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President—J. FORTESCUE FLANNERY, ESQ., M.P.

Volume IX.

SIXTY-NINTH PAPER

(OF TRANSACTIONS)

THE PROGRESS OF THE STEAM TURBINE.

BY

The Hon. C. A. PARSONS

(MEMBER).

READ AT

THE INSTITUTE PREMISES, 58 ROMFORD ROAD, STRATFORD,

ON MONDAY, 11TH OCTOBER, 1897.

DISCUSSION CONTINUED

ON MONDAY, 25TH OCTOBER, 1897.

PREFACE.

58 ROMFORD ROAD,

STRATFORD, E.

October 25th, 1897.

A meeting of the Institute of Marine Engineers was held here this evening, when a Paper read by the Hon. C. A. PARSONS at the meeting held on Monday, October 11th, was further discussed.

The meeting on the 11th was presided over by Mr. J. FORTESCUE FLANNERY, M.P. (President), and this evening the chair was occupied by Mr. J. MACFARLANE GRAY (Vice-President).

The Paper and Discussion follow.

JAS. ADAMSON,

Hon. Secretary.

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THE PROGRESS OF THE STEAM TURBINE.

BY THE HON. C. A. PARSONS.

READ AT 58 ROMFORD ROAD, STRATFORD, ON MONDAY, 11TH OCTOBER, 1897.

ADJOURNED DISCUSSION ON MONDAY, 25TH OCTOBER, 1897.

READ AT THE ARTS SOCIETY HALL, SOUTHAMPTON, ON WEDNESDAY, 17TH NOVEMBER, 1897.

READ ALSO AT THE UNIVERSITY COLLEGE, CARDIFF.

The earliest notices of heat engines are found in the "Pneumatics" of Hero of Alexandria, which dates from the year 200 B.C. One of the steam or motive power engines there mentioned is the Æolipiles, a steam reaction engine consisting of a spherical boiler pivoted on a central axis, beneath which is placed a flame. The steam escapes by bent pipes facing tangentially in opposite directions at opposite ends of a diameter perpendicular to the axis.

The globe revolves by reaction of the escaping steam, just as a Barker mill is driven by escaping water.

No practical or useful steam engine appears to have been made on this or any analogous principle until the year 1884, though many attempts seem to have been made on more or less crude lines. Meantime the piston engine of Papin, Savery, Newcomen and Watts has been developed during the last two hundred years, and by its general use has revolutionised the means of transit, and tended to vastly increase the productive power of labour generally.

The want of a fast-running engine for driving dynamos presented an immediate field for the application and development of a suitable steam turbine engine. The advantages of a steady running engine having no reciprocating parts, of small size and extreme lightness, were sufficiently obvious, provided that fairly economical results as to steam consumption could be realised. The highly economical results obtained from water turbines gave hopes that, provided suitable conditions could be arranged, similar efficiencies would be obtained with steam as with water; and assuming this to be possible it would naturally follow after taking all other losses into account that the steam turbine would be more economical in steam than the piston engine.

These possibilities and the interest of applying a practically new method for motive power purposes led us to build an experimental engine of ten horse-power, coupled directly to a dynamo. For practical reasons it was, however, necessary to keep the speed of rotation of the turbine as low as possible, and also to construct the dynamo to run as fast as possible, so as to couple the turbine directly to it; and in order to obtain the necessary conditions for steam economy the turbine was made what is called compound, or, in other words, a series of successive turbine wheels were set one after the other on the same spindle, so that the steam passing through them one after the other—the fall in pressure being spread over the series of turbines—

should be gradual, and the velocity of the steam nowhere more than was desirable for obtaining a high efficiency for each turbine of the series.

The turbine motor consists of a cylindrical case with rings of inwardly projecting guide blades, within which revolves a concentric shaft with rings of outwardly projecting blades. The rings of blades on the cylinder nearly touch the shaft, and the rings of blades on the shaft lie between those on the case and nearly touch the case. It will be seen, therefore, that there is left between the shaft and the case an annular space, which is fitted with alternate rings of fixed and moving blades. Steam entering around the shaft passes first through a ring of fixed guide blades by which it is projected in a rotational direction upon the succeeding ring of moving blades, imparting to them a rotational force ; it is then thrown back upon the succeeding ring of guide blades and the reaction increases the rotational force. The same process takes place at each of the successive rings of guide and moving blades. The energy to give the steam its high rotational velocity at each successive ring is supplied by the drop in pressure, and the steam expands gradually by small increments. In a moderate size turbo-motor there may be from thirty to eighty successive rings, and when the steam arrives at the last ring the expansion has been completed. On the left side of the steam inlet are the dummy or rotating pistons, which are fixed to and rotate with the shaft. On their outsides are grooves and rings which project into corresponding grooves in the case. By means of the thrust bearing of the motor, the longitudinal position of the shaft is adjusted, and grooves and projecting rings kept nearly touching, so as to make a practically tight joint. The object of these pistons is to steam balance the shaft and relieve end pressure on the thrust bearing.

With compound condensing turbines a steam efficiency comparable with the best compound or triple-expansion condensing engines was at length reached, and it was then resolved to test the application of the turbine to the propulsion of ships, for which purpose it seemed well suited, provided that as good an efficiency could be obtained from fast running screw propellers as with ordinary ones.

In January, 1894, a syndicate was formed to test thoroughly the application of the compound steam turbine to marine propulsion, and a boat was designed for this purpose. In view of the large amount of alteration that would probably be required before a satisfactory issue was reached, and the large amount of time and expense necessarily involved, it was decided to keep the dimensions as small as possible, but not so small as to preclude the possibility of reaching an unprecedented rate of speed, should all the parts work as satisfactorily as was anticipated.

