocating engine blower of about the same duty. The very high efficiencies for this type of plant was demonstrated by the results of recent tests. In a machine supplied to the Mount Lyell Mining Company, Tasmania, the volume of free air inhaled being 18,100 cubic feet per minute, and delivered at a pressure of 7in. mercury, or 255 adiabatic air horse power.

Steam pressure	140lbs. square inch.
Superheat	70° Fahr.
Vacuum at turbo exhaust	27in.
Barometer	30in.
Revolutions per minute	4100.

Under these conditions of steam and loading the steam consumed per air-horse-power hour, equalled 23·5lbs., equal to an over-all thermal efficiency of 34.3 per cent. Another machine supplied under very similar steam conditions, but of 670 air horse-power, resulted in a steam consumption of 22.5lbs. per air-horse-power, equalling an over-all thermal efficiency of 37.4 per cent. The turbo blower just described was suitable for blast furnace working, or copper converting plants with the normal pressure of about 10lbs. A turbo blower or exhaustor has also been arranged for larger volumes, and at lower pressures, and suitable for copper and other refining and general handling of air or exhausting blast furnaces of gases. Numerous plants for this latter purpose were now running in the large Scotch Iron Works, replacing blowers of the revolving drum type which often caused trouble by expansion or clogging of the rotary drums, neither of which troubles occurred in the turbine system. This system of low pressure blowing was accomplished by several propellers in series on one shaft driven by a high speed turbine, between each propeller was arranged a spiral form of guide vane, and pressures of 100 inch W.G. could be reached by multiplying the number of propellers in series. The first machine of this type was supplied to the Coltness Iron Company, Newmains, in 1904, and had run day and night continuously ever since without any sign of becoming choked by the dust and tarry matter, exhausting about 30,000 cubic feet of gas per minute with a suction capacity of 20in. W.G., and a pressure capacity of 8in. W.G. at the outlet, and was suitable for running up to 8,000 revs. per minute. Four such sets each weighing 4 tons replaced at the above Company's Works, twelve exhausters of Root's type, the drums alone of which weighed over 100 tons. For copper smelting the Rio Tinto Company, Spain, had several of these machines blowing normally 15,000 cubic feet of free air per minute at a pressure of 40ozs. per square inch, and the large number of blower plants of the Root's principle used in Australia for this class of work would make the following test figures of the Rio Tinto machines at variable loads of interest. With a steam pressure of 150, and a vacuum of 28in., running at a speed of 8,000 revs. per minute and inhaling 14,571 cubic feet of free air per minute, and compressing same to a pressure of 5.32in. mercury or an adiabatic air horse-power of 158, the steam consumed per hour equalled 4,657lbs. When running at 6,500 revs. per minute, inhaling 14,000 cubic feet per minute and compressing this volume to 2.21 inches of mercury, or an adiabatic air horse-power of 65, the steam consumed equalled 2,735lbs. per hour.

A rather novel use to which a machine of this description had for the last few years been running at the Glasgow Corporation Gas Works was for pumping town gas down hill, being termed a gas booster. For still larger volumes of air at still lower pressure, namely, a few inches of W.G. and suitable for ventilation of mines, tunnels and other purposes the diameter of the propeller was largely increased and two fans were sometimes arranged in parallel upon one shaft. These fans were installed at a number of collieries in England, exhausting 100,000 to 400,000 cubic feet per minute at a few inches W.G. pressure. The substitution of reciprocating motion for the early rotary principles laid down by Hero some 2000 years ago was, in many respects, the engineers historic parting of the ways from the ideal. It was not generally known that some years ago Mr. Parsons had a small Hero reaction turbine constructed which was wholly incased by a cast iron cylinder connected to a condenser with a back pressure of 1½lbs. absolute. Steam was supplied at a pressure of 100lbs. per square inch, and when running at 5000 revolutions per minute this machine gave out 20 H.P. and the steam consumption was only 40lbs. per B.H.P. per hour.

