THIRTY-FIRST PARSONS MEMORIAL LECTURE

The Prospect for Steam Propulsion

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The lecture discusses the present state of the art of steam propulsion for merchant ships, and reviews the present state of development of the major components of the steam installation.

An account is given of the development of reheat during the last twenty-five years, dividing the subject into the historical and the present state of development.

The author suggests that future steam installations will incorporate reheat as the conventional, and draws an analogy with the Diesel engine where the turbocharged version is now the conventional form of that engine.

It is suggested that much of the adverse criticism of steam installations has been due to mis-matching of components and poor equipment selection.

Design study teams composed of the owner, turbine, boiler, feed system and control design engineers are proposed as the most satisfactory way of integrating the installation design to achieve economy in first and operational costs.

The author challenges the normal method of selection of equipment by the conventional tendering procedure, criticizes the inadequacy of machinery specifications and recommends selection of equipment by nomination. Type-testing of ancillary equipment at an independent laboratory ashore (e.g. the British Ship Research Association research station) is put forward as an invaluable aid to equipment selection.

The author expresses the opinion that steam propulsion has now passed through its nadir and that its prospects, internationally speaking, are good; but the situation in the United Kingdom is bleak.

He concludes his lecture by giving a warning that unless marine engineering is revitalized in the United Kingdom, the art of steam propulsion design, in which this country is at present giving the lead, will be lost with no prospect of recovery.

1. INTODUCTION

Mr. Chairman, I should be grateful if you would convey to the President and Council of this Institute my appreciation of the great honour they have done me by inviting me to present the thirty-first Parsons Memorial Lecture.

I accepted the invitation with pleasure and then wrote to the Royal Society requesting a list of the titles of the previous Parsons Memorial Lectures and the names of their authors. Needless to say, my pleasure was tempered with humility by the illustrious names of the engineers and scientists who have preceded me in this task.

Many of these authors had three things in common. They had a personal and professional acquaintance with Sir Charles Parsons; they were experts in their own field of engineering or science; and their lectures were, almost without exception, in the nature of historical reviews of their respective fields, not infrequently in association with Parsons himself.

It is, of course, the inevitable result of the passage of time that there will be fewer and fewer people with a personal knowledge of Sir Charles, and it becomes less and less possible to describe from first-hand knowledge the achievements of this extraordinary man in so many spheres of activity.

My own slight acquaintance with him was in my early youth, before and during the first world war, when he allowed me to fish for trout in his lakes in Northumberland. Like every other subject he tackled, he tackled the raising of trout in a most scientific manner—and with very satisfactory results so far as I was concerned as an angler.

During the course of the preparation of this lecture I have sometimes thought that it might have been easier for me to discuss the influence of Parsons on the rearing of trout before the Piscatorial Society—if such a society exists—than to discuss the future of steam propulsion before the members of this learned Institute.

My predecessors, as I have said, were leading authorities in their respective fields of engineering and science, and it was perhaps natural that their lectures should have been, in a sense, retrospective.

I have no claims to expertise in any specialized field of engineering, so you must not expect an authoritative historical account of any particular branch of marine engineering. It is given to few these days to evolve novel ideas; the art today is rather in the field of co-ordination of ideas. What knowledge I have has been learned from others, either in discussion or by reading their publications, but mostly I think, by discussion. It would, therefore, be inappropriate to pick out individuals for special acknowledgement; the list would be far too long.

What I will attempt to do is to give a reasoned forecast of the future of steam propulsion, and, in that sense, my lecture is prospective. Had Parsons been alive today, there is no doubt that he would be deeply interested in the prospect for steam propulsion—hence the title of the lecture.

It is at least a subject that needs examination, more especially in the United Kingdom, the ancestral home of steam turbine propulsion, and one in which this country was preeminent.

Let us hope that it will not suffer the fate of some other branches of engineering of which this country has also been the home, to be destroyed by the twin forces of external aggression and internal inertia.

I hope to show that the last three years have seen a remarkable advance in steam propulsion engineering, which makes it increasingly attractive for a number of applications. Recent proposals for the improvement of steam propulsion, which are now international in extent, have been subjected to

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curiously disparaging attacks from certain quarters, the reasons for which I do not propose to speculate upon.

It has been my experience in life that the best advocacy for any case is to argue it on its own merits, as opposed to denigrating the opponent.

It is the user, and not the advocate, who, in the end, must be the judge of contending systems of propulsion.

You will not, therefore, expect from me an attack upon the Diesel engine, which has made great advances over the last ten years. Its achievements have acted, and are acting, as a spur to those engaged in the art of steam propulsion.

There is a number of appendices to the printed lecture, which I hope will be of assistance to readers. They are not suitable for projection, and, therefore, there will be no slides.

The opinions expressed in this lecture have developed from my personal experience, and must not be taken as reflecting those of the shipbuilding industry in the United Kingdom.

It should be noted that this lecture was written before the publication of the Report of the Shipbuilding Inquiry Committee 1965-1966 otherwise known as the Geddes Report.

2. RETROSPECT

"Any idiot can go on doing what has been done before, but it takes real courage, intelligence and character to assess the need of the future, to devise a sound programme and carry it into effect".

These words are taken from an address given by His Royal Highness, the Duke of Edinburgh, in 1962, at the school of Military Engineering, and it is in this spirit that I intend to approach my subject.

The outstanding historical weakness peculiar to steam propulsion has been the fact that its major components have, from the beginning, been developed almost independently of, and without respect to, one another. Each component has been designed in a kind of splendid isolation, the consequences of which have been gross over-provision of capacity, enhanced capital cost, and disappointing economic performance.

Steam installation design has, until recently, lacked the really expert co-ordination so necessary to get a correct balance between the various components of the system.

Installation design must now be seen as a highly specialized branch of marine engineering.

The most astonishing exception to the prevailing practice was the *Turbinia* herself, where the design of the whole vessel, hull, machinery, and propellers, was totally co-ordinated by Parsons.

The Diesel engine is, in one respect, an excellent example of co-ordinated design; it accepts fuel from the bunkers, converts the energy in the fuel, and delivers power to the propeller shaft quite automatically. This feature has been one of the chief attractions of the Diesel in comparison to the steam installation, which has, until recently, required the intervention of men at various stages of the conversion. A *sine qua non* for the successful future of the steam engine is, therefore, full automation from the fuel supply to the propeller shaft if the steam engine is to rival the Diesel engine in this respect.

Let us examine the possibilities of achieving this desirable state of affairs.

The principal requirement, before automation can be applied with confidence, is a very high factor of reliability of each component of the installation, together with an equal standard of reliability of the automatic control elements themselves. Unless the required standards of reliability are achieved, then dependence upon automatic control may lead to disaster.

I am sure that the desired standards are now available and it is now possible to have a fully automatic steam installation intrinsically more dependable than one requiring human intervention to maintain operational balance over the working range. This view is supported by the fact that there are ships already at sea with automatic controls and data logging equipment costing up to £150 000, which, it may be remarked, is about half the cost of the turbine machinery for a 30 000-shp installation.

It is of the utmost importance that the machinery installation should be designed, from the start, for automatic and remote control. It is entirely the wrong approach to regard control engineering as an afterthought to be hung on conventional machinery like presents on a Christmas tree.

Automatic control is not discussed in this lecture as a separate subject; its general principles are described in a paper by Thompson and Jones(1).

Remote control is a matter of choice as to the extent of its application, but before it can be applied with confidence the prerequisite is a fully automatic installation.

My task in dealing with my subject has been greatly eased by the fortunate fact that some excellent papers on the subject of steam propulsion have been presented before the learned societies within the last two or three years. These papers deal with the various aspects of this subject in great detail, and some will be referred to in the course of the lecture. I can recommend the reading of these papers to those seeking information on the details of the latest developments in steam propulsion.

3. BOILERS

A few months ago I was reading Baumann's (2) 1949 Thomas Hawkesley lecture. I was looking for some information quite unconnected with the subject of this lecture, when I came across the following passage commenting upon Sankey's Hawkesley Lecture which was given in 1917.

Baumann says:

> "Boiler plant being an essential component of the steam plant, one would have expected Sankey in his review of heat engines, to make reference to boiler development and tendencies. His omission might suggest that there has been little of interest to report."

There are still, I am afraid, people today who might, to coin a word, be classified as "Sankeyites". I am not a member of that society, as I hold very strongly to the opinion that the future prospect for steam propulsion depends more upon the excellence of boiler and combustion equipment than on any other component.

Fortunately for the other technologies engaged in the art of steam propulsion, there has been a revolution in boiler and combustion equipment design within the last two or three years.

Hutchison(3) (in his paper "Steam in Merchant Ships" read at the Convention on Steam Plant Engineering convened by the Institution of Mechanical Engineers at Harrogate in May 1963) is particularly interesting in his reference to boilers. His subject is tanker fleet operation over the previous 16 years. He says that boilers were the most costly single piece of the machinery installation to maintain; that difficulties have been experienced with slagging and internal corrosion; that airheaters were short-lived and built-up refractories have suffered badly, propeller-excited vibration being a contributory cause. He shows that the cost of boiler maintenance was equal to about half that of the hull maintenance, and was about equal to that of the rest of the steam and electrical machinery put together.

He goes on to say that it may be, that with the development of low excess air operation in marine boilers, many of the problems of superheater slagging and air-heater corrosion will be eliminated.

Hutchings(4) in his paper presented to this Institute in January 1966, in discussing combustion, with particular reference to the advantages of low excess air combustion, says that to maintain this quality of combustion in service the equipment must be properly chosen and proper consideration given to the arrangement of burners, the gas-flow pattern, and the combustion control system.

I will refer to the important subject of equipment selection in Section 12 of this lecture.

Hutchings also refers to the use of the radiant boiler for marine duties, two characteristics of which are an unusually large furnace which gives a long dwell period for the fuel partners, ensuring complete combustion within the furnace, the second being the virtual elimination of refractory materials.

A steam installation requires a number of automatically-controlled systems for successful functioning, but the most important in respect of the effect on the reliability and maintenance costs of the installation is undoubtedly the control of the combustion equipment. This in turn has depended upon the development of wide-range burners. These will now give satisfactory combustion with a turn-down rate of as much as 40 to 1, which is more than ample for any conceivable operational requirement.

There is a remarkable decrease in harmful combustion products once the excess air has been reduced below three per cent.

It is now practicable to control excess air to less than this, whereas only a few years ago 25 per cent was a common figure in service. It is not, therefore, unreasonable to anticipate that the maintenance costs of boilers will be reduced dramatically in comparison to those now in service.

For further and detailed information on the subject of combustion, Hutchison's(5) paper—"30 000 shp Unitized Reheat Steam Turbine Propulsion", and Chaikivsky's and Siegmund's(6) paper—"Low Excess Air Combustion of Heavy Fuels —High Temperature Deposits and Corrosion", are recommended reading.