The fulfilment of these anticipations was, however, much delayed, and almost frustrated, by a difficulty which, though foreseen, proved to be of a much more serious character than was anticipated. This difficulty was that termed by Mr. R. E. Froude "the cavitation of the water," or, in other words, the hollowing out of vacuous spaces by the blade of the screw; and this pitfall for the designers of screws for very fast vessels, though indicated by theory to exist, came upon us in the case of our very fast running screw, taxed beyond the usual extent, in its most aggravated form.

The *Turbinia*—as the boat is named—is 100 ft. in length, 9 ft. beam, and 44½ tons displacement. The original turbine engine fitted in her was designed to develop upwards of 1,500 actual horse-power at a speed of 2,500 revolutions per minute. The boiler is of the water-tube type for 225 lbs. per square inch working pressure with large steam space and large return water legs, and with a total heating surface of 1,100 sq. ft., and a grate surface of 42 sq. ft.; two firing doors are provided, one at each end. The stokeholds are closed, and the draught furnished by a fan coupled directly to the engine shaft. The condenser is of large size, having 4,200 sq. ft. of cooling surface; the circulating water is fed by scoops, which are hinged and reversible, so that a complete reversal of the flow of water can be obtained should the tubes become choked. The auxiliary machinery consists of main air pump and spare air pump, auxiliary circulating pump, main and spare feed pumps, main and spare oil pumps, also the usual bilge ejectors; the fresh-water tank and hotwell contain about 250 gallons. The hull is built of steel plate, of thickness varying from $\frac{3}{16}$ in. in the bottom to $\frac{1}{16}$ in. in the sides near the stern, and is divided into five spaces by watertight bulkheads. The deck is of steel plate, $\frac{1}{16}$ in. to $\frac{1}{8}$ in. in thickness. The approximate weights are—

Main engines	3 tons 13 cwts.
Total weight of machinery and boiler, screws and shafting, tanks, &c.... ...	22 tons
Weight of hull complete	15 tons
Coal and water	$7\frac{1}{2}$ tons
Total displacement	$44\frac{1}{2}$ tons

Trials were made with screws of various patterns, but the results were unsatisfactory, and it was apparent that a great loss of power was taking place in the screw. Owing to the cavitation of the water, the matter was then thoroughly investigated, theoretically and experimentally, and it was finally determined (as the best course to overcome the difficulty) to subdivide the turbine motor into several separate compound turbines. Consequently the single compound turbine engine was removed from the boat and replaced by three separate compound turbines, directly coupled to three screw shafts, working in series on the steam, the turbines being the high pressure, intermediate, and low pressure, and designed for a complete expansion of the steam of one hundred-fold, each turbine exerting approximately one-third of the whole power developed, the three new screw shafts being of reduced scantling.

By this change the power delivered to each screw shaft was reduced to one-third, while the division of the engine into three was favourable to the compactness and efficient working of the turbines. The total weight of engines and the speed of revolution remained the same as before. The effect on the screws was to reduce their scantling, and to bring their conditions of working closer to those of ordinary practice. The thrust of the propellers is balanced by steam pressure in the motors.

The rest of the machinery remains the same, though some changes in arrangement were necessary.

The usual lignum-vitæ bearings are used for the screw shafts.

The engine cylinders lie closely to the bottom of the boat, and are bolted directly to small seatings on the frames of sufficient strength to take the thrust of the propellers.

The centre of gravity of the machinery is consequently much lower than with ordinary engines.

At all speeds the boat travels with an almost complete absence of vibration, and the steady flow of steam to the motors appears to reduce the liability to priming; at any rate, no sign of this has yet occurred with ordinary Newcastle town water. No distilling apparatus has yet been fitted.

The boat has been run at nearly full speed in rough water, and no evidence of gyroscopic action has been observable, a result which would be anticipated from the known small amount of these forces under actual conditions; indeed, the *Turbinia* has so far proved herself an excellent sea boat.

The oiling of the main engines is carried on automatically under a pressure of 10 lbs. per square inch by a small pump worked off the air-pump engine; a small independent duplex oil pump is also fitted as standby. The main engines require practically no attendance beyond the regulation of a small amount of live steam to pack the glands and keep the vacuum good.

The advantages claimed for the compound steam turbine over ordinary engines may be summarised as follows :

1. Increased speed.
2. Increased economy of steam.
3. Increased carrying power of vessel.
4. Increased facilities for navigating shallow waters.
5. Increased stability of vessel.
6. Increased safety to machinery for war purposes.
7. Reduced weight of machinery.
8. Reduced space occupied by machinery.
9. Reduced initial cost.
10. Reduced cost of attendance on machinery.
11. Diminished cost of upkeep of machinery.
12. Largely reduced vibration.
13. Reduced size and weight of screw propellers and shafting.

For the purpose of going astern a small reverse turbine is used. This turbine has hitherto been of an inefficient form and has constituted a part of the low-pressure motor. The power consequently that has been developed has been very small, and has given an astern speed of three knots. A powerful reversing motor is, however, now being fitted of similar construction to the ahead motors; its weight is three quarters of a ton, and it is estimated that the astern speed will then exceed 10 knots. The turbine will be permanently connected to the central propeller shaft, and its casing will be connected to the condenser, and the amount of power spent in turning it when going ahead will be insignificant.

In June last the *Turbinia* steamed from the Tyne to Harwich at the average speed of 12 knots, and from Harwich to Cowes at the average speed of 16 knots. During and after the week of the Review she was run at speeds up to $34\frac{1}{2}$ knots, estimated from the curve of steam pressure and speed, and ample steam is provided by the boiler at the highest speeds hitherto reached. The steam consumption at $32\frac{3}{4}$ knots is estimated to be 14·5 lbs. per I.H.P. per hour, and at $34\frac{1}{2}$ knots, as deduced from the prolongation of the curves, it appears to be $13\frac{3}{4}$ lbs. per I.H.P. per hour.

In April a series of trials were made by Professor J. A. Ewing, and the following paragraphs are extracts from his report, which comprise, I believe, the most complete set of investigations made on the working of a small fast vessel.

