THE ADMIRALTY TEST HOUSE NATIONAL GAS TURBINE ESTABLISHMENT

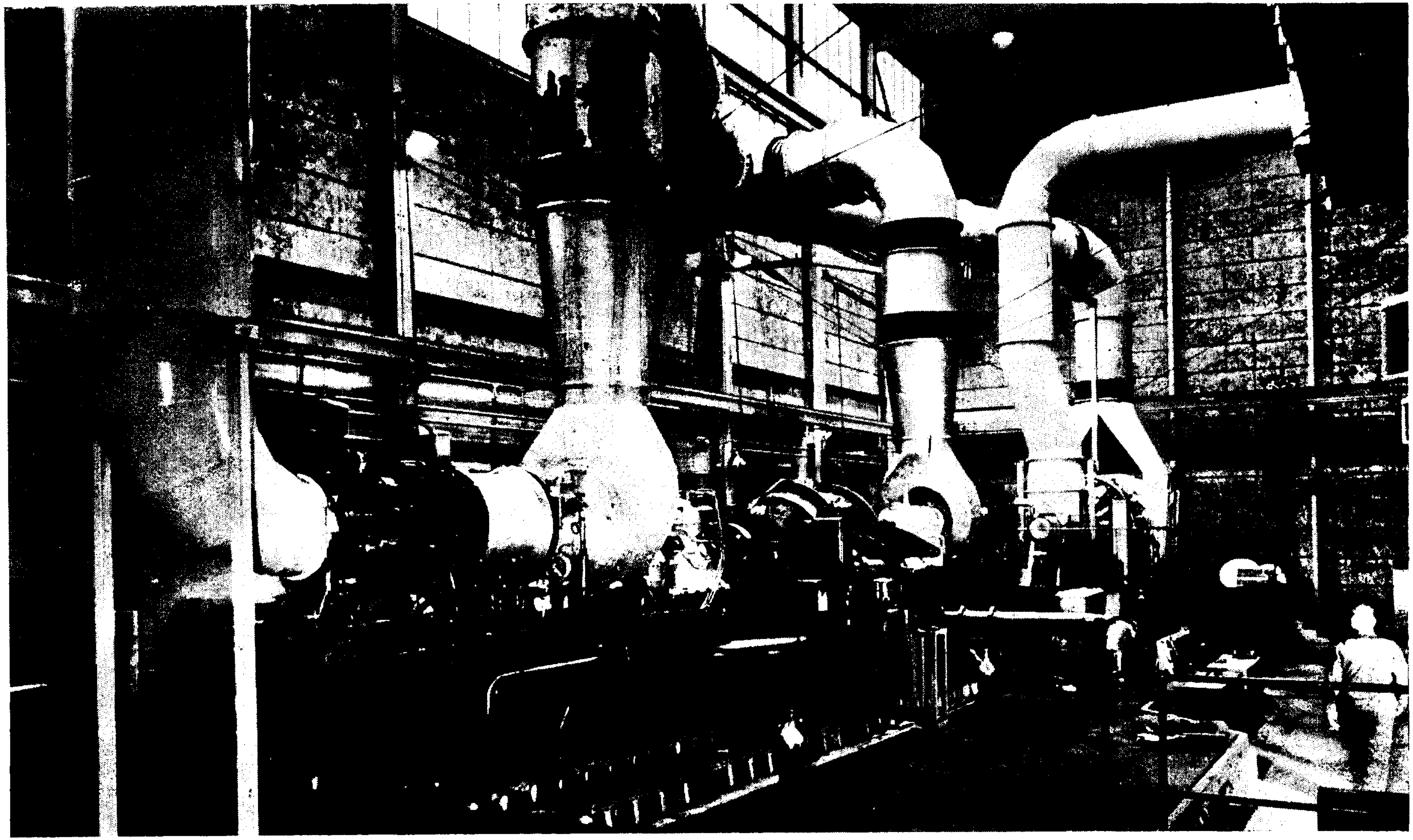
PURPOSE OF NAVAL MARINE WING

By 1947 the success of the aero gas turbine made it clear that, for marine purposes, there was in the gas turbine a potential rival to the steam turbine and the diesel engine. The gas turbine, however, differs from these established prime movers in that in order to produce a successful engine a very much more careful and accurate assessment of the performance of each of the major parts is necessary. If the gas turbine was to be made a success it was thus essential for the Admiralty first to have access to the best advice they could obtain on the design aspects of gas turbines, second to make sure that the gas turbine components were tested individually to see they achieved their intended performance, and lastly to test the complete engine not only to see that it achieved its intended performance thermodynamically but to see that its mechanical behaviour over prolonged periods of running was satisfactory; in fact that it was a reliable and robust engine suitable for use in a ship of the Royal Navy.