4. TURBINES

Twenty years ago the dominant turbine in the United Kingdom was the reaction type with a Curtis stage. This has now disappeared from the scene and not before its time. The double flow low pressure turbine, then in fashion, is also outmoded, except for powers in excess of, say, 35 000 shp.

The leading designs throughout the world now employ diaphragm turbines. These all start as impulse, but varying degrees of reaction are introduced depending on the stable from which the design originates.

The trend is towards fewer stages, primarily with the object of reducing the distance between bearing centres, and cost. Greater attention is being paid to symmetry of casing design, with the object of improving reliability under rapid changes of temperature during manœuvring.

Rotational speeds have been increasing, but at least a temporary halt has been called, because of propeller developments enabling lower main shaft speeds to be used. Economic factors favour a reduction in propeller speeds rather than an increase in turbine speeds. We are now at about the limit of the reduction ratio available with double-reduction gearing.

Further reduction in main shaft speed, or increase in turbine speed, will require the introduction of treble-reduction gearing, at least on the H.P. line. It is questionable whether any real economic advantage is to be gained by such a move. Higher rotational speeds mean higher stresses, and these may in turn require the use of new materials. No one responsible for design would be willing to accept such change without extensive full-scale testing, especially as the materials currently available to the designer are excellent for their purposes.

The British Ship Research Association in 1963 successfully tested for Pametrada a turbine of 22 000 shp with an inlet temperature of 1040°F (560°C). This turbine employs no exotic materials, and is as manœuvrable as those operating at lower temperatures. Turbines designed to operate at this temperature would be of little value unless the boiler could supply steam at this temperature with equal manœuvrability and dependability. This, I am satisfied, is now a practicable operating temperature for a boiler, and it is a matter of more than passing interest that both the turbine and the boiler have reached the same temperature end-point concurrently. The practicable limit of operating temperature at sea can be taken as about 1000°F (538°C), and I can see no advance on this in the foreseeable future.

We have, therefore, arrived at what may be called periodic finality so far as thermal efficiency of turbine installations is concerned.

With regard to the internal efficiency of the turbine, the opportunities for improvement are very small and the efforts of designers are likely to be concentrated upon detailed modifications to enhance reliability and to reduce first cost.

5. CONDENSERS

There has been no fundamental change in the design of condensers since the war. Performance is now more predictable and it has been possible, without detriment to efficiency, to make a modest reduction in fouling margins—which has a beneficial effect on size, weight and cost. There has been a definite move away from expensive ferrule tube attachments and expansion glands to expanded tube ends. Tube or tube end failures in service are exceptionally rare.

An examination of the variation in tube arrangement patterns of the competing designs shows wide dissimilarities; so do the relative proportions of length, depth, and width of the condenser shell. Two conclusions I can draw from these divergences are that we are not yet approaching finality in condenser design, and that the steam exhausting from the turbine does not follow precisely the arrows drawn so hopefully by the condenser designer to show the steam where to go. What is interesting is that the tube areas provided for similar powers and vacua are very much the same for all comparable designs.

It is unlikely that any startling advances in respect of reduction of size will be made, as this must depend on full-scale development testing. This is so expensive that it is most unlikely that any organization could invest in such a large research programme with the expectation of a reasonable economic return.

6. GEARING

A great deal of work on gearing has been done in the last twenty years, particularly in the development of material pairs, in machine design and measuring apparatus.

The hobbed and shaved gear still dominates the scene, though the few hardened and ground gears in service are satisfactory.

The rotating elements of marine gears are now of such excellence that they should give completely trouble-free service for the life of the ship, without the use of E.P. additives, at least for gears manufactured in the United Kingdom.

I would like to take this opportunity to give credit to gear designers, machine tool designers, metallurgists, development engineers, with whom I include the Navy and Vickers Gearing Research Association (N.A.V.G.R.A.) and Lloyd's Register of Shipping for the fact that marine gearing is now the most dependable and least costly to maintain component of marine propulsion plant.

The power of merchant steam machinery has roughly trebled in twenty years. Gear elements have got larger, and we are beginning to reach the limit of reduction ratios practicable with conventional gearing using conventional materials. The limitation is the sheer physical size of the main, or bull, wheel, and the machine tools available to make it.

It will, of course, be appreciated that on any given hobbing machine the accuracy of the finished product varies in inverse proportion to its diameter.

The use of large wheels involves the use of gearcases of correspondingly increased lineal dimensions, covering larger areas of ships' structure, with the inevitable consequence that preservation of the internal alignment of the gearing is becoming more of a problem for the designer.

It would be a mistake to suggest a limit of acceptable size of wheel (e.g. 160 inches, 180 inches, or 200 inches diameter) beyond which it is inadvisable to go, because so much depends on the accuracy of manufacture, the inbuilt stiffness of the gearcase, the design of the ship's structure and the location of the machinery in the ship. All I wish to emphasize here is that the bigger the main wheel the more difficult the problem.

The relative cost of gearing is increasing with the increasing speed of rotation of turbines and the decreasing rate of rotation of main shafts. The cost of conventional gearing is now about 40 to 45 per cent of the turbine-condenser-gearing complex, and it is inevitable that designers have been looking for new approaches to gear design, with the object of reducing costs.

The problems before the gear designer are reduction of cost, and the insulation of the gear elements against misalignment, whilst maintaining tooth loading within permissible limits. How are they doing it? Let us look at three designs.

Some years ago Pametrada adopted the locked train, or dual-tandem, type of gearing for merchant ship machinery of about 22 000 shp and upwards. This type uses two secondary pinions in place of one for each turbine, thus providing for twice the torque capacity within the same overall dimensions. Compare two gearboxes designed for 26 500 shp at 108 rev/min. The single-gear main wheel dimensions are 175 inches diameter by 43·5 inches face width; the dual-gear main wheel dimensions are 164 inches diameter by 33 inches face width. The weight of the former gearbox is 151 tons and the latter 121 tons.

The dual-tandem arrangement, in spite of its increased complexity, is less expensive for the same power than the single-pinion arrangement. The dual-tandem gear also occupies less floor area and is lighter.

General Electric of America announced their MST-13 design in November 1962. A feature of this design is that the main wheel, intermediate gear and turbine shaft centres are in a single horizontal plane. Two claims made for this arrangement are that it is cheaper to install and takes up less vertical space than the conventional arrangement.

Stal-Laval announced their AP series early in 1963. This also is a single-plane arrangement. A most interesting feature of this design is the adoption of overhung epicyclic gearing in place of parallel gearing for the first reduction. The service performance of this development will be watched with great interest. One obvious advantage that the AP arrangement has over the MST-13, is that the floor area covered by the propelling unit is reduced.

The single-plane arrangement, whatever its claimed advantages in other directions, is limited to a single secondary pinion for each turbine, and the maximum power for which these designs can be developed is restricted to a figure below that practicable for the dual-tandem design.

The single-plane design makes necessary the placing of the condenser on the same horizontal axis as the L.P. turbine, and this arrangement inevitably occupies more fore and aft space than a conventional arrangement with an underslung condenser.

When I was a seagoing engineer, I succeeded on more than one occasion in flooding the main condenser—but without damage to the turbines. I would take a good deal of convincing before I would be happy about repeating this performance with the condenser level with the L.P. turbine. I am not wholly familiar with the detail of the design of either of these single-plane L.P. turbine-condenser arrangements. No doubt this hazard has been considered and safeguards have been provided.

Pametrada's contribution to new concepts on the main propulsion unit is the Paraplan arrangement in which parallel gears are used for the primary reduction and epicyclic gears are used for the secondary reduction. This concept is not in itself new, as this configuration was used successfully 15 years ago in two British hydrogen-peroxide turbine-driven submarines, and in the experimental destroyer U.S.S. *Timmerman*.

One of the objections in the past to epicyclic gears has been the difficulty in arranging for internal inspection. The novel features in the Pametrada gear are the arrangement by which the axis of the epicyclic box can be tilted from the horizontal to the vertical plane for internal examination, the use of spur gearing in place of helical gearing, and the suspension of the gears. Details of this design have been published in the technical press, e.g. *The Engineer,* 12th March 1965, page 463.

Advantages claimed are in cost, weight and space, but, more important than these, the suspension of the secondary gearing isolates it from any possible effects of hull movement. The box is designed with a self-contained lubrication system, which can be rendered hygienic and sealed in the shop before installation.

For some installations the parallel and epicyclic gearing can be separated, the epicyclic secondary gear being placed aft. Such an arrangement might be particularly suitable for a fast dry cargo ship.

7. PROPELLERS

The initial work on the 30 000-shp reheat design described by Hutchison[5] started in May 1963. At that time the biggest propeller available to us was about 26 feet in diameter and it absorbed 30 000 shp at 110 rev/min. Subsequent to the completion of the investigation it became known that the propeller manufacturers in the United Kingdom were prepared to produce propellers of 30 feet in diameter which would absorb 30 000 shp at 80 rev/min. The estimated gain in propulsive efficiency by this change is eight per cent for this particular application.

Still more recent information is that propellers of 35 feet in diameter can now be made with improvements in propulsive efficiency of 11 per cent.

Such large propellers are heavy and introduce shafting problems. One solution is offered by Hutchison[5] who proposes a hollow-drum type tailshaft welded to a shaft coupling at the forward end and a conventional cone at the other. The external diameter of the journal is no less than 56 inches. Other designs are being developed which use the drum as a bearing journal only and transmit torque to the propeller through a quill shaft. Both designs require big bossing; both use oil-lubricated bearings.

It is now more than ever necessary that naval architects should pay special attention to the design of the associated ship's structure to ensure alignment being maintained under all service conditions and that the structure should be designed to resist vibration, particularly in the horizontal plane. It is not, I hope, asking naval architects too much to devote as much consideration to the design of the hull in way of the propeller as they are at present giving to the other end of the ship, if full advantage is to be taken of recent engineering developments.

Jung, in his contribution to the discussion of Coats[7] paper (which has been awarded the Silver Medal of the Institute for 1965), read at the joint meeting of the Institute of Marine Engineers, Schiffbautechnische Gesselschaft e.V. and the Institute of Engineers and Shipbuilders in Scotland, in May 1965, put forward proposals for contra-rotating propellers. He states that contra-rotating propellers at 80 rev/min show an improvement in propulsive efficiency of ten per cent over a single propeller rotating at the same speed. He considers that it is feasible to make contra-rotating machinery where turbines are employed and illustrates possible alternative means of doing this. He says that Stal-Laval will soon be in a position to offer counter-rotating units.

The controlled-pitch reversing propeller has attractive features but its relatively high first cost makes the case for its general adoption difficult to sustain. Claims in its favour in association with conventional machinery are too well known to need cataloguing here, so I will refer to one possible additional advantage which requires serious consideration. It is in association with reheat turbine machinery. By its use not only is there a simplification in turbine design by eliminating the astern elements—which of course applies also with conventional turbine machinery—but there is some simplification in the boiler and its control during the manœuvring conditions.

8. NUCLEAR PROPULSION

It is impossible in a lecture on the future of steam propulsion not to touch upon the subject of the use of nuclear energy at sea, because it seems inevitable that the steam turbine must be the mechanical means of its application.