"The mechanical friction of the turbines is particularly small, and the work spent on friction is not materially increased by increasing the range of expansion. This allows the steam to be profitably expanded much further than would be useful or even practicable in an engine of the ordinary kind. Apart from questions of friction, the addition of weight and bulk to allow for this extended expansion would be enormous in the ordinary engine; in the turbine it is very moderate. Steam is expanded nearly two hundredfold in the *Turbinia*, and this is accomplished with engines which are much lighter than reciprocating engines of the same power, although in these the expansion would be much less complete.

"I was present during trials on April 9th, 10th, 12th and 14th, along with my assistant Mr. Stanley Dunkerley, now Professor of Applied Mechanics, Royal Naval College, Greenwich. Further trials were made on April 21st and 23rd, when Mr. Dunkerley attended and made observations on my behalf. On April 13th the weather was too bad to allow sea trials to go on, and the day was spent in calibrating the water meters which were used to determine the amount of feed water supplied to the boiler.

"Rough weather was met with in some of the trials, and I had the opportunity of seeing that the *Turbinia* is for her size a good sea boat. The machinery worked with perfect smoothness, the screws did not race, and the bearings remained perfectly cool throughout. From first to last during the whole of the trials there was no hitch whatever or difficulty of any kind in the action of the turbines. Some twenty trial runs in all were made under various conditions as to speed, the range of speeds tested extending from $6\frac{3}{4}$ knots to $32\frac{3}{4}$ knots. In a large number of the trials observations were made of the consumption of steam, the feed water being measured by meter. In some of the later trials a Kent's reciprocating meter was also used, to give a more trustworthy measurement of the comparatively small consumption at low speeds, and this meter was also tested by delivery from a tank. Its measurements were found to agree closely with those of the Siemens meters, even at the lower limit of speed.

"Full speed trials were made on April 10th, the boat having then been in the water for fully a fortnight. Two successive runs on the measured mile, in opposite directions, in smooth water, and at the slack of the tide, gave the following data :

	First run.	Second run.
Time on the mile	$109\frac{4}{5}$ secs.	110 secs.
Corresponding speed in knots ...	32·79	32·73
Mean speed in knots	32·76	
Revolutions per minute of high-pressure and intermediate shafts		2,230
Revolutions per minute of low-pressure shaft ...		2,000
Steam pressure in boiler by gauge ...	210 lbs. per sq. in.	
Steam pressure on admission to high-pressure turbine	157 ,,	
Greatest pressure in stokehold, by water gauge ...		$7\frac{1}{4}$ in.

"The speed reached during this trial, 32·76 knots in the mean, is, I believe, the highest recorded for any vessel. It is greatly in excess of the speed hitherto reached in boats so small as the *Turbinia*. Steam was blowing-off at the safety-valve during the trial, showing that more might have been supplied. The drop in pressure of fully 50 lbs. between the boiler and the turbine could easily be reduced by using a larger steam pipe. If, for instance, the drop were halved, it may be anticipated that at least $1\frac{1}{2}$ knot would be added to the speed.

"It is interesting to compare the results with those that are obtained in high-speed boats using engines of the ordinary type. The propulsive co-efficient, or ratio of propulsive to indicated horse-power, in such boats appears to be about 0·55 or 0·6, and their consumption of steam (at full power) is not in general less than 18 lbs. per I.H.P. hour. Taking the most favourable co-efficient, this would correspond to 30 lbs. of steam per propulsive horse-power hour, as against the 29 lbs. found in these trials of the *Turbinia*.

"It is clear then that the exceptional speed developed in the *Turbinia* has been achieved without sacrifice of economy and that the substitution of turbines driving high-speed screws in place of reciprocating engines driving screws of much more moderate speed is not attended with increased consumption of steam as far as fast running is concerned.

"A direct comparison such as here made of feed-water with work spent in overcoming resistance is the most satisfactory test that can be applied, for it takes account of the efficiency of propellers as well as motors, and is independent of any estimate of the propulsive co-efficient in a boat driven by turbines. The power may be much reduced with but little increase in consumption of steam per P.H.P. hour. The turbines are remarkably handy and allow sudden starts to be made with impunity. I made experiments to see how rapidly speed could be got up. Starting from rest, a speed of rotation corresponding to 28 knots was acquired in 20 seconds after the signal was given to open the stop valve.

"A conspicuous feature is the absence of vibration, due to the absence of reciprocating parts and the perfect balance of the turbines. The contrast in this respect with ordinary high-speed boats is most striking. An incidental merit of the turbine is that it needs no internal lubrication, and the oil which circulates through the bearings has no opportunity of mixing with the steam. The advantage of having the condensed steam free of oil will be particularly felt in cases where water-tube boilers are used.

"It may be confidently expected that the results obtained in this experimental steamer will be surpassed; but taking the results as they stand it is clear that the substitution of turbines will allow an immense reduction to be effected in the weight and size of marine engines to obtain the same power; and, further, that this may be done without increasing the consumption of coal. For naval purposes it allows of the crowding into small craft of an amount of engine-power such as has hitherto been impracticable, with the attainment of correspondingly increased speed.

"The general impression I have formed from the trials is entirely favourable to the prospects of this novel method of marine propulsion. The mechanical simplicity of the turbines and the absence of exposed parts and of working joints will go far to secure them against breakdown. They have a distinct advantage over ordinary engines in first cost, in probable cost of maintenance, and in cost of attendance, as well as in bulk, in weight, and in freedom from vibration. There appears no reason to doubt that in regular use at sea their running will be as consistently steady and good in every way as it has been throughout these trials.

"The application of steam turbines to torpedo boats, destroyers, gunboats and cruisers, is to be anticipated from their unique capacity for developing great power and high speed with light and compact machinery. Apart, however, from these uses it appears to me highly probable that they will in time be adopted in the mercantile marine. The conditions in a fast passenger steamer are favourable to the economical application of steam turbines, and in such steamers the smoothness of their running will be a strong recommendation. I see no drawback likely to detract from the advantages which they plainly possess."