In this country by far the greatest part of the money spent on gas turbine research has been devoted to aero gas turbines and an immense amount of design knowledge has been built up, a large part of which is applicable to marine gas turbines. The knowledge obtained by the firms in this country is made available to the National Gas Turbine Establishment and the National Gas Turbine Establishment in turn keeps the firms informed of the results of its own researches. Thus the N.G.T.E. is in possession of an immense store of data on design problems. Data of this sort in written reports is not of too much direct value to the Admiralty; what is of more value is the advice which individual experts can give the Admiralty out of their own experience. It was thus natural for the Admiralty, by arrangement with the Ministry of Supply, to set up a Naval Marine Wing in the N.G.T.E. to act, amongst other functions, as a liaison between the Admiralty and N.G.T.E. for information between the experts and the Admiralty.

The testing of such components requires high horsepowers, and a large outlay on plant; for example to test even a comparatively small compressor such as that of the Allen 1,000 kW gas turbine alternator requires some 4,000 h.p. (there are means of reducing the horsepower requirements but at the expense of accuracy). Only very large firms can afford such facilities and a smaller firm will have either to make use of facilities available at another firm or use the facilities available at N.G.T.E. These latter include compressor test rigs of 6,000 h.p. at 18,000 r.p.m., 14,000 h.p. at 12,500 r.p.m. and roughly corresponding facilities for turbine rig tests and combustion chamber rig tests. The Naval Marine Wing serves as a liaison for the Admiralty in rig tests of components for Admiralty engines at N.G.T.E.

Considering the last requirement for testing complete engines, including endurance testing; in view of the fund of knowledge available at N.G.T.E. and the advice which is immediately available in the event of any difficulty, it was natural for the Admiralty to site the test house that would be required at the N.G.T.E.



THE TEST BAY

GENERAL DESCRIPTION OF THE ADMIRALTY TEST HOUSE

Objective

The Admiralty Test House has been designed for carrying out trials, under something approaching Service conditions, of gas turbines intended for main propulsion up to 10,000 s.h.p., but provision has been made for expansion of the test bed in the future if required for larger engines or for a greater number of small ones. A hydraulic brake is provided to absorb the load. A load tank has also been installed to deal with the testing of gas turbine alternator sets up to 1,000 kW output, with a 25 per cent. margin for overload. Instrumentation is full, and both control and observation arrangements are centralized. Auxiliary machinery is provided to cater for gas turbine sets which are not self contained in this respect, and heavy fuel can be heated to the correct temperature for burning.

The Building

The building is of steel framed concrete construction. It is nearly square in plan, 100 ft by 94 ft, orientated so that the exhaust gases are discharged on the leeward corner of the prevailing wind and the inlet air taken from the opposite corner well above ground to reduce dust intake. The flat roof is 50 ft above the ground. A number of buildings containing gas turbine and allied plants (not for naval purposes) have been erected in the neighbourhood ; and a grouping of electrical equipment, cooling towers, oil tanks, and heating has been arranged to serve the common needs of all buildings.

Subdivision

The main part of the building is the test bay, which runs the full length (100 ft) from floor to roof and is about the beam of an A.A. or A.S. frigate (40 ft). It contains the test bed, and has a temporary wall at the south end so that it and the test bed can be extended if necessary. A 20-ton electric traveller serves the whole test bay, and also a one-ton hand traveller. High up along one side runs the inlet air trunking, with extensions down to the bed, and on the other side the exhaust trunking is led up and out to an external duct built on a flat extensive roof. Big doors at the north end admit lorries to a loading platform under the crane. A ventilator runs about the full length of the roof and the test bay is of spacious appearance, well lit by side windows and overhead flood lights, and enhanced by a scheme of light colour painting. All walls and roof are lined with slabs of compressed fibre to damp noise.

On the ground floor to the east side of the test bay are a fuel oil and lubricating store, a pump room which is open on one side to the test bay and which contains the fuel and lubricating oil auxiliary machinery including heaters, coolers, etc., and an electrical room with switchgear, transformers, rectifiers, emergency diesel generator and rotary converter.

On the ground floor to the west side are a workshop and store.