This subject can be divided conveniently into two parts, the economics and the engineering.

Sir Frank Whittle is reputed to have said some years ago that more gas was talked about gas turbines than ever went through them. I wish I could coin as good a phrase about the economics of nuclear propulsion.

There has been, over the past years, an unending spate of argument about the economics of nuclear propulsion; sums have been worked out with the utmost precision from data of remarkable dubiety. For example, I have seen fossil fuel rates for steam turbines quoted from 0·5 to 0·56lb/shp h; I have seen the cost of furnace fuel quoted from 90 shillings to 140 shillings a ton, and it is probable that the cost of nuclear fuel can be made to vary correspondingly.

In the Journal of the Joint Panel on Nuclear Marine Propulsion, Volume 9, October 1965(8), the Chairman of the meeting, Mr. H. N. Pemberton is recorded as having said "People in this country . . . seemed to have been mesmerized by economic problems, when the real thing was to get ahead and develop reactors which would work."

It is interesting to speculate how the modern economist would have argued the case for or against the introduction of steam propulsion in place of sail; the introduction of steam turbines in place of steam reciprocating engines; the introduction of the aircraft turbine jet engine with its specific fuel consumption perhaps three times that of contemporary piston engines which it replaced. I suggest we should take care of the engineering and the economics will look after themselves in the process of time. The essential thing is to gain experience. And that experience must be with steam turbines as the prime mover.

The quality of steam which has been offered to the turbine designer has been saturated steam at 600lb/in^2 or higher; with some reactor designs there seems to be some doubt about the complete purity, in the radio-active sense, of the steam supply, and there is a paramount need to guard against the slightest contamination of the condensate by sea water.

The intractable problem, from the turbine design aspect, is the use of saturated steam in the turbines. Turbine designers are sometimes accused of being over-pernickety about this. The suggestion is made that they should take a look at some of the old turbines which ran successfully on saturated steam years ago. I know about this, because my experience up to the early '30s was exclusively with saturated steam; but the inlet pressure to the turbines was less than 200lb/in^2 and the blade speed of the order of 200 ft/s for direct-drive turbines and less than double that figure for single-reduction geared turbines. Even under those conditions, blades at both ends (and I would emphasize both ends) of the turbine suffered seriously from erosion.

It is to be hoped that reactors will soon be able to produce superheated steam. Once they do, there is no intractable problem for the turbine designer; the turbine will then have for all practical purposes unlimited durability. Such machinery might be most attractive for long-haul, high-powered dry cargo ships.

9. REHEAT

Phase I—Historical

The idea of using a reheat steam cycle for marine propulsion is not new. The first merchant ship with reheat entered service in 1942, and three notable designs were produced over the next fourteen years.

This I have called Phase I, or the historical period, of the application of reheat to marine propulsion.

Cycle diagrams of these four designs are given in Appendix A to the printed lecture.

I do not intend to give a detailed description of these designs, which are recorded in the Transactions of various learned societies to which references are given in the text. I would, however, like to draw attention to one or two salient features and, particularly, to some of the reasoning behind the development of these various designs.

1942—s.s. *Examiner*. It was desired to improve the thermal economy of steam turbine installations, but at this time it was considered unwise to exceed a steam temperature of 740°F (393°C). The designers therefore looked to higher pressure to achieve the result and selected 1200lb/in^2 as there was plenty of operational experience of this pressure ashore. A single stage of reheat was introduced primarily to avoid excessive wetness towards the exhaust end of the turbine.

This ship had two twin furnace boilers with the object of controlling superheat and reheat temperatures.

Contemporary with this design, some designs of superheat boilers also used twin furnaces for the control of superheat.

In the *Examiner* the control of superheat and reheat by the use of twin furnaces was not entirely satisfactory, and the superheat and reheat temperatures had to be reduced to obtain a reasonable control over maximum temperature(9, 10).

1945—s.s. *Venore*. A limitation on this design was the need to use only non-strategic materials, and the temperature was limited to 750°F (399°C). Reheat was introduced, again primarily for the purpose of reducing wetness. The pressure in this case was 1450lb/in^2, and double reheat using steam to steam reheaters between H.P. and I.P. and I.P. and L.P. turbines was adopted. Two conventional single-furnace superheat boilers were used in this installation(11).

1945—*Beaver* Class (four ships). Reheat was adopted for these ships, largely to reduce wetness, as the owners had experienced severe blading and casing erosion in earlier ships in service.

Electric drive was selected; this avoided reheater protection problems during manœuvring. The use of electric drive more or less cancelled the efficiency gain due to reheat.

A feature in this design was the adoption of only one single furnace boiler operating at 850lb/in^2 and 850°F (454°C) with independent damper controls of both superheat and reheat temperatures. These single boiler installations proved satisfactory in service.

It is interesting to note that the more advanced modern reheat designs have also adopted the single boiler with single furnace and damper controls, thus following the example set in the *Beaver* Class more than 20 years ago(12).

1956—*Empress* Class (three ships). These are twin-screw ships with H.P. and I.P. turbines in tandem with reheat between them. Steam is supplied from three superheat boilers in one of which is incorporated the reheater. The requirement that full power must be available from the two non-reheat boilers necessitated a relatively complicated valve and pipe system, together with high weight, space and cost(13).

1960—Projected Express Passenger Liner. A scheme for a four-shaft 300 000 shp reheat installation was put forward by Pametrada for an express passenger liner. The steam conditions selected for this installation were 1000lb/in^2/1000°F (538°C)/1000°F (538°C) at turbine inlets, with reheat at 250lb/in^2. This installation is described in an article by Dr. T. W. F. Brown, then Director of Pametrada, published in the *Marine Engineer and Naval Architect* in June 1960. These pressures and temperatures are the same as those selected for the installation described by Hutchison(5) in 1965.

Phase II—Current Design

The steam cycles recently adopted by the leading designers of reheat installations are given in Appendix B. The exception is A.E.G. whose cycle has not been published.

The information given in this Appendix has been abstracted from various sources and it is possible that there may be some minor variations from the original figures. I apologize for any inconsistencies there may be, but absolute accuracy is not important here, as my object is to show the salient features of the designs; it is not the intention to make economic comparisons between them.

Ishikawajima-Harima have published information on four cycles designated R.801 to R.804. R.801-803 all use reheat between the H.P. and L.P. turbines. R.802 is to be installed in the mammoth 205 000-dwt tanker now under construction. The main turbines of the R.802 design resemble the G.E. MST-13 which is a single-plane arrangement with the condenser at the level of the L.P. turbine. The secondary gears are single tandem.

Reheat is introduced between the H.P. and L.P. turbines, and because of the low pressure at which reheating takes place, it is not practicable to reheat to the initial superheat temperature and in consequence the gain in efficiency is small. Steam is supplied from two boilers, one of which incorporates a separately fired reheater. There are three furnaces in this design. The reheat boiler configuration resembles that used in the s.s. *Examiner*.

The I.H.I. R.804 design resembles the MST-14 design, except that the initial pressure is somewhat lower and that advantage is taken of the return to dual-tandem gearing to place the condenser under the L.P. turbine.

The General Electric MST-14 design employs a combined H.P./I.P. turbine with central steam inlets and an L.P. turbine. This design employs dual-tandem gearing with good power distribution. The condenser is maintained at L.P. turbine level in this arrangement.

Steam is supplied from a single reheat down-fired radiant boiler with damper controls for superheat and reheat temperatures.

The A.E.G. design employs a combined H.P./I.P. turbine and an L.P. turbine with underslung condenser. Single-tandem gearing is employed.

It is understood that this design will employ a single down-fired radiant boiler with damper controls for superheat and reheat.

The Stal-Laval design employs three separate turbines. The H.P. and I.P. turbines are in tandem and drive through dual-reduction epicyclic gearing. The L.P. turbine drives through single-reduction epicyclic gearing. Both lines drive through single pinions to the main wheel.

A single down-fired radiant boiler with damper controls for superheat and reheat temperatures is incorporated in this design.

The Pametrada design uses three separate turbines. The H.P. and I.P. turbines use single—and the L.P. turbines dual-tandem gearing. This arrangement provides good power distribution.

This design uses a single reheat down-fired radiant boiler with damper controls for superheat and reheat temperatures.

The I.H.I. (R.804), G.E., A.E.G. and Pametrada designs all incorporate alternators and feed pumps driven by the main engine.

The I.H.I. (R.804) and G.E. designs incorporate auxiliary turbines for driving the alternator and feed pump, which can be disconnected from the main engine when required.

The A.E.G. design uses separately turbine-driven alternator and feed pump as standby. Pametrada uses a Diesel-driven alternator and turbine-driven feed pump as standby. Stal-Laval use a bled steam turbine for driving the alternator and main feed pump in tandem.

It will be seen that, with the exception of the I.H.I., R.801 to 803 designs, the proposed reheat systems are all variations on the original theme. The points of similarity and of difference are interesting and give the user a wide choice.

The fuel rates for all except the earlier I.H.I. designs, are, for all practical purposes, the same.

The salient features of the different designs are given in Appendix D.

10. RENAISSANCE OF REHEAT

The Renaissance of Reheat in the United Kingdom was conceived in London on 8th May 1963; the child was born on 27th September 1963 but, because of the need for commercial security, the birth was not announced publicly until 23rd April 1964. These facts are given for the record.

I hope a description of the method of working adopted for this design study will be of interest.

It was agreed from the beginning that a boiler designer and a feed system designer should be invited to take part, together with the owner and the turbine designer, from the commencement of the design study.

It was also agreed that nothing was to be incorporated in the design unless there was practical experience of its satisfactory operation at sea, in land installations, or under full scale laboratory test conditions.

The work was divided amongst the individuals of the group on the principle that cobblers should stick to their lasts.

The owner defined the operational requirements, including the need to manœuvre with equal facility as conventional machinery and the limitations on fuel quality. He determined, by exhaustive investigations conducted on ships in service, the effects of age, fouling, weather, the loaded and ballast conditions on the speed of the ship and on variations of shaft speed. He was the judge of the practicability for shipboard operation of the proposals the design specialists suggested as the intallation design developed, and that the solution fulfilled the overall economics of the operational schedule.

The turbine designer was responsible for selecting the steam conditions and the point of reheat, subject only to the practicability of his proposals from boiler design considerations. He selected the power distribution between the turbines to make the best compromise between gear design and thermal efficiency. He defined the requirements of the lubrication system and other equipment ancillary to the turbines.

The boiler designer was responsible not only for the boiler design, but also for the selection of combustion equipment, combustion control, and other automatics in association with the boiler.

The feed system designer's task was to remove from the condenser water at one physical and chemical condition, and deliver it at another set of conditions specified by the boiler designer.

The control design engineer was brought in at an early stage. It cannot be over-emphasized that, for the satisfactory application of automatic and remote control, the equipment to be controlled must be designed for the purpose by close collaboration from the inception of the design, between the machinery and control designers.