In conclusion, the application of the steam turbine principle to fast ships in general, including passenger vessels, Atlantic liners, and ships of war, would appear to present no special difficulties. It may be said, generally speaking, that the larger the scale on which the engines are made the simpler is the construction, the higher the steam efficiency, and the lower the speed of rotation. In the sizes hitherto constructed (the largest being the engines of the *Turbinia*) this has been found to be the case. In applying turbine engines to a large passenger vessel or warship of, say, 30,000 I.H.P., probably four screw shafts with two screws on each shaft would be adopted; each of the four shafts would be driven by one compound turbine at a rate of between 400 and 700 revolutions per minute, and the turbines would consist of the high pressure, the intermediate, and two low pressure, each turbine developing approximately one quarter of the total power. The screw propellers would be about one half the diameter of ordinary twin-screw propellers and the aggregate blade area would approximate closely to ordinary practice. With such engines, the consumption of steam per propulsive horse-power would probably be less than that found in the mercantile marine, and considerably less than that found in engines of war vessels, where space and other conditions must necessarily be considered. There is also no limitation in steam pressure in the case of turbines other than those imposed by the boilers, and it is probable that in conjunction with water-tube boilers higher pressures than those at present usual would be generally adopted. With turbine engines in passenger vessels there would arise no questions of vibration from machinery or propellers, and in the event of one screw shaft or one motor becoming disabled the one affected can be more readily taken out of action than is the case with ordinary engines, and the parts being lighter can be more easily dealt with by the staff on board; thus the liability to serious breakdown is considerably reduced.

DISCUSSION

ON THE

PROGRESS OF THE STEAM TURBINE

(PAPER BY THE HON. C. A. PARSONS)

AT

58 ROMFORD ROAD, STRATFORD,

MONDAY, OCTOBER 11*th*, 1897.

CHAIRMAN:

THE PRESIDENT.

The PRESIDENT: The subject is now open for discussion, and I invite you to begin at once.

Mr. J. MACFARLANE GRAY (Vice-President) said that, in order to start the discussion, he would just say that in the presence of the author no other person had any right to make any remarks upon this subject. He did not think that anybody knew anything about this machine, except Mr. Parsons himself, who knew all about it, and the best thing those present could do was to ask questions now they had the opportunity. Mr. Parsons had had faith in this turbine; he had stuck to it, and now had astonished all engineers by the machine he had produced. There must be many points as to which gentlemen present would like further information, and Mr. Parsons was prepared to tell them all about it. The ingenuity which Mr. Parsons had applied to this machine was worthy of the admiration of every engineer; and he was reported to have made a practical turbine machine for electrical work to make 18,000 revolutions a minute.

Mr. JOY asked Mr. Parsons how the indicated horse-power of his engine was ascertained? How would he take an indicator diagram?

Mr. PARSONS replied that it was not possible to take an indicator diagram of an engine like that of the *Turbinia*, and it was a little difficult to explain clearly how the figures given were ascertained. But, stated shortly, the indicated horse-power was ascertained by a comparison of the speed of the ship with her calculated resistance, checked by the consumption of water within a given time. It was very easy to get at the efficiency of a turbine engine when it was connected to a dynamo.

At the request of Mr. Macfarlane Gray, Mr. PARSONS further explained and illustrated, by means of a sketch on the blackboard, how loss of power resulted owing to cavitation of the water, when the screw revolved at very high speeds; and said that according to the experiments carried out by Mr. Thorneycroft and Mr. Sydney Barnaby it was deduced by them that when the mean pressure upon the projected area of the screw blades exceeded $11\frac{1}{2}$ lbs. this effect of cavitation began. In the case of the *Turbinia* they at first experienced great loss of power, due to the cavitation of the water, but by dividing the motor into a number of separate motors they were able to reduce the mean pressure of the water upon the propeller blades and avoid the cavitation entirely, and so secure a good efficiency of the propellers at the same angular speed as before.

The PRESIDENT: Do I understand that in the case of the *Turbinia* there are three propeller shafts and three screws on each shaft?

Mr. PARSONS: Yes.

The PRESIDENT: At what intervals?

Mr. Parsons: Three diameters. The diameter is 18 inches.

The President: Does the pitch of the succeeding screws increase?

Mr. Parsons: No, they are all uniform at present.

The President: Have you tried increasing the pitch?

Mr. Parsons: Yes, we tried it and there was a slight advantage, but it increased the cost of the screws, and all the later sets of trial screws were of uniform pitch.

Mr. Macfarlane Gray asked if the range or area of the projecting blades in the motor was the same all along.

Mr. Parsons: No, they increase gradually from the inlet to the exhaust.

Mr. J. R. Ruthven (Member of Council): There is one remark that fell from Mr. Parsons in the course of his reply—I think to Mr. Joy—to which I should like to draw attention, and that is as regards the propulsive efficiency of this engine. I think he estimated it at between 55 and 60 per cent. I believe that, according to the late Mr. Froude, 40 per cent. is a very good efficiency for the total machinery on board ship. I should like to know how the difference arises in this case—whether it is explained by the improvement in the machinery?

Mr. Parsons: I believe the 40 per cent. was obtained with the *Greyhound*, but she was an old ship and coppered. Moreover, I think she had very old and heavy engines. I believe that about 50 or 60 per cent.

is the general result in modern torpedo-boat practice, and has been determined from the results of many trials.

The PRESIDENT then observed that there was one gentleman present who was historically connected with the application of turbines for marine propulsion, although in his case the turbine was applied directly to the water, while in the engine before them the turbine was applied to the steam. Nothing could be more interesting than the presence on this occasion of an engineer who had had so many years' experience of what had happened in relation to this subject, covering two generations. He hoped he was not taking a liberty if he asked Mr. Ruthven, senior, to favour the meeting with a few remarks on the paper before them.

Mr. RUTHVEN, senior, said that this was the first time he had seen the arrangement and design of the steam turbine of Mr. Parsons, and he did not understand anything at all about it, but there did not appear to be any connection between this engine and water turbines.