On the first floor to the east side of the test bay is a flat open roof supporting the exhaust duct and splitters, and also a hut over the pump room containing two gravity tanks, one for fuel oil and the other for lubricating oil.

On the first floor to the west side of the test bay are the control room and three offices. The control room window is designed to be opposite the centre of the test bed when the extension has been built.

On the second floor to the west side are the air intake arrangements which run the full length of the building.

On the third floor to the west side is the tank room for the dynamometer header tank, the ceiling being level with the ceiling of the test bay to form the roof of the building.

Plant Design

Plant design was commenced in August, 1948, when a Captain (E) was appointed to the National Gas Turbine Establishment to build up a Naval Marine Wing. As the requirements for testing large gas turbines, particularly in adaptation to naval or marine use, necessitated broaching fresh ground and peering into a very dimly lit future, design involved considerable ground work and imagination.

Construction

The scheme was shaped in sufficient detail to ' Lay the Keel ' in May, 1951, when work was commenced on the test bed. The building around it was started soon after. The construction of the building and installation of standing machinery was executed mainly by contract supervised by the Ministry of Works, who met many difficulties due to the current shortage of steel, and conflicting demands of the rearmament programme. The contractors did well to complete the building ready to run the first engine trials within 18 months from the arrival of the first girder for the frame of the building.

DESCRIPTION OF PARTS

Test Bed

The test bed was modelled on a larger one built at Pametrada. It consists of a mass of heavily reinforced concrete, 6 ft deep, carrying four parallel lines of cast iron girders of massive construction. Each line is made up by nine ' I ' section girders each 8 ft long set end to end with a 1½ in. space between. The top faces of the girders are 15 in. wide and their centre lines are set 3 ft apart. The girders, in addition to being grouted in to half their depth, are bolted down by 2-in. bolts of considerable length which extend down into the concrete and are secured to the actual reinforcing. The whole structure, therefore, is of very solid construction and its weight should prevent vibration troubles. It is sunk in the ground so that deck plates on either side level with it form a convenient floor for the test bay, graded to the approach road outside.

The girders were levelled before being finally bolted down to within five thousandths of an inch of datum level and the average level of each girder is within two thousandths. Slots are provided at frequent intervals along the flanges of the girders for engine holding down bolts up to 2⅛ in. diameter.

A 20-ton electric crane and a 1-ton hand crane serve the whole length of the test bed and the loading platform.

Air Inlet

Air is drawn through a series of portable splitters to reduce noise and thence by way of a bank of dust filters (down to 10 microns) to a venturi nozzle consisting of throat, measuring section, and diffuser. It then continues through steel trunking of section 5 ft square into and along a distributing shaft high up along the length of the test bay, take-off pieces interchangeable in position with simple straight-through pieces, composing the distributing shaft. Ducting shaped to suit the size and position of the intake to turbines on the test bed is led down from the take-off pieces. So far as possible, ' cascades ' i.e. internal deflector plates, are fitted to right angled bends to reduce eddy losses.

The actual venturi throat with its measuring length and diffuser, and the parts immediately preceding it (the air inlet entry piece, which collects the air which has passed through the filters, and a length 6 ft in diameter containing a honeycomb section for straightening out the flow prior to entering the throat) are made of wood. All parts of the inlet trunking which are outside the test bay, both wood and steel, are supported on rubber strips to damp noise.

There are two interchangeable venturi assemblies, one having a 36-in. throat for measuring mass flows between 150 and 50 lb/sec., and one with a 28-in. throat for smaller mass flows.

Exhaust

Exhaust trunking from each turbine on the test bed is led up to a common duct, which takes the gases out of the test chambers to a diffuser and set of splitters on the flat roof to the east of the test bay. Two water injection rings are incorporated in the system to assist in further silencing, they are fed from a pump which draws water from the dynamometer header tank, a maximum of 6,000 gallons per hour at 100 lb/sq. in. being provided.