This was, I believe, an unique example of intimate co-operation between an owner and specialist designers in the development of an optimized steam installation, with the owner taking a leading part from the inception of the design. Such co-operation is essential if the best economic solution to the design of a steam installation is to be achieved; it is vital if the design is to incorporate reheat.

The achievements of the group exceeded expectations, and it was agreed that the owner should ask Yarrow-Admiralty Research Department to examine and assess the proposals. Y.-A.R.D. subsequently made recommendations modifying the original proposals in detail, which resulted in some improvement in the cycle efficiency.

I have spelt this out in some detail in the hope of convincing others of the virtues of this procedure.

The rather guarded public announcement in April 1964 was received with scepticism in the United Kingdom, but it attracted a great deal of attention abroad and a number of foreign designs, which have many points of similarity to the British concept, have recently been published and have aroused considerable interest in this country.

"And herein is that saying true; one soweth and another reapeth"(14).

11. ECONOMICS

A great deal has been published on the comparative economics of competing propulsion systems. The major contestants are steam and Diesel and within these camps are the lesser rivalries of reheat and conventional steam; direct coupled and geared Diesels.

The protagonists, spurred on by commercial interest, argue their cases with the flexibility of Olympian gymnasts and, on occasion, have oversold their wares, sometimes to the long term detriment of the technology which they advocate.

Having said that, I now declare myself as a protagonist of steam and, more precisely, of reheat steam propulsion within its field of application.

The principal economic argument in favour of the Diesel engine was its vastly superior thermal economy. This now has gone by the board. The practice of comparing fuel rates based on shaft horsepower for the study of propulsion economics is now outmoded, as the propulsive efficiency of modern steam machinery with low-speed propellers is up to ten per cent better than Diesel propulsion for tank ships.

This superiority is not claimed, at least in full, for steam propulsion for fast dry cargo ships, as it is not always practicable to accommodate a large slow-speed propeller on ships with relatively shallow draught, but it is often practicable to use a single propeller with a turbine in place of two with Diesels, with a corresponding gain in propusive efficiency.

It is undeniable that steam installations are much lighter than Diesel engine installations of the same power, and require less engine room length. It is a matter for the naval architect to take what advantages he can from these savings. Any saving in the cost of the ship should be credited to the economic advantage of steam propulsion.

It has been said that reheat introduces undesirable complexity in comparison with conventional steam machinery. The added complication is only undesirable if it is economically unjustified or if it decreases reliability.

Sufficient has already been said to justify reheat on economic grounds. What about its effect on reliability?

A few additional dampers and an additional steam heater have been introduced into the boiler. The additional steam heater, or reheater, is in respect of reliability no better and no worse situated than is the superheater. The extra dampers are more or less a duplication of those already in the boiler for the control of superheat.

The additional complexity in the turbines is the use of two small turbines (Pametrada, Stal-Laval) or one compound H.P./I.P. turbine (G.E., I.H.I. and A.E.G.) in place of a conventional H.P. turbine, and two lengths of steam pipe between the turbines and the reheater. No extra valves nor anything of that sort are required in these new installations. The additional items are so reliable that their introduction does not impair the reliability of the installation in the slightest.

A fact, and a very important one, so often forgotten when comparing reheat and conventional turbine machinery, is that, because the working fluid in circulation in a reheat installation is only about 80 per cent of that in a conventional plant of the same power, the sizes of components are correspondingly reduced, e.g. the L.P. turbine for a 30 000-shp reheat installation is of corresponding size to that of a 24 000-shp conventional plant. The same rule applies to the boiler, condenser, feed systems, and so on.

It is because of the reduction of component size that the cost of a reheat plant, based on the same fuel rate, is less than that of a conventional plant. The cost of a reheat plant, taking full advantage of the available improvement in thermal efficiency, will lie between 100 and, at the very most, 105 per cent of the corresponding conventional propelling machinery.

The use of reheat in steam installations is analogous to the use of turbochargers on Diesel engines. There is an added complexity and a reduction in size.

Who would, for one moment, consider reverting to the "simple" Diesel engine in the interest of reliability?

It is for these reasons that I have arrived at the conclusion that the conventional steam installation of the future will incorporate reheat.

12. SPECIFICATIONS

We have, so far, considered the present state of the art of steam marine propulsion.

There have been great improvements, especially within the last two or three years, in the design of boilers, combustion equipment, automatic controls and instrumentation, and in the attitude of mind which accepts the view that a steam installation design is "one and indivisible" and not merely collecting together somewhat distantly related components.

It is not, therefore, unreasonable to predict that reliability and durability—which terms are by no means synonomous—will be higher and maintenance costs lower than past experience with steam machinery might indicate, provided good component matching is achieved.

How is the requisite quality of all the components to be assured? How are we to ensure that we get value for money, which in the end is really what we are all after? What do we mean by value?

Sir Norman Angell[15], the economist says—

> "The quality called value not only evades all examination by the senses but its very conception is so abstract and difficult that the ablest economists are not fully agreed as to its statement."

In the light of this, can any engineer feel really assured that he can obtain value for money by the normal tendering procedures which are the common practice today?

The art of producing a precise specification is very difficult and sometimes an impracticable one, and with rare excceptions those produced for ships' machinery leave much to be desired.

Considerable space is given, for example, to telling the designer how to design his particular speciality. In a recent specification the turbine designer is instructed to ensure that his turbine casings are adequately ribbed to avoid distortion; in another it is stated that the boiler must have a precise number of square feet of heating surface. Such statements are of no conceivable value to the purchaser and are an embarrassment to the designer. It is clear that these kinds of statement have been lifted straight out of some ancient specification, or from a manufacturer's descriptive literature.

I am much more seriously concerned about the specifications for equipment ancillary to the major components. For example, the oil-burning equipment and its automatic controls are often so vaguely described and in such general terms that practically anything offered will comply with the specification. Tenders are tabulated and it becomes very difficult not to accept the lowest one. Let me give another example.

The manœuvring valve for a turbine for use in conjunction with remote control may be selected by the owner or builder without consultation with the turbine designer — who really knows about control valve design—and with no liaison whatever between the designers of the control system, valves and turbines. The owner then finds that his machinery is difficult to control.

A shipowner, in a debate between shipowners and shipbuilders arranged towards the end of last year by the North East Coast Institution of Engineers and Shipbuilders, said (and I quote):

> "It is understandable but regrettable that shipbuilders, when given a free hand, and sometimes when they are not, specify or suggest that which is towards the bottom of the list in cost."

My only quarrel with this statement is that the shipbuilder is picked on as the only culprit in buying cheap. My experience is that the shipowner is often equally culpable in this respect, by confusing cheapness with economy and forcing the shipbuilder to toe the same line.

The correct way to ensure the suitability of ancillary equipment is to leave the selection of all that associated with the generation of steam to the boiler designer; all the automatic controls, including manœuvring valves, bleed and dump valves, and the lubricating system in association with the main turbines, to the turbine designer; and the whole of the feed system, including water treatment, to a specialist in this field.

There is, in addition to the ancillary mechanical equipment, the provision of the necessary instrumentation or data-logging equipment. As the working temperature of the installation approaches closer to the limiting temperatures of the materials used in the construction of the machinery, the accuracy, durability, and quick response of temperature sensing instruments is becoming more and more important.

I have yet to see a specification of this type of equipment so precisely defined that it would be safe to make a selection from a list of so-called competitive tenders.

How, then, is the selection of unsuitable equipment to be avoided? There are two ways—the first by precise specification which, as I have already said, is usually impracticable, and the other is by selection.

The financial pundits will oppose the economic heresy of selection by nomination. They will argue that if you nominate a supplier he will escalate his prices and allow his technology to stand still.

My experience, which extends over more than thirty years in this field, is that this procedure nearly always has the opposite effect. The manufacturer whose equipment, though cheap, is not selected because it does not measure up to the technical requirements, must improve his standards or go out of business.

A mass of legalistic verbiage designed to tie down the supplier is, even in these days, no substitute for mutual confidence.

I do not under-estimate the problem which faces the managing engineer in a period of rapidly advancing technologies when faced with making the choice of his equipment. Much, of course, will depend upon his experience and the opportunities he has had of keeping abreast of developments. His task will be eased if he leaves the selection of ancillary equipment to the major component designers. He can also be greatly assisted if he has available to him test reports on the equipment in which he is interested.

Much of the work done when I was at the Admiralty Engineering Laboratory was devoted to type testing. Manufacturers of, for example, small commercial Diesel engines were invited to submit their engines for a series of tests by which the performance of the engine was assessed in all its aspects, e.g. economy, durability, reliability, accessibility, and so on. The development engineers made recommendations to the manufacturer for the improvement of his engine. The advantage was to both sides.

Type testing was, at first, looked upon with considerable suspicion, but later on its value was appreciated and progressive manufacturers submitted engines on their own initiative for type testing.

Appropriate procedures for testing such items as centrifuges and filters were also devised. We gained a wealth of experience by the end of the test series, but we were still unable to define precisely a centrifuge or a filter, though we established the limitations of each. But we could design a good lubricating system.

It is appreciated that shipowners do try out new equipment at sea, and it is testing at sea which must be the final arbiter.

But sea trials are best done subsequent to thorough independent laboratory testing, where an item can be tested to its limits under strictly controlled conditions by experienced development engineers. Items can rarely be taken to an end point during testing at sea without hazarding the ship.

The British Ship Research Association is admirably suited, both in respect of its equipment and the ability and experience of its development engineers, for this sort of testing, and it is good to know that some test programmes have already been started. The results of such testing will, I am sure, be of the greatest value to the shipowner and to the machinery designer in selecting his equipment.

I am not advocating the pursuit of a policy based on the idea that "money's no object". Far from it. What I have tried to do is to propound an engineering equivalent of Gresham's Law, which states that bad money will always force out good.

I conclude this section by expressing the opinion that the best judge of value is the experienced managing engineer. He should be competent to assess what is a fair and reasonable price to pay, taking into consideration the technical merits of his choice. It is at least clear from the quotation from Sir Normal Angell that this subject of value baffles the economist.

13. THE PROSPECT FOR STEAM

The present time is particularly appropriate for considering the future of steam propulsion.

On technological grounds there is no reason for waiting in the hope of a further worthwhile improvement in thermal efficiency. I believe we have arrived at a state of periodic finality in this respect.

The recent jump from 0·5 to 0·4 lb/shp h fuel rate, which was initiated three years ago in this country, cannot again be repeated; it can only be emulated.

Machinery could be designed for higher efficiency but it would not respond to the almost instantaneous changes in power, including reversal, which are essential at sea. Power plant for use at sea is on its own, does not form part of a grid system, and there is no standby propulsion plant. The outage for defects which is tolerated in land stations is quite unacceptable for marine propulsion, and this is why the design of marine turbines must be a separate and distinct specialization from that of land turbines.