The advantages of rotary motion had of recent years been grasped and appreciated in the use of rotary driven centrifugal pumps, the low capital cost, simplicity and low cost of maintenance of such a system, even if not actually as efficient as the reciprocating system, possessed advantages which could not well be overlooked. Some ten years ago the turbine was successfully applied for driving centrifugal pumps direct, and two turbo pumping sets were, during the 1902 drought, supplied to the New South Wales Government, and had for the last few months been in operation at the Ryde Pumping Station. The design and capacities of these two sets differed. The first set capable of raising 1½ million gallons per day, 700ft, consisted of three seperate centrifugal pumps in series running at a speed of 3330 revolutions per minute, which on test actually delivered about 1¾ million gallons to a height of over 900ft. at a speed of 3700. The water H.P. when delivering 1½ million gallons per day at 762ft. height being 252 and the steam consumption as tested by Professor Goodman for the New South Wales Government with dry steam at a pressure of 57lbs. per square inch and a vacuum at turbo exhaust of 27·46in., barometer being 29·65in. equalled 7039lbs., or 27·93lbs. per water horse power. These pumps consisted of a double sided runner or impellor 12in. in diameter, revolving in a bushed casing with the usual whirling chamber, and on each side of the pump runners were a pair of small propellers which assisted in feeding the runners. The air pumps were worked from the main turbine shaft by worm reduction gear as also was the small oil pressure pump. The water being pumped was diverted by a throttle valve through the main condenser and a vacuum was regularly obtained at Ryde of from 28·5 to 29in. of mercury. The second set of pumps for raising 10,000,000 gallons per day 80ft. was on the propeller in series principle, termed an augmentor pump and consisted of three separate pumps in series, the general arrangement being similar to the centrifugal set.

On the greatest development of steam turbine work, namely, in Marine Propulsion, he would just mention that the rapidity with which the Parsons marine turbine had come forward, was, he thought, unique in the annals of engineering, and must have even surprised Mr. Parsons, who very early in the turbine's career saw the great future for it on the sea. Ten years ago the experimental launch "Turbinia" was the sole representative of turbine propulsion. The "Turbinia" was at first fitted with one turbine of the Parsons radial flow type, driving one shaft on which was mounted one two bladed propeller, the slip of which amounted to about 50%. By a long series of trials this slip was reduced to 37·5%, by the adoption of three propellers, set about three diameters apart on the single shaft, the revolutions per minute being 1,780 and a speed of $19\frac{3}{4}$ knots was attained. Nine different sets of propellers were tried, but low efficiencies resulted in each case. The single turbine was then replaced by three separate parallel flow units of high, intermediate, and low pressure cylinders, the intermediate being provided with a reversing turbine, each of the three shafts were fitted with three propellers, and it was found by this division of the turbine into three parts of equal power gave a great increase in the propeller efficiency, which Mr. Parsons estimated at about 50%. This change resulted in a speed of 32 knots and later 34 knots was maintained on a trial run from Spithead to Southampton Water.

The total weight of the three turbines and shafting was 3.65 tons which at a speed of $34\frac{1}{2}$ knots equalled 2,300 I.H.P., or 4lbs. per I.H.P. Single propellers on each shaft later superseded the three in series. It would thus be seen from this hasty description of experiments with the "Turbinia," that propeller design for high speeds presented great difficulties to Mr. Parsons. The general formulæ for slow speed propellers when adapted to high speed propellers was found to heat the sea in about the same proportion as they did useful work in propelling the vessel through the water. A great amount of data was collected from the trials of the yacht "Turbinia," and in 1899 an order for a 31 knot turbine propelled destroyer ("Viper") for the British Government was undertaken, and about the same time another order came from Messrs. Armstrong, Whitworth for turbine machinery for a vessel of the same description. The dimensions of these two boats were very alike. The "Viper" being similar to the usual 30-knot destroyers of this class, being 210ft. long, 21ft. beam, and fitted with two complete engines, each divided into high and low pressure cylinders, and each driving two propellers per shaft, or a total of eight propellers. On the official full weight trials and a displacement of 370 tons, she attained a speed of 37 knots or $42\frac{1}{2}$ miles per hour for a half hour's run, representing about 11,500 I.H.P. in a vessel of 370 tons displacement, against about 6,000 I.H.P. developed in the