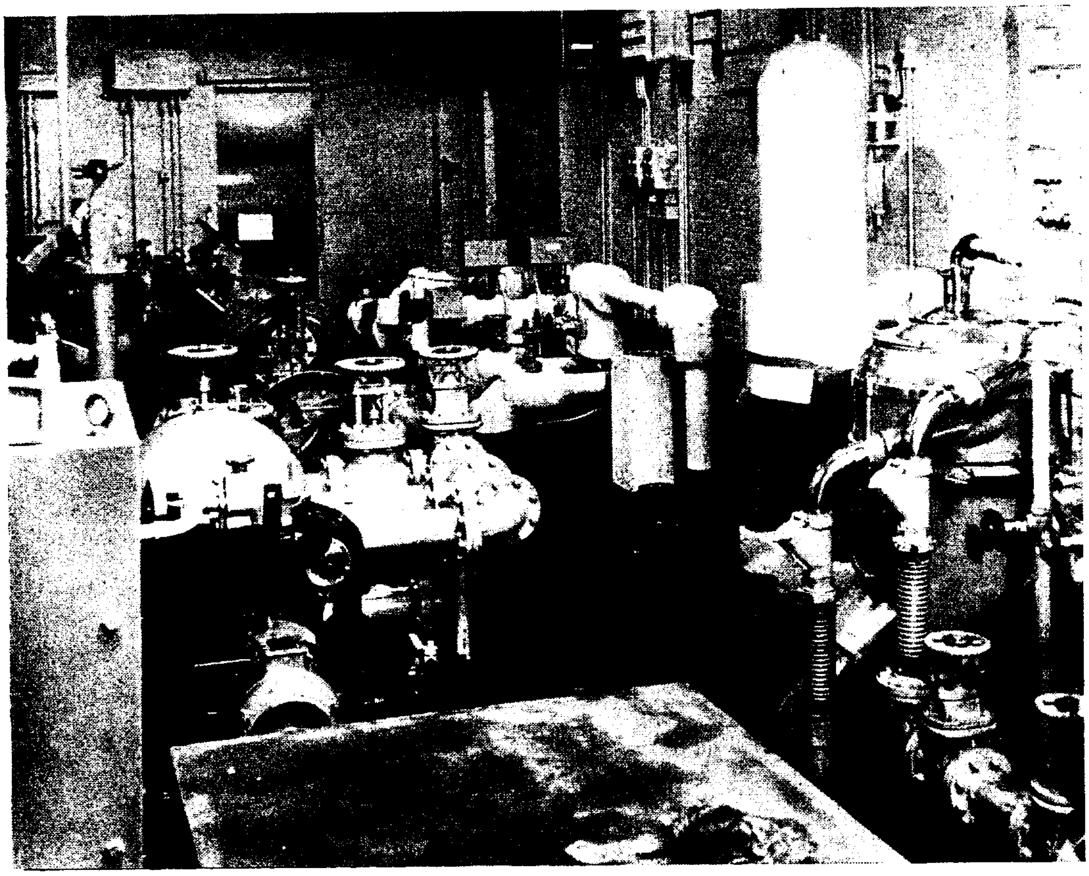
Bellows pieces allow expansion in the individual leads of trunking from each turbine, and an expansion gland is fitted in the common duct at the end of the diffuser.

Dynamometer and Water Circuit

A Heenan and Froude double-ended reversible water brake type dynamometer, mounted on a stool, capable of being sited as required on the test bed, is provided to absorb load up to 10,000 s.h.p. in either direction. Its maximum permissible speed is 1,100 r.p.m. and the slowest speed at which the full horse power can be absorbed is about 620 r.p.m. Remote control of the back pressure valves, which regulate the load, is arranged from the control room, and a hydraulic weighing gear also enables the torque to be measured from the control room. A feature of the weighing gear is an oscillator to prevent inaccuracies in readings due to sluggishness in the transmitting and receiving pistons and in the long lengths of piping connecting them.

The brake is designed to stand, within certain speed and power limits, an instantaneous reversal of torque. Within the short time (visualized as little as 15 seconds) required for the system to slow down, stop, and speed up in the reverse direction, a change-over cock enables the weighing gear to recommence registering. The brake can be run with its axis inclined at any angle up to 11° with the horizontal, to enable it to test engines which are installed at a rake.

A 12,500-gallon header tank supplies water to the brake at a constant head of about 40 ft, and the brake drains to a hot sump through a 14-in. pipe. The water is then pumped to a cooling tower and again from the cooling tower pond to the header tank. An overflow from this tank to the hot sump of ample capacity, enables the head to be kept constant despite varying requirements of the brake, and both pumps and ' key ' valves in the system are controlled from the control room. The pumps and cooling tower are designed to give a margin over the maximum requirements of the brake, which are 64,000



THE PUMP ROOM

gallons per hour cooled from 140°F. down to 100°F., and the 6,000 gallons per hour referred to under ' Exhaust ' (which is, of course, supplied but not returned). Float controlled make-up valves on this and all other cooling tower ponds mentioned in this article are designed to give ample compensation for evaporation and other likely losses.