For further advances in thermal economy, the steam engineer must await the development of suitable materials for operation at higher temperature, or upon the oil chemist to develop an economic means of removing the harmful constituents (e.g. sulphur, vanadium) from fuel oil. If the chemist does succeed in this, then the gas turbine may become a serious competitor. But such developments do not appear to be on the horizon.

Neither does there seem to be a prospect of much further improvement in the thermal economy of the Diesel engine. Both types of prime mover are approaching asymptotes in this respect.

Choice of type of machinery will depend on power, weight, space and rational economic considerations; but, probably now more than ever before, on personal preference and other more or less intangible, though often quite logical, considerations.

At what power do economic considerations suggest that steam should take over from Diesel? There is no simple answer to this question, and I do not propose to lay myself open to attack by enthusiastic protagonists of other methods of propulsion by offering a definite figure. All I will say is that the higher the power the better the case for steam, and the lower the power the better the case for the Diesel. The debatable ground is quite wide, and is affected by considerations both economic and sociological; for example, Americans do not like Diesel engines; Scandinavians prefer them; in Australia there seems to be a preference for steam at relatively lower powers (e.g. 10 000 shp upwards), this preference being based on the attitude of crews to self-maintenance, the high cost of labour, the relatively low cost of fuel, the long hauls, even on the coastal trade, and long passages in hazardous waters where dependability is at a premium.

I believe that the demand for steam machinery has passed through its nadir and will now show a relative increase. I base this conclusion on a number of grounds. There is the remarkable improvement in thermal efficiency of steam plant throughout the world; the increasing size of bulk carriers, especially tank ships, which now exceed 200 000 dwt and require powers in excess of 30 000 shp, and the ability of the steam turbine to use low speed propellers with consequent improvement in propulsive efficiency of about ten per cent.

The increasing demands for high speed dry cargo ships is another development favourable to steam, where short engine rooms and minimum weight are particularly important. It is reported that six fast cargo ships, each of 72 000 shp, have been ordered in America and that owners in the United Kingdom and in other countries are considering ships in this category.

It is to be hoped that port efficiency will improve and new methods of cargo handling will reduce the turn-round time of dry cargo ships. This will result in an improved utilization factor of ships as transports rather than as stores. The better the utilization factor, the better the case for steam.

I have suggested that the prospect for steam should now improve. Let us look at the present position.

There were, at 31st December 1965, 419 ships with machinery of 15 000 shp and over on order in the world. One hundred and thirty have steam machinery; of these 49 are building in America.

It is not easy to assess the rate of building, but it would not be far wrong to assume that the present world demand for steam installations is about seventy sets a year. This is equivalent to about £70 million worth of business, of which the turbine machinery accounts for about one-third. The world market for steam propulsion machinery is valuable and can be expected to improve.

What, then, is the position in the United Kingdom?

There were, at 31st December 1965, ten steamships building, of which three have been ordered within the last twelve months. The prospect in the United Kingdom, therefore, is bleak. Let us look at some of the causes of the present state of affairs.

A self-evident cause is that very few ships with steam machinery are being ordered in the United Kingdom. A reason for this is that very few berths exist capable of taking the mammoth tankers for which steam machinery is so attractive, and delivery and price are said to be unfavourable in comparison with some foreign yards. It is to be hoped that, when the demand arises for fast dry cargo ships for which steam is the appropriate means of propulsion, British shipbuilders will come into their own and secure orders for them.

The minimum rate of manufacture of marine turbines probably lies between eight and twelve sets a year for viability. A demand of this order from United Kingdom shipbuilders is not expected in the immediate future.

If it is desired to maintain an active marine turbine facility in the United Kingdom with the present home demand well below the viable minimum, then it must be either subsidized by some means, or turbine machinery must be exported. The possibility of subsidy is a political and controversial matter, and it would be quite improper for me to express an opinion on this in a lecture of this nature.

That a market exists abroad there can be no doubt, but it will take a most forceful sales campaign if it is to be exploited, and to conduct such a campaign certain minimum conditions must be met. I cannot do better than to quote Sir Denning Pearson's(16) Fawley Foundation Lecture on this subject. He says:

> "To compete in the international market it is necessary to have an adequate design team, development facilities and equipment to enable the product to be properly developed and tested before it is launched on the market; a technical and commercial sales team capable of selling the product to overseas customers; a service organization capable of providing adequate product support."

He goes on to say:

> "What is needed is a company which is prepared to concentrate on a single product line, or a group of product lines . . ."

Marine engineering in the United Kingdom has been with few exceptions, a subsidiary department of shipbuilding, and its primary function has been to supply the shipbuilder with machinery for his own ships. None of the shipbuilders has the necessary organization to conduct an aggressive machinery sales campaign abroad. What I have said will not, I hope, be taken in any sense as an adverse criticism of the shipbuilders as shipbuilders, whose principal business is to sell ships, not machinery.

The electrical industry in the United Kingdom, which has, on occasion, supplied turbine machinery for merchant ships built in this country, has not shown any apparent interest in the export of marine turbines.

The one exception for marine steam turbines was the old Parsons Marine Steam Turbine Company which had a very considerable export business of turbines of their own design, but is now, alas, defunct.

The competition from abroad is very powerful and exuberant. Please note that it comes from the two countries with the highest wages and living standards in the world.

14. CONCLUSIONS

This completes the survey of the factors affecting the future prospects of steam propulsion and it now remains for me to sum up.

There have been recent important developments in boiler design, combustion equipment, and in the associated automatic controls which promise to increase the reliability and durability, with a reduction of maintenance costs of future steam installations.

That the modern co-operative approach to installation design enables economies to be made in both capital and running costs.

That the renaissance of reheat still further improves the economy and reduces the comparative size of components to about 80 per cent of current conventional machinery of the same power. The cost of reheat machinery, when related to the same specific consumption, is less than that of conventional machinery.

Modern reheat designs need not be complex, and there are no limitations on the manœuvring of reheat machinery additional to those acceptable with conventional plant.

That steam installations embodying reheat will be regarded as the conventional rather than the exceptional. This situation is closely analogous to the turbocharged Diesel which has now established itself as the conventional form of this engine.

That steam propulsion has passed its nadir and its position, relative to Diesel propulsion, should improve in the future because of the increasing power requirements of both tankers and high-speed dry cargo ships.

That the break-even point between steam and Diesel for a particular service will be lowered in favour of steam because of the improved thermal economy of steam and its ability to use low-speed propellers giving greatly improved propulsive efficiency.

That the design of steam turbine plants is now a highly specialized branch of marine engineering, and to secure the full benefits from associated technologies, close co-operation between an owner and the design specialists is essential from the conception of the ship design.

That the world prospects for steam propulsion are good, but are bad in the United Kingdom.

That to maintain a viable steam turbine industry in this country, it must be organized for export with a strong sales force. There can be no question that a market abroad exists which is at present being supplied from high wage and living standard countries.

That, if for temporary economic expediency, this country allows its present world leadership in marine turbine technology to be lost, it will be gone for ever with no possible hope of recovery.

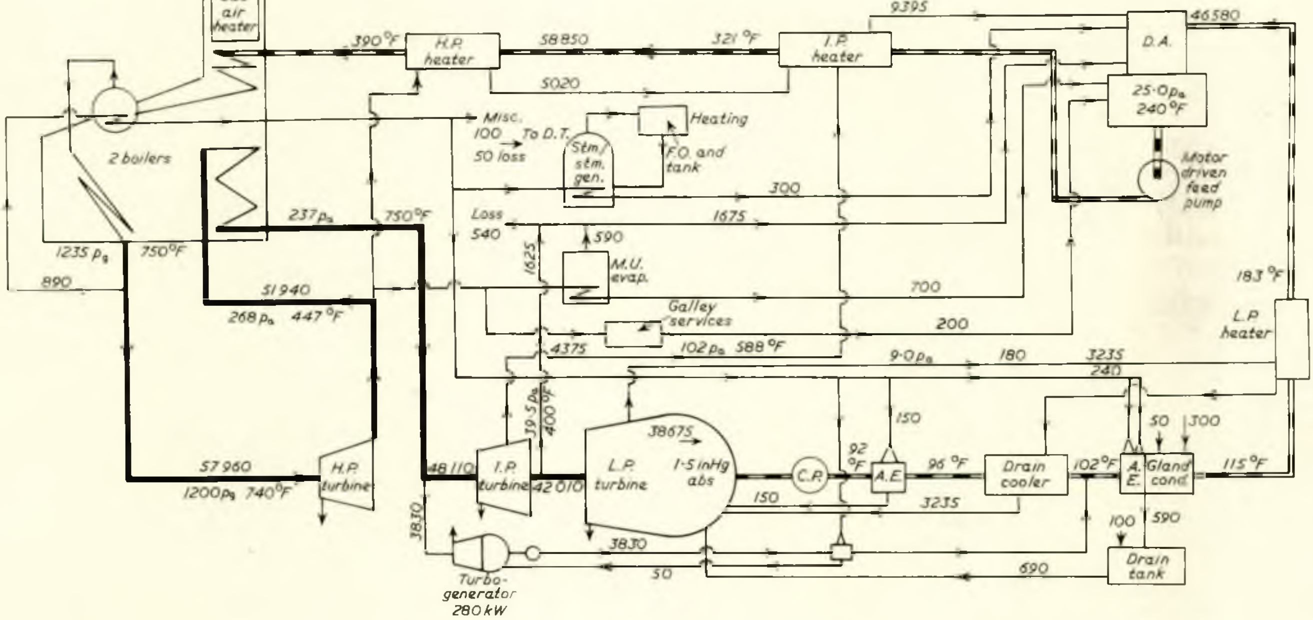
Let me conclude this lecture with a quotation from Rollo Appleyard's(17) biography of Sir Charles Parsons.

> The date is 1890. The conversation is between an American engineer and Sir John Biles, a friend of Parsons. The American wanted Sir John to persuade Parsons to adopt mass production techniques for his turbines.
>
> The American: "Why does not Parsons take all the orders?"
>
> Sir John: "He takes all he wants to keep his works going at the price the other fellows get for their reciprocating engines."
>
> The American: "So like you Britishers! If you can get your price, you jog along without any ambition. Why, if I owned the invention I should sell as much below the other fellow as ever I could afford. I should soon shut up their works and I should scoop the pool and make my own price."