30-knot destroyers of very similar dimensions and displacement. At a speed of 31 knots the guaranteed coal consumption per I H.P. per hour was 2·5 which was easily reduced to 2·38lbs. The next step in 1900, namely, the order for the Clyde passenger boat "King Edward," being designed with turbine machinery, the success of which resulted in a somewhat larger boat the "Queen Alexandra" being built, which revolutionised the method of propulsion in vessels of their class in which should be included the "Loongana" and cross channel boats. The next most striking test was that between the third-class cruisers "Amethyst" and "Topaz" of equal hull displacement and boiler power, but differing in the method of propulsion. The "Amethyst" being fitted with turbines, and the "Topaze" with ordinary reciprocating engines. The chief dimensions of these boats were as follows :—Length, 360ft.; beam, 40ft.; draught, $14\frac{1}{2}$ft.; displacement, 3,000 tons; and designed for a speed of $21\frac{3}{4}$ knots with 9,000 I.H.P. Trials showed that the very utmost speed possible with the "Topaze" was 22.1 knots, whilst the "Amethyst" easily steamed 23.63 knots. Not only must the additional speed of $1\frac{1}{2}$ knots per hour, or an access of power of over 36 per cent., and resulting in saving of over 10 per cent. of coal per hour, and the corresponding greater steaming range be taken into account, but the air pressure in stoke-hold was half an inch less for the higher speed compared with the "Topaze." To this also have to be added the other advantages of turbines such as decreased weight and height, and greater accuracy of gun-sighting—due to absence of vibration. The plotted curve, Plate XXI., showed the coal consumption at various speeds, it would be noticed that at speeds below $14\frac{1}{2}$ knots, the "Topaze" was the more economical, but at this point the curves crossed, and at speeds of over $14\frac{1}{2}$ knots the advantage was solely with the "Amethyst," at 18 knots—about 20 per cent. advantage, at 20 knots nearly 30 per cent., whilst the saving at full power was over 40 per cent. Subsequently the exhaust steam from the auxiliary engines was passed through the low pressure turbines, and altered the points at which curves crossed to 10 knots. The additional steaming range at 18 knots due to coal saving was 30 per cent., at 20 knots 47 per cent., or in other words, at a speed of 20 knots, each boat having the same amount and quality of coal on board, the turbine-propelled "Amethyst" could steam 3160 miles against the "Topaze" and sister ships, with the reciprocating engines, 2140 miles. These figures were plotted on figure 8, shown in diagram form on Plate XXII. The "Amethyst" propeller slip at 20 knots equalled 14.4 per cent. and at full speed of 23.63 knots equalled 17 per cent. Previous to the foregoing tests, in nearly all cases tank experiments were wholly relied upon to give the necessary propulsive horse power for turbine-driven boats, and these experiments with ships of similar hulls clearly demonstrated the superiority of the turbine without the approximate data of tank experiments. Similar tests were carried out on the Midland Railway steamers "Londonderry" and "Antrim," the former being turbine-driven, and fitted with Parsons' patent vacuum augmentor maintaining a vacuum of $28\frac{1}{2}$ to 29 inches (barometer 30.2). The rise of vacuum due to the augmentor being $1\frac{1}{4}$ to $1\frac{1}{2}$in. of mercury, and the resulting nett saving in steam consumption amounting to about 6 per cent. The next adoption of the turbine was for the Atlantic passenger service, the Allan Line adopting the system in two steamers of 15,000 tons, which were built for a speed of 17 knots, and on trial attained $19\frac{1}{2}$ knots. These boats have been in service since 1905.

In the same year, 1905, the Cunard Company ordered the "Carmania" with turbine machinery of 21,000 H.P., the hull of which was similar in all respects to the "Carronia." The latter was fitted with twin quadruple expansion engines. The "Carmania" had three shafts, and three propellers of 14ft. diameter, revolving at 185 revolutions per minute, and a trial speed of 21 knots was attained against the "Caronia's" 20 knots under similar conditions.