Load Tank

For absorbing the output of alternators driven by gas turbines under test, arrangements have been made to provide a variable load for A.C. current up to 440 volts and 1,250 kW by means of a load tank, situated in the open with switchgear in the electrical room. The load tank is divided into four equal portions, three of which have a common water level kept steady by float controlled supply, and the fourth level varied by two pumps which are controlled from the control room. Current from the alternator is fed to a supply-breaker controlled from the control room, and thence to four switches one to each quarter of the tank, locally controlled, but with indicators in the control room, which is connected, of course, by telephone. Thus it is possible for the control room to vary the load either in steps throughout the whole range or gradually through a chosen range. Space has been left for further switch gear to connect to the grid in future, if required.

Fuel System

Fuel stowed in two 10,000-gallon ready-use tanks (each designed to give a 10-hour run) is pumped by either of two electrically driven rotary type pumps, through strainers and filters, and by a cross-connected system, up to the discharge valve at the end of the system, to which is connected the suction system of the turbine under test. Incorporated in the test house system are a steam-worked heater, two Titan centrifugal separators in parallel, a 1,300-gallon overhead tank for centrifuged oil, and a second steam-worked heater, all of which can be by-passed when running on light oils. Additional by-pass arrangements are provided to enable turbines to be started up on light oil and switched over to heavy residual oil, hot oil circulating pipes being included.

The system is designed to supply up to 1,000 gallons per hour of clean fuel at about 20 lb/sq. in. and at a suitable temperature to the suction side of the fuel pump of the engine being tested. Steam heating is provided to heat residual oils up to 120°F. in the 10,000-gallon ready-use tanks, up to 180°F. in the first heater for centrifuging, and up to 220°F., in the second heater. Thermostatic control is provided on the heaters. Suitable filling arrangements are made to charge the ready-use tanks from a large tank farm.

A ' Tecalameter ', read in conjunction with specific gravity readings taken from a sampling cock, measures the flow. Dip stick readings of the ready-use tanks are taken as a long-time check.

Lubricating Oil System

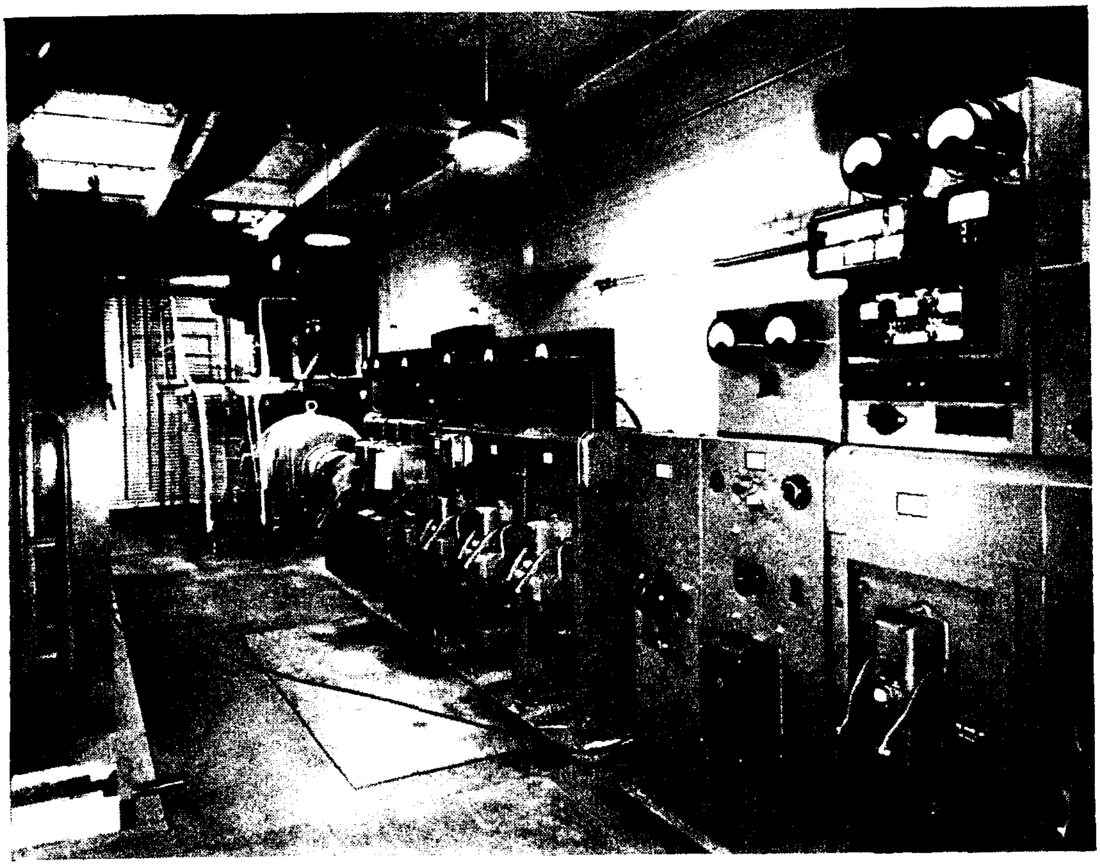
A complete lubricating system charged with Oil OM–100, is provided by the standing plant, capable of supplying about 15,000 gallons per hour up to a pressure of 36 lb/sq. in. to the inlet of the distribution system of a gas turbine under test, and of receiving the drainage in a drain tank. In cases where the turbine has its ancillary supply pump, the oil can be supplied from a header tank giving a head up to about 16 ft instead of through an electrically driven pump, but the latter can be put into use at short notice if the turbine's pump (itself probably under test) were to fail.