Mr. NEWALL (Member): This is quite a new thing to me, and, like Mr. Sage, I must ask to be excused from discussing it. However, it looks to me like the thin end of the wedge, in this respect, that the machinery for driving ships is being remarkably cut down in weight, and, broadly, it looks as though the day is approaching when the commander may have hold of the handle on the bridge, and thus be able to take direct control of the machinery. When first put on board ship, propelling machinery took up a lot of room and had a lot of moving parts. Every cylinder, for instance, had at least ten parts, which necessitated a number of connecting pins. When they found out the importance of saving coal and space, engineers began to cut away parts of their machinery. First of all one eccentric was thrown overboard, then the number of joints was reduced, then we had an improved link motion; indeed, almost every day brought forth something new. Mr. Parsons has reduced the marine engine down to one part—that is to say, from the propeller to the boiler there is only one moving part—so that I am afraid we shall all be out of work soon. There is a great deal of credit due to Mr. Parsons for this machine, but as it stands it looks as if it is a machine that the commander is going to take control of. We have to look at these things as evidence of progress; but to-day we almost wonder how our forefathers lived because they did not do things so properly, and yet they used to make the most of what they had. As many joints as they could get, and as much ship room as they could take up, was apparently their object, and plenty of funnel. With regard to the machine that has been explained to us to-night I cannot say anything; but from the standpoint of a marine engineer I must say that it looks like reducing weights down pretty low; and I hope we shall still be able to keep our hands and minds up to the mark necessary to follow such a machine as the one under discussion.

Mr. H. C. WILSON (Member) asked what kind of water-tube boiler Mr. Parsons used on the *Turbinia*, and if any difficulty was experienced in regard to air pressure in the stokehold.

Mr. RICHARDSON (Member of Council) observed that the cylindrical chamber containing the blades seemed a very likely place for an accident to happen; and he should like to know whether in the event of an accident occurring at sea the parts could be easily taken to pieces for repairs. He should also like to know the clearance between the edges of the revolving rings of blades and the inside of the cylindrical case.

Mr. PARSONS: The cylinders of the motors are made in halves and bolted together so that the covers can be easily lifted and the turbines examined; the clearances vary from 1-25th to 1-10th of an inch; there is no contact or rubbing whatever within the motors, and no oil or grease comes into contact with the steam.

Mr. DREWRY (Member) said it appeared to him that two great features of this engine were that there were equal temperatures and no dead centres.

Mr. WALKER: I have had a slight experience with a Parsons' engine in driving an electric-light engine; and, with reference to Mr. Richardson's question, it may be interesting to the meeting to know what happened when an accident occurred. Before, however, referring to the accident, I must draw Mr. Parsons' attention to the fact that in the drawing of the machine which he has shown us to-night there is no strainer for straining the steam. In the turbine engine that I had to do with there was a wire gauze cage for straining the steam, and by some means this cage got blown away; some dirt got into the blades, and about a third of the first lot of blades carried away. The engine was subsequently opened up and examined, and the broken pieces cleared away; and great anxiety was felt as to whether the machine would work the lights the following night. Another strainer was put on and the engine set to work, and it was found to work as efficiently as before and to maintain the same number of lights, although, as I have said, about a third of the first lot of blades had been broken off.

Mr. MACFARLANE GRAY: Did the machine continue running with the broken pieces in it, or did you have to stop it when the accident occurred?

Mr. WALKER: No, the machine went on running with the broken pieces in it, but the light was bad. New rings were afterwards sent for, and they were fitted in the places of those that had been broken.

Mr. John Adamson (Member of Council) inquired if Mr. Parsons found any difficulty in fixing the blades so that they would not shift.

Mr. Parsons: They are keyed to the shaft and caulked, and cannot shift.

Mr. J. H. Thomson (Chairman of Council) expressed regret that it had not been found possible to have this paper printed before the present meeting. Had members been able to obtain copies beforehand, he had no doubt that there would have been a better discussion. The subject was new to most of them, and they were not prepared to get up and speak upon it off-hand. However, before their next meeting, they would doubtless have the paper in print, and they would then, he thought, be able to deal with it in a more satisfactory manner. In the course of this discussion reference had been made to the kind of water-tube boiler used on the *Turbinia*, but it seemed to him that for the purposes of this paper it did not concern them how the steam was generated. What they had to consider was how the steam was to be used. Mr. Richardson had mentioned the difficulty that might arise in effecting repairs, and another gentleman had given them his experience in the case of an accident, which was very interesting. That gentleman showed that if even they did away with one of the blades the efficiency of the machine was not very much impaired, and that they could fall back upon the others. With reference to the straining of the steam, he should think that the use of a fine wire gauze, with steam at 160 lbs. per square inch, was a source of danger to the machine, because it seemed to him that there was a great risk of the wire gauze carrying away and getting among the collars. He should fancy that a kind of trap would answer better than a strainer. He noticed that in the course of the paper the author mentioned the vacuum; but where in the drawing before them was the air pump?

Mr. PARSONS: There is no novelty about the air pump, which is worked by a separate engine of the ordinary type.

Mr. THOMSON: The air pump is worked by a separate engine altogether?

Mr. PARSONS: Yes.

Mr. THOMSON: Well, it is important to have elicited that information, and it is only by asking questions that we find out these things.

Mr. WILLIAMS (Member) said that if, as had been remarked by one of the speakers, they were decreasing the number of pieces in the marine engine they were certainly increasing the number of pieces in the boiler. It was now over nine years since he saw a Parsons' turbine engine used for electric lighting on board an Atlantic liner. That engine ran efficiently and attracted great attention; and there was an engineer on board who predicted all that Mr. Parsons had told them that evening about the use of the turbine for marine propulsion. That engineer was now the chief of one of the crack Atlantic liners. There was one suggestion that he (Mr. Williams) would throw out for Mr. Parsons' consideration, and that was whether he had tried compounding this machine in a sense somewhat different from that in which the term compounding was generally used. Could Mr. Parsons, after passing the high-pressure steam through the turbine, work it through an ordinary engine? As the author had been so successful in developing the type of engine before them, it appeared possible that the same mechanical skill and ingenuity might be displayed in accomplishing, or at any rate trying, something in the direction he had indicated. Personally, he felt very much obliged to Mr. Parsons for reading such an interesting and valuable paper.