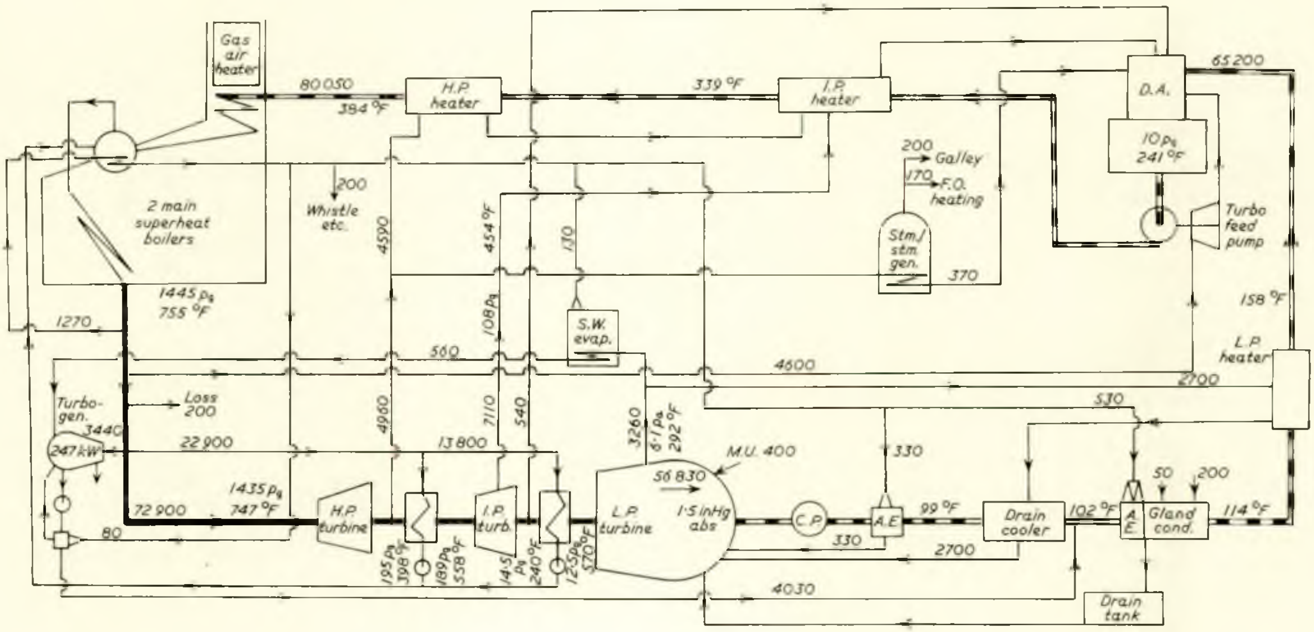
Mr. Chairman, I think I can hear others repeating these words now!

APPENDIX A

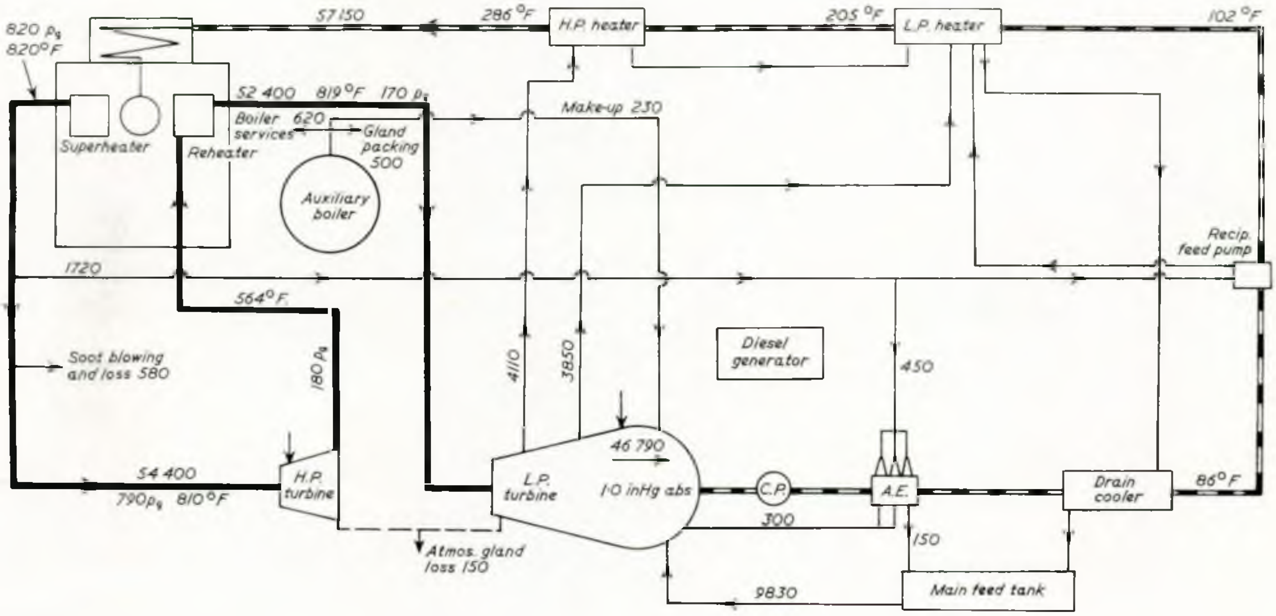
REHEAT CYCLES: PHASE I—HISTORICAL DESIGNS



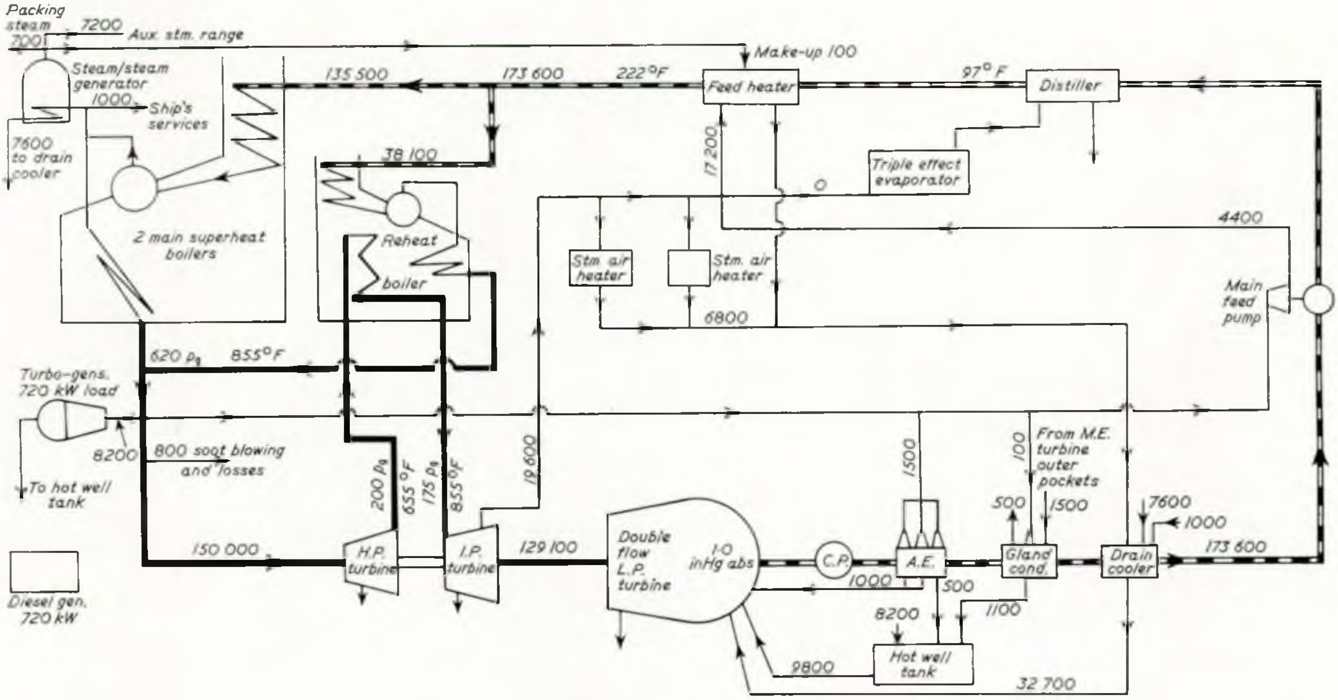
(a) *8000-shp reheat installation—s.s.* Examiner



(b) *11 760-shp reheat installation trials data—s.s.* Venore



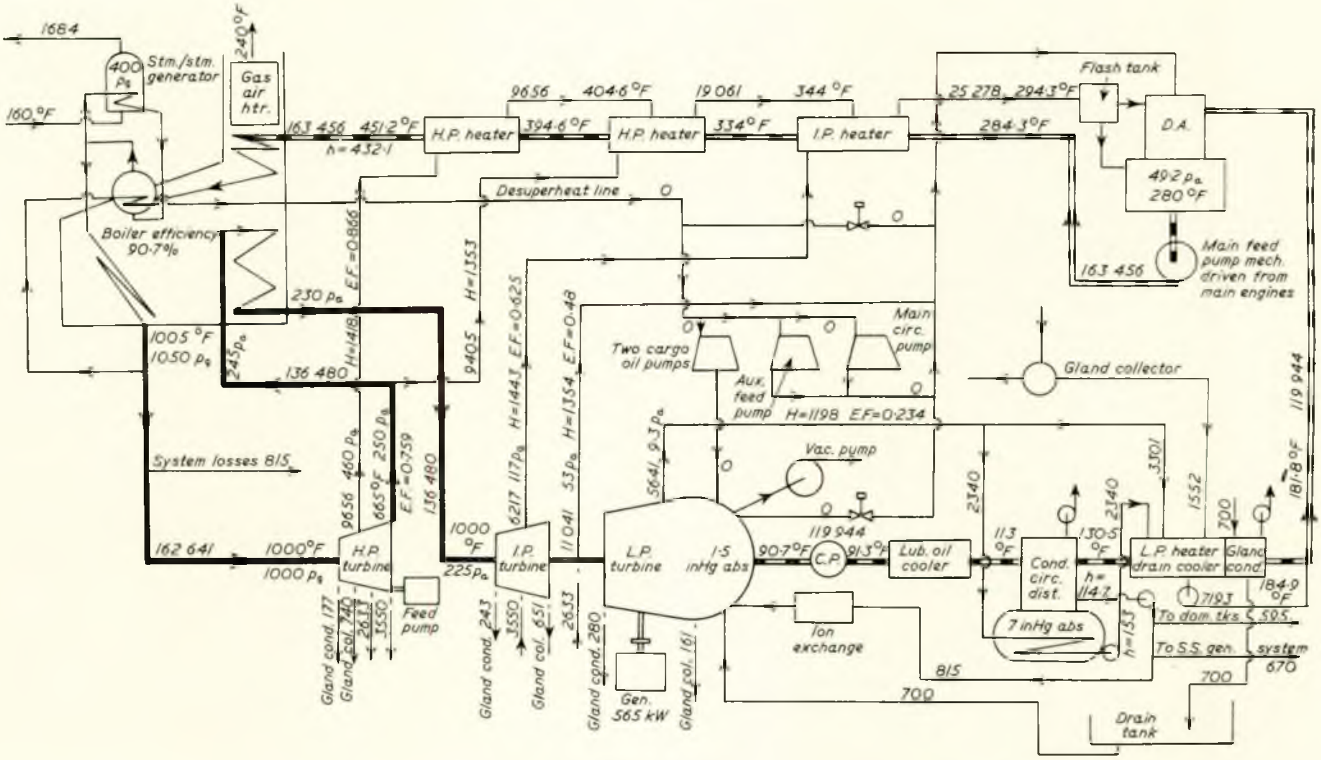
(c) *9000-shp reheat installation voyage data—t.e.v.* Beaverglen