The oil which returns to the drain tank is drawn out through a strainer by an electrically driven lobed booster pump which delivers it through ' Clinsol ' filters at about 30 lb/sq. in. to two water-cooled coolers and thence to the header tank, whence a downtake leads it, through a ' Tecalameter ' and orifice plate in parallel either direct or through the 36 lb/sq. in. pressure pump, to the turbine under test. In order to maintain a constant level in the header tank, a pre-adjusted weir in the tank allows oil to overflow back to the drain tank, the booster pump being run at a speed to deliver more oil than the turbine-requires. An Alfa Laval centrifugal separator draws oil continuously from the drain tank and returns it there, or can similarly deal with the oil in the header tank.

To provide for a shut down due to grid failure (which would stop the booster pump) a small emergency pump worked from an emergency diesel generator can lift enough oil from the drain tank to the header tank to keep the turbine bearings lubricated whilst the turbine is being turned by its turning motor (which, if D.C., can also be supplied from the emergency diesel generator). The 36 lb/sq. in. pressure pump can also be driven off this emergency diesel generator so as to keep up supply to the bearings (as long as the oil in the header tank will last) whilst the turbine is slowing down.

When the turbine under test is self contained as regards its lubricating oil circuit, the centrifugal separator in the standing plant can be used through connections provided for flexible pipes. Temporary connections can be made to use the standing plant coolers if required, or to use the standing plant as a stand-by lubricating system.

A 5,000 gallon storage tank provides the main reservoir from which the oil can be run down to the drain tank.



THE ELECTRICAL ROOM

Intercooler and Lubricating Oil Cooler Circuits

An 18-in. bore pipe from a pump which takes suction from a separate cooling tower forms a supply main, running along the east side of the test bed, to any intercoolers which may be part of the turbine under test. A similar return main is provided along the west side of the test bed and thence out of the building to a hot sump, whence it is pumped to the top of the cooling tower. Both supply and return mains are built up of interchangeable lengths to meet whatever positions the intercooler inlets and outlets may happen to occupy on the test bed. Control of pumps and key valves is arranged for from the control room. A 6-in. pipe is led off the end of the supply main to two lubricating oil coolers, which are in series, and thence direct to the hot sump. The whole system is designed to circulate 230,000 gallons per hour and cool it from 89°F. down to 72°F.

The nearby cooling tower for a Parsons 10 MW gas turbine alternator is cross-connected with the intercooler and dynamometer systems so that any tower can be used for any of the three services.

Electrical Equipment and Circuits

The main electrical supply is fed from the grid and distributed to the neighbouring buildings at the usual 415 volts 3 phase 50 cycles. This is, in general, used for driving the standing plant and for lighting the building but a large portion of it can be converted into either 440 volts 3 phase 60 cycles or 220 volts D.C., in order to run auxiliary machinery attached to gas turbine plants which are intended for ships having either of these systems. In addition a 50 kW supply of D.C. at 220 volts is available from an emergency diesel-driven generator to give limited lighting, lubrication and other services needed to prevent damage to a turbine on trial in case of failure of the main supply due to grid failure or other cause.