Mr. SWIFT (Member) asked if there was any real advantage in having steps in the cylindrical case containing the blades, or whether there might not be parabolic curves to correspond with the expansion of the steam.

Mr. PARSONS replied that, in answer to Mr. Swift's question, there would be practically no gain in economy of steam arising from placing the turbine blades on a cone or parabolic surface of revolution, while the cost of construction would be much increased. The placing of the turbine on cylinders of different diameters resulted in a nearly perfect distribution of the steam.

Mr. SMITH asked if Mr. Parsons had tried any experiments with regard to skin friction. If they were going to increase the speed of vessels to such an extent, the subject of skin friction ought to have the best attention of engineers. Would it not be desirable for some of our engineering firms to give this matter of skin friction their undivided attention ?

Mr. PARSONS then replied to the questions and criticisms of the various speakers, and illustrated many of his replies by references to the large drawing of his engine exhibited on the wall. He explained how, with a steam turbine, it was possible to expand a great deal further than with a reciprocating engine. The water-tube boiler on the *Turbinia* was a boiler of the ordinary straight-tube type, with half-inch tubes, but with very large water legs at each end of the boiler. It was not a very light boiler, and there was not much difference between it and one of Yarrow's or Thorneycroft's. With regard to the question of breakdown, the blades were originally made in the form of rings with teeth cut on their periphery, and they had a good many cases of breakdown. But now the blades were made of wire, so that it was practically impossible to have a flaw in them, and accidents were very rare. The weight of the

Turbinia's engines was about one third of that of an ordinary engine of the same power. In reply to Mr. Williams' question, he might say that some time ago he had patented the combination of a reciprocating engine with a turbine; the former expanded the steam down to nearly the atmospheric pressure, and the turbine took up and completed the expansion down to the condenser pressure—a part of the expansion which could not be utilised in any reciprocating engine. With such a combination very excellent results might be anticipated.

The PRESIDENT: I have now the very pleasant duty of moving from the chair a very hearty vote of thanks to Mr. Parsons for the remarkable paper which he has given us upon a remarkable subject. It has always been considered that an engineer, if he be a good engineer, must be a Scotchman; occasionally it has been admitted that he may be an Englishman; but never until to-night, I think, have we had fully proved to us that an engineer of surpassing genius may be an Irishman. But when we remember that Mr. Parsons is the son of that great Lord Rosse, who, by the telescope which he constructed two or three generations ago, made astronomical discoveries possible which before were impossible, and showed such remarkable mechanical genius in the construction of that telescope, we see that, after all, there is much truth in the theory of heredity in engineering genius and the power of construction, as well as in other matters. I do not think that anyone who was present at the Naval Review in June last, and who saw the *Turbinia*, as I did, running in and out between the numerous vessels at anchor, could doubt for a moment that something entirely novel, both in speed and in manœuvring ability, had been disclosed to the world. As a matter of practical business, I have from day to day found shipowners, who rely upon my opinion, asking me whether or not they should hold their hands a little in ordering steamers, because there seems to be a general idea that a new era of development, and a new sphere of improvement rendering present vessels obsolete, is dawning upon them. When we find business men having thoughts of that kind, and making inquiries of that nature, there can be no doubt whatever that this system of propulsion by a rotary steam engine is seizing hold of the minds of men who will have much to do with the ultimate adoption of it. In the first instance, we must proceed by the application of this principle to small vessels; but the question will be whether, in the course of development, this new system may not possibly be applicable to large vessels, and may therefore become suitable for use practically in large cargo and passenger ships. No one who has well considered the action of the reciprocating engine can doubt that there must be a waste of power in the reversal of momentum of all the moving parts twice in each revolution; for although, strictly speaking, there is theoretically no loss of energy in reversal of momentum *per se*, practically the effort of retardation occurs when the crank pin is near to or else actually traversing the dead arc of its motion, and the energy then being transferred is obliterated by friction. Take, for example, an engine running at the comparatively low speed of sixty revolutions a minute; the reciprocating parts, even at that speed, must change their direction of motion twice in each second. The loss of power associated with this change of motion is, in the case of the rotary engine now before us, entirely removed, and an important advantage must arise from this cause. Whether or not this system can be adapted to ordinary vessels of large size will greatly depend upon the question of the speed at which they may be driven. At present, as I understand, Mr. Parsons has found as the result of his experience that no lower speed than 15 knots would fully develop the economy of the system. You will perceive that where you have a very high speed of revolutions in the engine this system of expansion may lend itself to taking great advantage of that speed. All economy in the use of steam in any engine must arise from expansion. Here we have a system which lends itself, as no other system of compound cylinders would lend itself, to expansion in great ratios, an expansion equal to two hundredfold in extreme cases; and with such power of expansion as that we have the possibility of taking the fullest advantage of high boiler pressures. Mr. Parsons has been experimenting since 1884—that is to say, now for 13 or 14 years—and it is only now that he has succeeded in bringing this beautiful machine to the state of practical development in which it at present stands. I myself remember an experience with a Turbo motor, as it was then called, for driving an electric lighting plant in an early oil-tank vessel that used to run to London, and we found that that engine ran pretty well, but it was not economical in steam. There was then, however, no application of expansion; but now by this beautiful system we have the possibility of great expansion, and therefore the possibility of getting the best result out of the engine. One notes with interest the very great lightness of this machinery in proportion to the power developed; and in this we have one of the reasons why the *Turbinia*, although of such small dimensions, is, absolutely, as I understand, the very fastest vessel afloat. I learn from Mr. Parsons that he is now fitting the *Turbinia* with a stern-going engine more powerful than the present one, which will give her a speed of ten knots astern, as compared with three knots as at present; and that he is also intending to construct a larger boat of the torpedo-boat destroyer type, which it is estimated may be capable of going from 36 to 40 knots an hour. When we recollect the very small size of the *Turbinia*, and compare her with a vessel of the size I have indicated, we see that it is not unreasonable to expect that, if a vessel of the length of the *Turbinia* can be driven at a speed of 33¾ knots an hour, a vessel of the larger size may be driven at a speed of from three to seven or eight knots faster. Then we shall have, no doubt, in due course—and I hope that I may have the opportunity of being associated with so great an improvement—the application of this system to some quick passenger vessel of larger size than the *Turbinia* and capable of keeping the sea at all times. We have all, I am sure, the utmost satisfaction in giving Mr. Parsons our heartiest thanks for this interesting and valuable paper, which discloses to us an entirely new field of observation, and which has led even the most experienced among the engineers present to reflect upon the wonderful possibilities of marine engineering in the time to come.