The Express Cunarders now about ready for trial had four shafts, and four propellers revolving at about 160 revolutions per minute. Each of the high pressure turbine drums were 9ft. in diameter, the low pressure drums being 15ft. 8in. in diameter, and having low pressure blades of a maximum length of 22in., making overall diameter of 19ft. 4in. The very excellent results of the turbine-propelled battleship "Dreadnought" confirmed the wisdom of the Admiralty in entirely adopting the Parsons turbine in the present naval programme. With the exception of one class of vessel, practically all types are now represented as being suitable for turbine propulsion. This exception, and which in many respects was the most wished for application, was the ordinary cargo tramp. In vessels of this type the speed and horse power was comparatively low, when compared to the passenger steamers that had been mentioned, and thus the speed of revolution of turbine was low, or the propeller slip became excessive. On the other hand, a spindle of large diameter became necessary with short blades, presenting an annulus of comparatively small area for the passage of small quantity of steam, which should be nearly proportional to the horse power, and thus the result tended towards an inefficient turbine.

An early application of the exhaust or low pressure steam turbine, was, however, expected with this class of boat, the steam expanding from boiler pressure to about atmospheric in the reciprocating engine, and then passing to the low pressure turbines of relatively large diameter, high vane velocity ratio, and long blades to suit the naturally increased volume of steam at low pressures and expanding down to within a half pound of barometer, as against the present marine practice of about 2lbs absolute. This 29in. vacuum was easily reached and fully utilised by the abundance of ever cool circulating water and with the help of the vacuum augmentor. This type of turbine as already pointed out was a most economical heat user, and tramp steamers so fitted would possess the further advantage of having more than one propeller at its service.

APPENDIX.

Since writing the foregoing paper the author has analysed more closely the evolution of the present Parsons' blading, and desires to add the following remarks:—The early blades, or vanes for the parallel flow turbine, were formed by simply taking a gun metal disc say of 6in. diameter, having a hole of $4\frac{1}{2}$in. in the centre, thus making an annular ring the thickness of which was about $\frac{3}{8}$in., and by milling slots at an angle of about 30 to 40 degress on the periphery to a depth of half an inch, a ring of blades having a plain trapezoidal section resulting. Fig. 1, Plate XXIII., showed such a ring, and the vane diagram being as shown in Fig. 2, Plate XXIII. This arrangement, of course, gave torque to the shaft upon which was mounted a series of such wheels, but obviously, the flat edges created wasteful eddies upon the incoming stream by being rudely diverted at the entrance edge, also when the stream flowed over the trailing edge of the vanes of being retarded by the same defect. The aim in the design of a vane was naturally to arrange for minimum friction, shocks, and resulting eddies so that the stream line was as unaffected as possible, but at the same time to direct the course of the steam in the desired direction. The square edged vanes found a parallel in the river punt. The next step was to devise a scheme whereby the entering edge of the vane would be parallel with the stream lines, and be sharp edged at the entrance and exit, and further direct the leaving stream more obliquely. The vanes of the annular ring, shown in Figs. 2 and 3, Plate XXIII., were now cut at a sharper angle, about 25 to 30 degrees, and the entering edge being bent, scraping and filing was resorted to at the exit edge as shown in Fig. 4. This resulted in a more efficient vane and steam passage. Later the idea occurred that the blade shapes might be solid drawn and caulked into dove tailed grooves. The theoretical blade was now possible, and easy curves took the place of the straight faced vane, having as sharp edges as was practically possible. A slight hook at the inlet edge was a feature of the early shapes, the idea being to ease the flow from one row of blades to another, then the thickening up of the back of the blade was so devised as to make when two blades were placed side by side, a nozzle of slightly increasing area towards the outlet. The present vane shape he had already likened to a fish in water, but a perfectly parallel case was the fish endeavouring to swim against a quick running stream but unable to make headway. It was generally believed that a fish travelled through the water at a minimum of loss due to friction and eddy making, no commotion or bubbles being visible when he plied his way, so, to a large extent in the case of the present blades most of the metal was towards the entering edge and a gradual run off to the rear, and although it was impossible to construct a vane with a tail of membrane thickness, as in the case of the fish, they were made with a fine knife edge, as also was the entering edge. The vane was then curved to give an angle which when struck from the tangent of the concave face was about 25 degrees with the dove-tail groove in the turbine spindle or cylinder, and which vane extracted about 70 per cent. of the available heat energy in the stream. Fig. 5, Plate XXIII., showed the latest form, and the hook at the entrance edge as previously mentioned being abandoned. All blades, with the exception of special abnormal types, were of the same shape, and were set in relation to each other in the same proportion. The only consideration which called for different sizes were those of mechanical strength, the blade being considered as a uniformly loaded cantilever beam. With further reference to Parsons exhaust steam turbines, where the supply of steam in this type of turbine was intermittent, a steam accumulator was introduced which acted as a thermal fly-wheel to the turbine supply, storing up the excess heat when the supply was too great for the load, by the steam condensing in the accumulator at about atmospheric pressure, part of this water being immediately re-evaporated to supply the necessary heat to the turbine. If the exhaust steam supplied be altogether discontinued, live steam at boiler pressure is admitted by an automatic reducing valve at about 15lbs. absolute when the pressure in the accumulator was reduced below a predetermined point, thus insuring a steady supply, or as an alternative to the reducing valve, a high pressure turbine was arranged in tandem to take full boiler pressure and do useful work in expanding the steam to a pressure suitable for the low pressure turbine. The Stafford Coal aud Iron Co., England, were utilising their exhaust steam for driving Parsons' turbine blowers of about 400 A.H.P. each.