The main supply is led to a 750 kW oil immersed switch on the 415 volt 50 cycle 3 phase switchboard in the electrical room, and on this switchboard are mounted metalclad switches to supply the various services as follows :—

300 kW motor alternator set for conversion to 440 volts 3 phase 60 cycles.

Two 175 kW transformer rectifier sets for conversion to 220 volt D.C.

Three heaters in lubricating oil header tank, and four heaters in lub. oil drain tank.

Heater on lubricating oil centrifuge.

Overhead travelling crane in test bay.

Various pumps, etc., in the pump room, viz., two fuel oil boost pumps, lubricating oil boost pump, fuel oil separators with ancillary pumps, lubricating oil centrifuge, exhaust duct cooling water pump.

Workshop machinery.

Lighting (two circuits, each single phase).

Welding points and small power plug points.

Two 30 amp. switches in test bay for driving lubricating or other temporary pumps which may happen to come with turbines on test.

The motor alternator set mentioned above supplies current to the 440 volt 3 phase 60 cycle switchboard (all in the electrical room), where it is distributed to any of the following which may be on the gas turbine under test :—

Starting motor (up to 300 kW).

Turning motor (25 kW).

Two fuel oil pressure pumps (each 25 kW).

Two lubricating oil pumps (each 10 kW).

Two miscellaneous pumps or fittings (each 25 kW).

The two transformers and rectifiers supply a total of 350 kW at 220 volts to the D.C. switchboard (which is fitted with open knife type switches), all in the electrical room, whence it is distributed to the same services as the 440 volts 3 phase 60 cycles, and in addition, to some of the lubricating oil pumps.

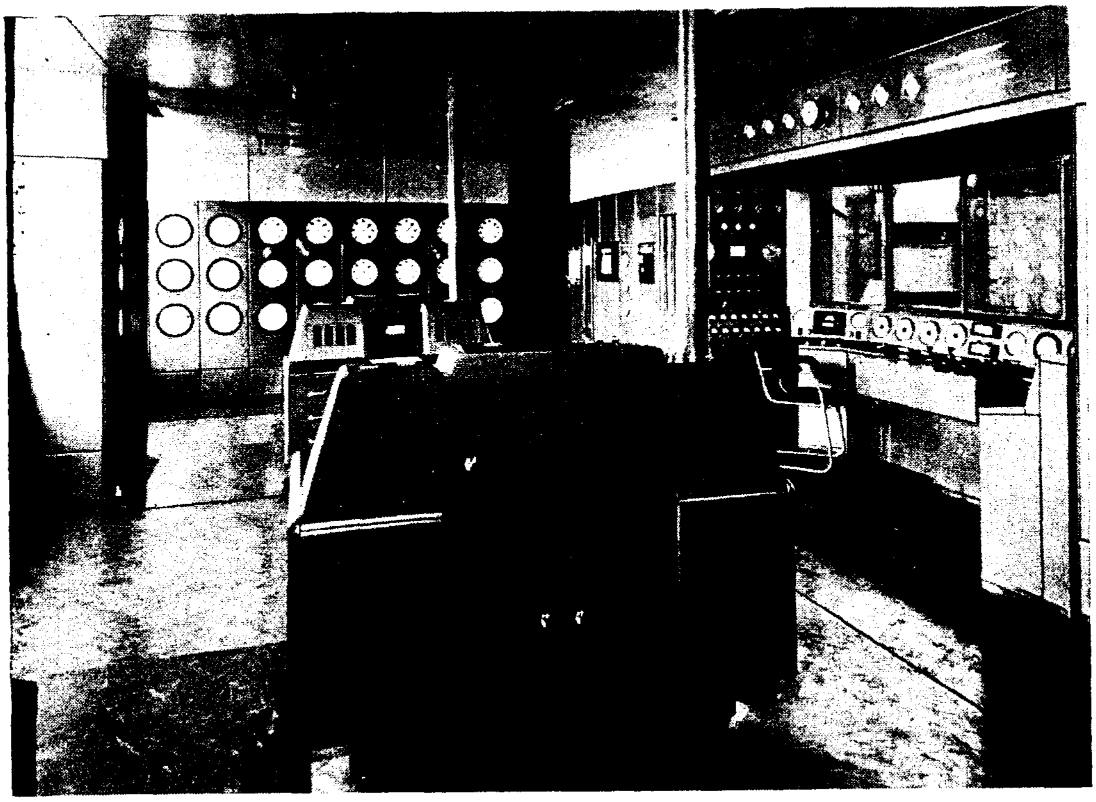
The emergency diesel generator is connected by a change-over switch to some of the items which are normally supplied by the transformers and rectifiers, viz., turning motor and lubricating oil pumps. It also supplies a small emergency pump to lift a limited flow of lubricating oil from the drain tank to the header tank, and an emergency circuit.