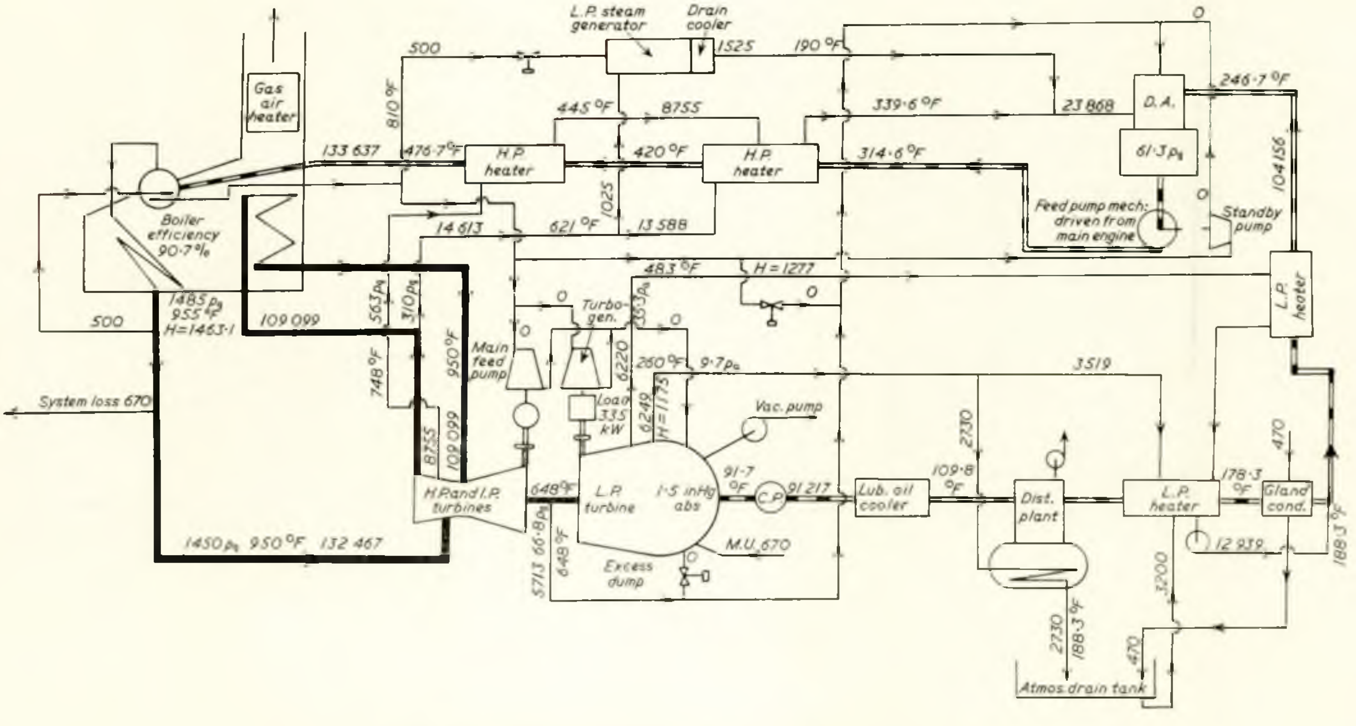
(d) 2 × *13 250-shp reheat installation voyage data—t.s.s.* Empress of Britain

APPENDIX B

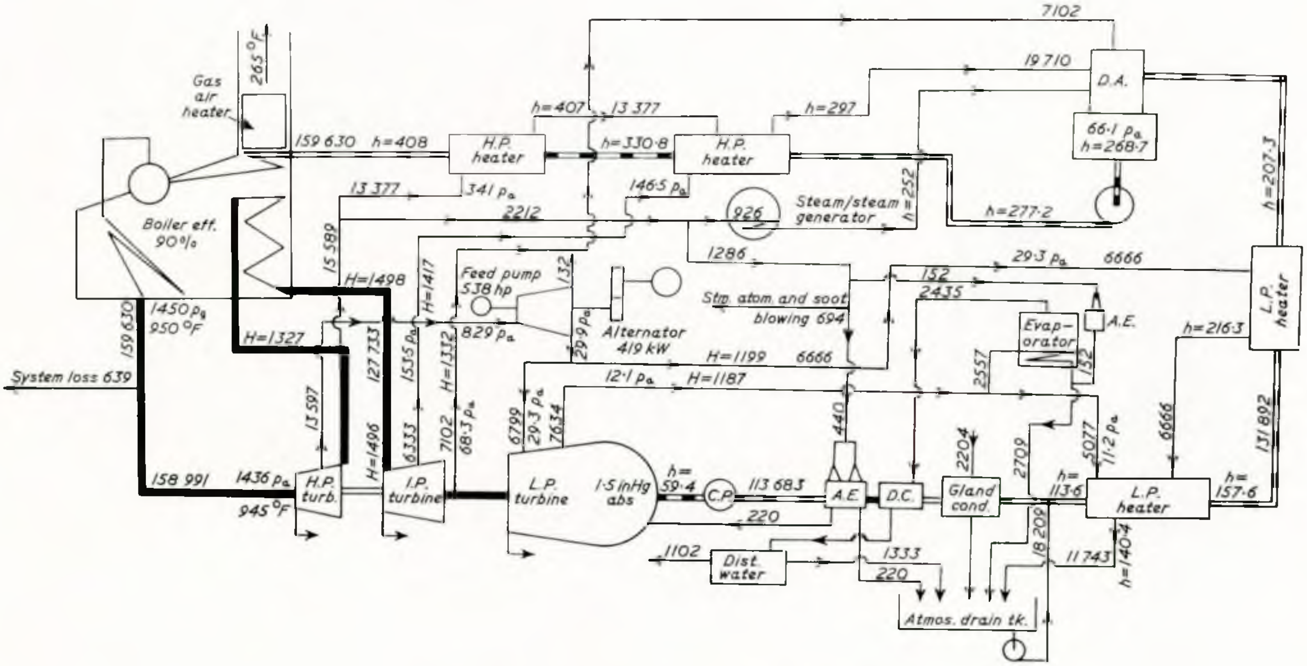
REHEAT CYCLES: PHASE II—CURRENT DESIGNS



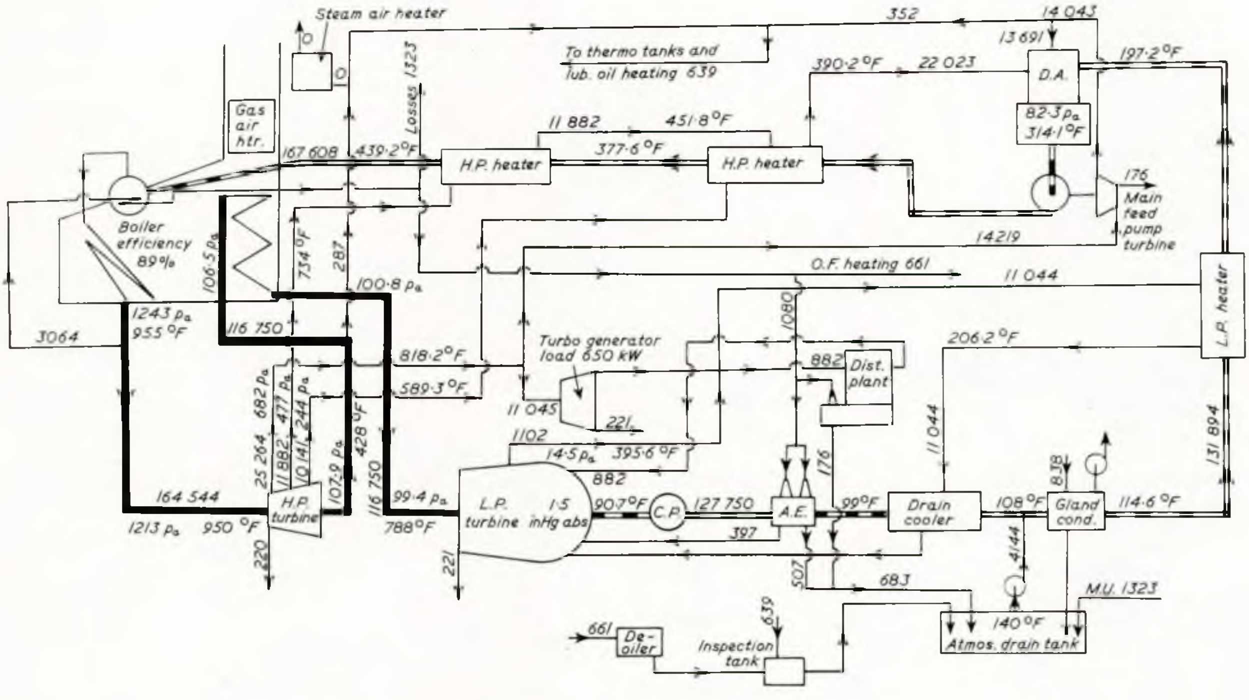
(a) *30 000-shp reheat installation—Pametrada*



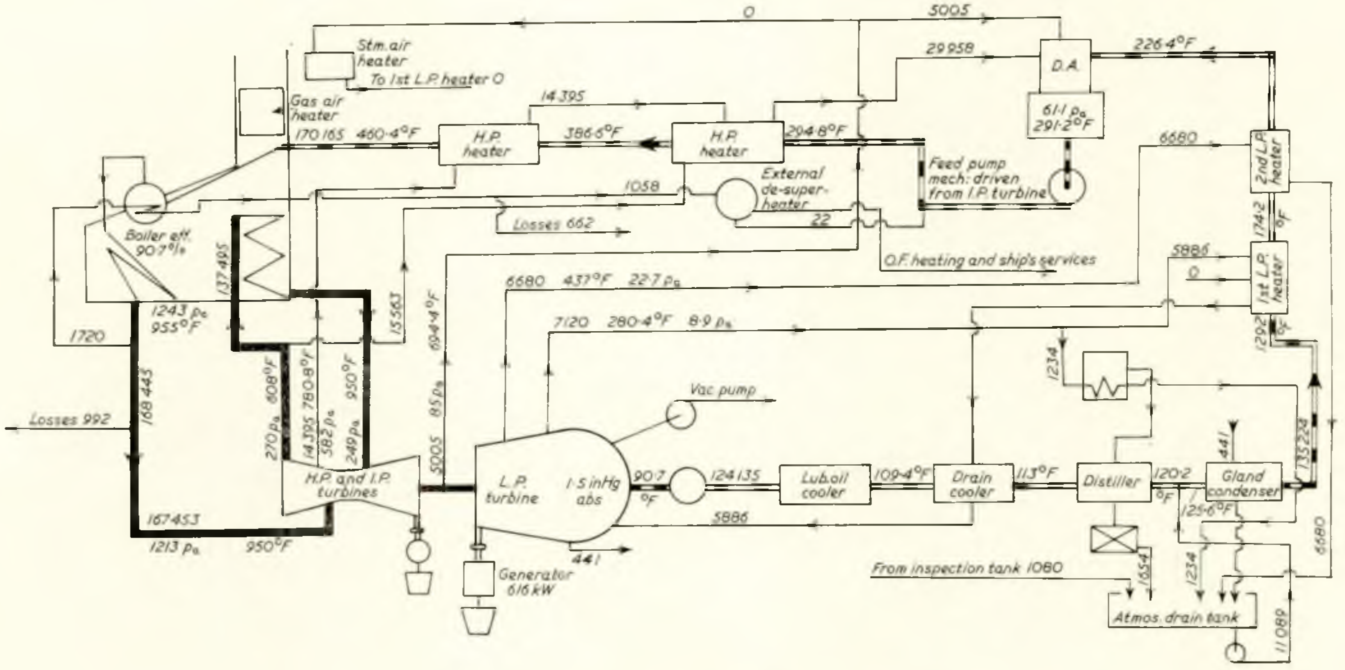
(b) *22 800-shp reheat installation—General Electric*