Mr. SAGE seconded the vote of thanks to Mr. Parsons, and it was carried with cheers.

Mr. PARSONS briefly acknowledged the vote and said he thanked the President and all present for the very kind and attentive reception that had been accorded his paper.

The PRESIDENT announced that the discussion on the paper would stand adjourned until Monday, October 25th.

A vote of thanks to the President, proposed by Mr. MACFARLANE GRAY, concluded the meeting.

DISCUSSION CONTINUED

AT

58 ROMFORD ROAD, STRATFORD,

ON

MONDAY, OCTOBER 25th, 1897.

CHAIRMAN:

MR. J. M. GRAY (*Vice-President*).

The CHAIRMAN in opening the proceedings called attention to the principal features of the turbine engine described in the paper, and stated that Mr. Parsons was unfortunately unable to be present at this meeting, but was represented by Mr. Martin, who would be prepared to answer any question on the subject. With the aid of sketches on the blackboard, Mr. Gray explained how a great increase of effect ought to be expected from expanding to a very low absolute pressure, as in the Parsons' engine.

Mr. FROOM (Member) inquired the object of Mr. Parsons in having two or three propellers on one shaft.

Mr. MARTIN: The original difficulty in using only one screw arose from the cavitation of the water, although probably that is not the only reason why three propellers were subsequently used. A considerable advantage resulted from dividing up the turbine and using two or three shafts with three screws on each. There was also a considerable advantage in the steam consumption. The cavitation of the water was the chief difficulty that led to the use of three shafts and three screws on each, instead of only one.

The CHAIRMAN said that perhaps he might be allowed to supplement the answer just given by Mr. Martin. The gentleman who put the question doubtless supposed that the second propeller on each shaft would simply be working in the water that had previously been set in motion by the first propeller; but the explanation was that the propellers were very small, and this smallness of dimensions exaggerated the distance between the screws. Each propeller acted upon comparatively new water, and in that way the motion created by the first propeller had practically no detracting effect upon the water which was operated upon by the second and third propellers.

Mr. FROOM raised a further question as to the action of the steam turbine being due to the action of the steam on impact or reaction.

The CHAIRMAN replied to this inquiry in some detail, and illustrated his reply by means of a sketch on the blackboard. He said he had often explained to members of this institute how pressure and impact were the same thing, and how when steam acted upon a piston what was called pressure was really impact and reaction. He asked them to take the case of a solitary molecule of steam acting upon an ordinary piston. Let them suppose that this molecule of steam was travelling in the cylinder at the rate of 1,000 ft. per second, while the piston was travelling one foot per second in the same direction. It eventually struck the piston, and the velocity of the impact was 999 ft. per second, as the piston was moving and its velocity had to be deducted to get the velocity of impact. Then the steam molecule rebounded from the piston, and what, he asked, was the velocity of the rebound? The velocity of the rebound was always the velocity of the impact, and therefore the velocity of the rebound was 999 ft. per second. But this was the rebound from a piston moving one foot per second, or 998 ft. velocity in relation to the stationary cylinder. It had lost velocity to the extent of two feet per second, and it had lost that velocity in the impact and rebound. Every time that a molecule of steam struck the piston it lost velocity equal to twice the velocity of the piston. In Parsons' engine the velocity of the steam was diminished by twice the velocity of the blade that it struck. The steam lost nothing by striking the stationary blades; it was only the moving blades that it did work upon. This loss of velocity was transfer of energy. In every cubic inch of steam there were more than a million molecules, and each one hit millions of times each second. This velocity was the molecular velocity of steam. The velocity through the turbine was molar or stream velocity, which was the source of power in the water turbine but not in the steam turbine, on the whole. Throughout the action of the steam there was a continuous expansion going on creating steam velocity, which was immediately lost again in impact and made up again in the next expansion when passing the stationary deflecting blades. In the tortuous steam canals formed by the deflectors they had steam expansion in its best form, free from initial condensation along with the impact action or reaction of the hydraulic turbine.

Mr. J. R. RUTHVEN (Member of Council): There are two points as to which I should be glad if Mr. Parsons or his representative could give us some further information. In the first place, I should like to know the quantity of water that is evaporated by the boilers at any given speed; and, secondly, I should like to know the force that is on the thrust at the time —the propulsive force.

Mr. MARTIN: I do not know that I can give you that information off-hand.*

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* At 34½ knots the indicated H.P. is estimated to be 2,104 and the consumption of water 13¾ lbs. per I.H.P., and the thrust approximately 4½ tons.

Mr. RUTHVEN : Perhaps you may be able to furnish the information at another time, by correspondence.

Mr. MARTIN : Yes, I shall be very pleased if I can.

Mr. SARGEANT (Visitor): Can you give us the diameter of the propellers ?

The CHAIRMAN : Eighteen inches.

Mr. SARGEANT : And the pitch ?