The emergency diesel generator is intended to supply, during grid failure, sufficient lubricant whilst a gas turbine is slowing down after being shut off, and to turn it (and maintain an oil circulation) whilst it is subsequently cooling, as is necessary for some types.

Oldham lamps, fitted with hold-off switches to close on main current failure, are wired in to a 230 volt A.C. circuit throughout the building, as secondary lighting.

A small amount of 24 volt D.C. lighting is provided (by separate transformers and rectifiers) for instruments in the control room.

Workshop machines are fitted with 24 volt lighting (A.C.) from transformers.



THE CONTROL ROOM

Control and Instrumentation

Considerable thought and research has been put into the design and instrumentation of the control room, which as mentioned earlier, will become even more the focal point when the building and test bed are extended.

In deciding upon the number and type of instruments which should be provided, it was necessary to consider the great variety of engines from small electrical generators to medium and large type propulsion units which may be sent here for testing.

Thus in the first layout of the control room, instrumentation by the best known methods has been provided for complete performance analysis of gas turbo generators/alternators up to 1,250 kW and propulsion units up to 10,000 s.h.p. In doing this, however, some assumptions as to likely cycle arrangements have been inevitable, but in general the most complicated cycles thought likely have been catered for.

The following cycle for a propulsion unit is given as an example :—

3 stage compression with two intercoolers.

2 reheat chambers, a free power turbine and heat exchanger.

The present engine test arrangements include the performance and endurance running of the 1,000 kW gas turbine alternator manufactured by Messrs. W. H. Allen, Sons & Co., Ltd., of Bedford, and the acceptance trials of the reversible 10,000 h.p. dynamometer manufactured by Messrs. Heenan and Froude, Ltd., of Worcester, for which two Metropolitan-Vickers ' Gatric ' engines *ex* M.T.B.s are coupled one at each end of the brake. The ' Gatric ' engines were the first gas turbines in the world to go to sea. All the necessary instrumentation for these two projects has been amply covered by the overall facilities available.

The instrument panels, of unit construction and interchangeable, were supplied finished with suitable ' cut outs ' ready for the flush mounting of the instruments. All the instruments and the intensive and intricate system of pressure gauge piping, and electrical wiring running into several miles have been installed entirely by the test house staff.

Particular attention has been paid to the measurement of the mass flow through the air intake and to the means of obtaining the accurate temperature and pressure distribution throughout the whole of the aerodynamic cycle.

Firefighting Equipment

Means are provided for the test house staff, which is small, to deal with small fires and also to take immediate steps to start fighting a major fire pending the arrival of the Establishment Fire Brigade which is a standing force.

Hand appliances are distributed throughout the building on the following lines :—

Hand CO_2 extinguishers are placed in pump room, electrical room, test bay, control room, and workshop, and soda acid extinguishers in the control room.

Hydrants fed from a ring main which serves the site are situated at each end of the test bay and outside the offices. Close to them are hoses, jet spray branch pipes of the London Fire Brigade pattern, pattern No. 7233 FB2(s) foam making branchpipes, and drums of foam compound. Foam inlet tubes are fitted to the chequer plates in the pump room and adjacent part of the test bay for use with the foam making branchpipes when dealing with fires in the ' bilges '.

The pump room area and adjacent part of the test bay, with hot oil pipes, heaters, etc., is a special fire risk, and a ' Mulsifyre ' system of protection by water sprayed from nozzles overhead is installed. It is intended for use only with major fires, and is operated either by deliberate action (by means of compressed air) from the control room, or automatically by temperature worked detectors. The fuel oil and lubricating oil store, known as the ' tank room ' is also provided with a ' Mulsifyre ' system. The water for these systems is supplied from the ring main for the site.

The electrical room is fitted with fixed CO_2 protection, nozzles distributing the gas throughout the room from a battery of bottles in the tank room. The lubricating and fuel oil header tanks are fitted with air operated jettison valves worked from the control room.

The floor of the tank room under the three storage tanks (two of fuel and one of lubricating oil) forms an oil-tight sump divided into three parts, each of which is designed to hold the contents of the tank above it if the tank be damaged.