(c) *30 000-shp reheat installation—Stal-Laval*



(d) *27 611-shp reheat installation R.802—Ishikawajima-Harima.H.I.*



(e) *29 583-shp reheat installation R.804—Ishikawajima-Harima.H.I.*

Appendix C

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APPENDIX D

TECHNICAL PARTICULARS OF REHEAT INSTALLATIONS

Ship and turbine type	Shaft horse-power, British	Inlet pressure, lb/in² g	Inlet temp. °F	Reheat pressure, lb/in² g	Reheat turbine inlet temp., °F	Reheat pressure / Initial pressure	Turbine arrangement	Condenser (a) flow (b) situation	Gearing	Power distribution	Electric generator drive	Feed pump drive	Boilers type	Feed heating (a) stages (b) final feed temp.	Shaft rev/min	All purpose fuel rate, lb/shp h
Examiner Allis-Chalmers	8000	1200	740	222	740	0·185	Separate: H.P. I.P. and L.P.	(a) single (b) underslung	All single tandem articulated	H.P.: 29·6% I.P.: 32·4% L.P.: 38%	Reheated steam condensing	Motor driven	Single uptake reheat double furnace	(a) 4 (b) 390°F	96	0·513
Venore Bethlehem Steel	11 000	1410	740	1st. reheat 185 2nd. reheat 15	565 565	0·131 0·01	Separate: H.P. I.P. and L.P.	(a) single (b) underslung	Double reduction nested	H.P.: 30·9% I.P.: 28·2% L.P.: 40·9%	Live steam condensing	Live steam turbo	Two drum bent tube comb'n engineer corp.	(a) 4 (b) 384°F	95	0·504
Beaverglen C.A. Parsons	9000	800	850	185	850	0·231	H.P. and L.P. in tandem	(a) double (b) underslung	Electric transmission	H.P.: 23·4% L.P.: 76·6%	Diesel	Live steam recip.	Johnson water tube Melesco convection superheater and reheater	(a) 2 (b) 285°F	108	0·544
Empress of Britain Pametrada	2x 13 500	590	850	180	850	0·305	H.P. and I.P. in tandem. Separate L.P.	(a) double (b) underslung	H.P. and I.P. single tandem. L.P. single tandem. Both semi-articulated	H.P.: 22% I.P.: 41% L.P.: 37%	Live steam condensing and Diesel	Live steam turbo	F.W. control superheat with two furnaces and 'D' type reheat	(a) 1 (b) 222°F	123	0·55

PHASE I HISTORICAL DESIGNS

Turbine type	Shaft horse-power, British	Inlet pressure, lb/in² g	Inlet temp. °F	Reheat pressure, lb/in² g	Reheat turbine inlet temp. °F	Reheat pressure / Initial pressure	Turbine arrangement	Condenser (a) flow (b) situation	Gearing	Power distribution	Electric generator drive	Feed pump drive	Boilers type	Feed heating (a) stages (b) final feed temp.	Shaft rev/min	All purpose fuel rate, lb/shp h
Pametrada	30 000	1000	1000	235	1000	0·235	Separate: H.P. I.P. and L.P.	(a) single (b) underslung	H.P.: single tandem I.P.: single tandem L.P.: dual tandem	H.P.: 27·2% I.P.: 29·5% L.P.: 43·3%	Mech. off L.P. main turbine	Mech. off H.P. main turbine	One B&W radiant top fired damper controlled	(a) 5 (b) 451°F	110	0·398
G.E.	22 800	1450	950	310	950	0·214	H.P. and I.P. in one casing Separate L.P.	(a) single (b) axial	H.P. dual I.P.: tandem L.P.: dual tandem	H.P., I.P.: 51·0% L.P.: 49·0%	Mech. off L.P. main turbine	Mech. off H.P./I.P. main turbine	One F.W. two drum top fired damper controlled	(a) 5 (b) 476·7°F	80	0·399
Stal-Laval	27 993	1421	945	316	945	0·222	H.P. and I.P. in tandem. Separate L.P.	(a) single (b) axial	Epicyclic primaries single tandem	H.P., I.P.: 55·0% L.P.: 45·0%	Bled steam from H.P. turbine. One turbine drives both units	Bled stm. from H.P. turbine.	One B&W radiant top fired damper controlled	(a) 5 (b) 430°F	—	0·407
I.H.I. R.802	27 611	1198	950	93	788	0·078	Separate H.P. and L.P.	(a) single (b) axial	H.P.: single tandem L.P.: single tandem	H.P.: 43% L.P.: 57%	Bled steam from H.P. turbine	Bled stm. from H.P. turbine	One F.W. twin furnace reheat. One F.W superheat	(a) 4 (b) 439·2°F	95	0·436
I.H.I. R.804	29 583	1198	950	255	950	0·213	H.P. and I.P. in one casing. Separate L.P.	(a) — (b) underslung	H.P. dual I.P.: tandem L.P.: dual tandem	H.P., I.P.: 50% L.P.: 50%	Mech. off L.P. main turbine	Mech. off H.P./I.P. main turbine	—	(a) 5 (b) 460·4°F	—	0·402
A.E.G.							H.P. and I.P. in one casing. Separate L.P.	(a) single (b) underslung	H.P.: single I.P.: tandem L.P.: single tandem		Mech. off main gearing	Mech. off main gearing	One B&W radiant top fired damper controlled		80	

PHASE II CURRENT DESIGNS

APPENDIX E

PREVIOUS PARSONS MEMORIAL LECTURES, 1936-1965

Year	*Title, Lecturer and Institution*
1936	"Sir Charles Parsons and Steam" by Sir Frank E. Smith, K.C.B., D.Sc., F.R.S. (North East Coast Institution of Engineers and Shipbuilders).
1937	"Scientific Activities of the late Hon. Sir Charles Parsons, O.M., K.C.B., F.R.S." by G. Stoney, D.Sc., F.R.S. (Institution of Electrical Engineers).
1938	"Sir Charles Parsons and Marine Propulsion" by S. S. Cook, B.A., F.R.S. (Institution of Mechanical Engineers).
1939	"Some Researches on Steam Turbine Nozzle Efficiency" by Dr. H. L. Guy, F.R.S. (Institution of Civil Engineers).
1940	"The Engining of Highly Powered Ships" by Sir Stephen J. Pigott, D.Sc. (North East Coast Institution of Engineers and Shipbuilders).
1941	"Sir Charles Parsons and the Royal Navy" by Sir Stanley V. Goodall, K.C.B., O.B.E., R.C.N.C. (Institution of Naval Architects).
1942	"Reduction Gearing for Marine Steam Turbines" by S. F. Dorey, D.Sc., Wh.Ex. (Institute of Marine Engineers).
1943	"Optical Topics in part connected with Sir Charles Parsons" by Lord Rayleigh, F.R.S. (The Physical Society).
1944	"The Determination of Critical Speeds, Natural Frequencies and Modes of Vibration by Means of Basic Functions" by Professor C. E. Inglis, LL.D., F.R.S. (North East Coast Institution of Engineers and Shipbuilders).
1945	"High Voltage Research at the National Physical Laboratory" by R. Davis, M.Sc. (Institution of Electrical Engineers).
1946	"Recent Developments in Optical Glass Manufacture" by Sir Hugh Chance (Institution of Civil Engineers).
1947	"Parsons—The Man and His Work" by Sir Claude Gibb, C.B.E., M.E., F.R.S. (Institution of Mechanical Engineers).
1948	"British Marine Gas Turbines" by T. W. F. Brown, C.B.E., D.Sc., S.M., A.R.T.C. (North East Coast Institution of Engineers and Shipbuilders).
1949	"Progress in Marine Propulsion, 1910-1950" by K. C. Barnaby, O.B.E., B.Sc. (Institution of Naval Architects).
1950	"Sir Charles Parsons and Cavitation" by Professor L. C. Burrill, M.Sc., Ph.D. (Institute of Marine Engineers).
1951	"Sir Charles Parsons and Optical Engineering" by F. Twyman, F.R.S. (The Physical Society).
1952	"From Stodola to Modern Turbine Engineering" by C. Seippel (North East Coast Institution of Engineers and Shipbuilders).
1953	"Continuity of Electricity Supply" by H. Leyburn, B.Sc.(Eng.) (Institution of Electrical Engineers).
1954	"Factors Influencing the Continuing Development of the Steam Turbine" by F. Dollin, B.Sc. (Eng.) (Institution of Mechanical Engineers).
1955	"The Development of the Gas Turbine" by Sir Harold Roxbee Cox (Institution of Civil Engineers).
1956	"A Review of Naval Propulsion Engineering Progress in the Last Ten Years" by Vice-Admiral Sir Frank T. Mason, K.C.B. (North East Coast Institution of Engineers and Shipbuilders).
1957	"Aspects of Propellers for the Royal Navy" by R. W. L. Gawn, C.B.E., D.Sc., R.C.N.C. (Institution of Naval Architects).

1958 "Some Recent Progress in Nuclear Engineering" by Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S. (Institute of Marine Engineers).

1959 "Atmospheric Imaging Systems" by Dr. C. R. Burch (The Physical Society).

1960 "Sir Claude D. Gibb—Engineer" by A. T. Bowden, B.Sc.(Eng.), Ph.D. (North East Coast Institution of Engineers and Shipbuilders).

1961 "Magnetohydrodynamics" by Professor M. W. Thring, M.A. (Institution of Electrical Engineers).

1962 "The Duty and Development of Modern Power Station Plant" by F. H. S. Brown, C.B.E., B.Sc. (Institution of Mechanical Engineers).

1963 "Spadeadam Rocket Establishment" by A. B. Mann (Institution of Civil Engineers).

1964 "The High-speed Generator—Eighty Years of Progress" by W. D. Horsley (North East Coast Institution of Engineers and Shipbuilders).

1965 "Sir Charles Parsons and the Naval Architect" by Professor E. V. Telfer, Ph.D, D.Sc. (Royal Institution of Naval Architects).

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