The CHAIRMAN : I cannot give you the pitch—we have not got it—but according to the speed of the vessel the pitch would be between 2 ft. 6 in. and 3 ft.

Mr. SARGEANT : May I ask the object of having the three propellers in line ?

The CHAIRMAN said that if the three propellers on each of the three shafts were not put in line they would require nine shafts instead of only three. Mr. Parsons at first thought that a difference in pitch would be better, and he made them so. He was in doubt, and he asked nature by experiment to tell him which method he should use. The answer he obtained was that the practical benefit of variation was so small that it could not be measured, but he could very easily measure the advantage of having the nine propellers all the same, and he therefore made them alike.

Mr. SARGEANT : It seems to me that the second propeller would be moving or working in the vacant space caused by the first propeller, and that in consequence there would be a loss of power.

The CHAIRMAN : The author thought the same as you at first, and he tried it, and as the result of his experiments he now uses nine propellers of the same pitch, and the three on each shaft in line.

Mr. RUTHVEN : It would be a point of interest to many of us to know how those little curved blades in the turbine are made.

Mr. MARTIN replied that at present these blades were wire drawn. Each blade was fitted with a square base, and it was keyed into the shaft and caulked. It was not at all a difficult operation to fit the blades into the shaft ; they could be put in very quickly.

Mr. SARGEANT : Do you use two or three bladed propellers ?

Mr. MARTIN : I think they are three bladed propellers.

Mr. SMITH (Member of Council) said it would be interesting if they could be informed what would be the gain or loss if, instead of allowing the steam to go below the atmosphere, Mr. Parsons made the final exhaust above the atmosphere. Could he possibly get the latent heat back again into the boiler, and, if so, what would he gain or lose by it ?

The CHAIRMAN said it would take a long time to answer Mr. Smith's question. It had been the dream of a great many would-be inventors to put the latent heat back again. These men imagined that the steam engine was handicapped by the latent heat of water being so great. The Marchant engine and other follies had therefore been put before the public. When a better knowledge of steam was obtained it was found that the greatness of the amount of the latent heat of water was the secret of the greatness of the economy of steam power.

Mr. RUTHVEN asked what value Mr. Parsons got out of the coal by using his engine—whether more or less than in an ordinary engine ?

The CHAIRMAN: He claims it to be as economical as the most economical engine, and the results obtained by the careful experimental tests made by Professor Ewing, the great authority on steam, corroborate this claim.

Mr. SWIFT (Member): Like the other gentleman who has spoken, I should very much like to get at the pitch of the blades on the *Turbinia's* propellers. But the water turbine has been worked out, and we can get certain positive results—certain data. By using that data from the angles of the blades, pressure, etc., and by working through the water turbine, we might get to know something further by using the expansive properties of steam, but until we get an indicator diagram of this engine how can you tell whether you get so much horse-power per pound of coal? These are theoretical questions that must be left with Mr. Parsons for the present. He is working them out. But there is another practical point which strikes me. I see that the weight of this engine in the *Turbinia* is said to be three tons odd, but that is only half the engine. Mr. Parsons said that he proposed putting in another turbine to take the boat astern at the rate of ten knots an hour. But what is ten knots an hour astern when a boat is going thirty-four knots an hour ahead. In my experience you can never get a ship astern fast enough to please those in charge on the bridge; and to get the same result astern as ahead you will have to double the plant. There is no mistake what is coming. The turbine will be the thing of the future, but we must not jump to the conclusion that this is a complete and perfect engine. I should like to hear the views of other gentlemen present as to whether they consider that in a boat going thirty-four knots an hour ahead a power to go only ten knots an hour astern is sufficient.

Mr. MARTIN: I believe that a power to go astern at 10 knots is in accordance with the usual requirements. Can any steamer go astern as fast as she goes ahead ?

Mr. Swift : But in the present steamers you have the full power of the engines while reversing.

Mr. Martin said he thought that for all practical purposes the power to go astern at 10 knots an hour was sufficient. With regard to Mr. Ruthven's question, he might state that it was very easy to get at the efficiency of the turbine engine when it was connected to an electric motor. Recently a steam consumption of 23 lbs. per electric unit per hour for a 150-unit machine had been obtained. A 32-unit machine gave a steam consumption of 36 lbs. per unit. In all large sizes the steam turbine was quite as economical as an ordinary engine, and even more so when condensing.

Mr. W. McLaren (Member) asked if Mr. Parsons made any provision for holding the weight of the go-ahead screws when the vessel was going astern.

The Chairman, in reply, said it was not necessary to make any provision for holding the screw, because when the vessel was going astern the other screws would simply revolve with the water and cause the turbine to revolve. Mr. Swift had raised a very interesting question, but his (Mr. Gray's) view was that the power to go astern at 10 knots was quite sufficient. It must be remembered that Mr. Parsons could start his engine full speed astern at once. The stern action of the propellers came into operation almost immediately, and stopped the vessel very quickly. Several of the members seemed to think that a speed of only 10 knots astern was worthless, but he reminded them that this was intended for a fighting boat, and they should remember with pride that a certain regimental musician could not play a "retreat" at all.

Mr. JOHNSTON proposed a hearty vote of thanks to Mr. Parsons for his valuable and interesting paper.

Mr. RUTHVEN seconded the motion, which was carried unanimously, and

Mr. MARTIN, in acknowledging the vote on behalf of Mr. Parsons, said he had been desired by the author to say how exceedingly sorry he was that he had been unable to attend this meeting.

Mr. RUTHVEN proposed a vote of thanks to Mr. Macfarlane Gray for presiding, and this having also been unanimously passed the meeting terminated.

ADDENDA.—Since the date of the reading of this paper, and the discussion thereon, the *Turbinia* has been fitted with the reversing turbine, weighing, complete, three-quarters of a ton. Owing to delays from the strike and unfavourable weather she has only as yet made short runs astern in the Tyne, but the astern speed realised appears to accord with the anticipated results.