STEAM CONSUMPTION TEST ON No. 5 TURBO ALTERNATER AT THE CARVILLE POWER HOUSE NEWCASTLE-ON-TYNE, ENGLAND.

After six months Service ended February 17th, 1907.

Test Number.	Duration in Hours.	Mean Calibrated Load in Kilowatts.	STEAM.			Speed Revolutions per Minute.	Vacuum at Turbo exhaust, with 30 inch Barometer.	WATER.		
			Pressure in Pounds.	Temperature at Turbo ° Fah.	Superheat ° Fah.			Total Condensed.	Pounds per Hour.	Pounds per Kilowatt Hour.
1	½	No Load. not excited	180	460	80	1200	28·875″	1,835	3,670	...
2	½	No load. excited	211	453·3	61	1200	28·95″	2,603	5,206	...
3	1	2,192 87	202·4	492·1	103	1200	29·036″	31,836	31,836	14 517
4	1½	4,045·14	197·4	495	108	1200	29·066″	83,972	55,981	13·839
5	1½	5,901	195·8	503·2	117	1200	28·95″	119,182	79,454	13·464
6	½	6,921·8	198·4	505·5	118·5	1200	28·765″	47,390	94,780	13·692
7	1	5,164·07	199·9	508·5	120·5	1200	29·039″	68,180	68,180	13·189
8	3	5,059·38	194·4	477·9	92	1200	29·195″	203,5·9	67,853	13·411

ERRATA.

Page 100, line 11, "5" should read "·5."

Page 100, lines 15 and 16 should read :—

" types, existed in the fact that the heat energy was extracted and performed external work as steam was actually expanding,"

Page 101, line 20, "300" should read "100."

Page 102, line 10, "XV" should read "XVII."

Page 104, line 31, "XVII" should read "XVIII."

Page 105, lines 35-6, should read :—

" The above figures being the result of actual tests upon a 1500 K.W. set. A vacuum of 29in., mercury barometer 30in., was"

Page 106, lines 8 and 9, should read :—

" water to the amount of steam condensed was about from 50, to 55 to one, and the percentage to total power generated, used"

Page 107, line 21, should read :—

electricity, if circulating water be available in sufficient quanti-

Page 108, line 29, "Plate XV" should read "(No. 1)"

Page 109, line 1, should read :—

" field effect being abnormally large, and plane of commutation,'

Page 109, line 11, should read :—

"current upon the field. A steam cylinder, fitted with piston and'

Page 109, line 20, should read :—

" round the armature, which would counteract the distorting"

Page 109, line 28, should read :—

" distortion of the field, provided a sufficient counter E.M.F."

Page 110, line 14, should read :—

" row of fans were the guide or air spin extracting vanes, which"

Page 112, line 8, should read :—

" K.W. hour, thus dispensing with the sometimes misleading"

Page 113, line 22, should read :—

" air horse power with"