FIG. 1.—M.G.B. 2009 IN THE SOLENT, AUGUST 1947

Daily Graphic

PART I

GAS TURBINE PROPULSION IN A NAVAL CRAFT

M.G.B. 2009 *made naval history in August,* 1947, *being the first vessel to be propelled at sea by a gas turbine. The arrangement of the installation emanated from the Department of the Engineer-in-Chief of the Fleet ; the manufacture of the equipment and the work of installation in the craft at Messrs. Camper and Nicholson Ltd. being entrusted to Metropolitan-Vickers & Co. Ltd., whose descriptive brochure on the subject is reproduced herewith. It is intended to publish details of the installation work and trials in later issues of this Journal.*

In M.G.B. 2009, an experimental naval craft employing a gas turbine, normal cruising and astern power is provided by two 1,250 B.H.P., 2,400 r.p.m. Packard internal combustion reciprocating engines, each engine driving its own propeller through a reduction gear. Maximum ahead power is obtained by bringing into operation a completely independent Metropolitan-Vickers gas turbine of 2,500 S.H.P. which drives a third propeller through speed reduction gearing, to supplement the power of the reciprocating engines.

This is the first naval vessel ever to be propelled by a gas turbine. When the Admiralty entrusted the equipment to Metropolitan-Vickers, it was decided that a jet engine that had already been developed by the Company should be employed for the gas generator portion of the plant. New development, as far as the gas turbine was concerned, was thus in the main confined to the power turbine and its gears, and to certain modifications to the control system. It was fully appreciated at the outset that this jet engine or gas generator possessed performance characteristics that were not ideal for use with power turbines for duty of this character, chiefly in respect of its somewhat low compression ratio, and it was realised that overall efficiency would be affected on this account. It was felt however that only by such means could experience be obtained in the actual operation and control of such a craft within a reasonably short time. Moreover, with a gas turbine that is essentially a peak load plant, fuel consumption is of secondary importance.

GAS TURBINE PLANT

Gas Generator

The compressor is a nine-stage axial flow machine with aerofoil section blades of aluminium alloy. The moving blades are mounted in axial serrated slots in a forged aluminium alloy drum, and the fixed blades in dovetail slots axially disposed in the stator casing, which is also of aluminium alloy.

The rotor, which is shown in Fig. 2, is provided with a conical extension piece to the end of which is secured an extension for the mounting of the turbine disc. This combined rotor is carried in two ball bearings with the turbine disc overhung. The forward or compressor end bearing acts as a thrust bearing ; the turbine end bearing is carried in a splined housing which has freedom of axial movement against spring compression.

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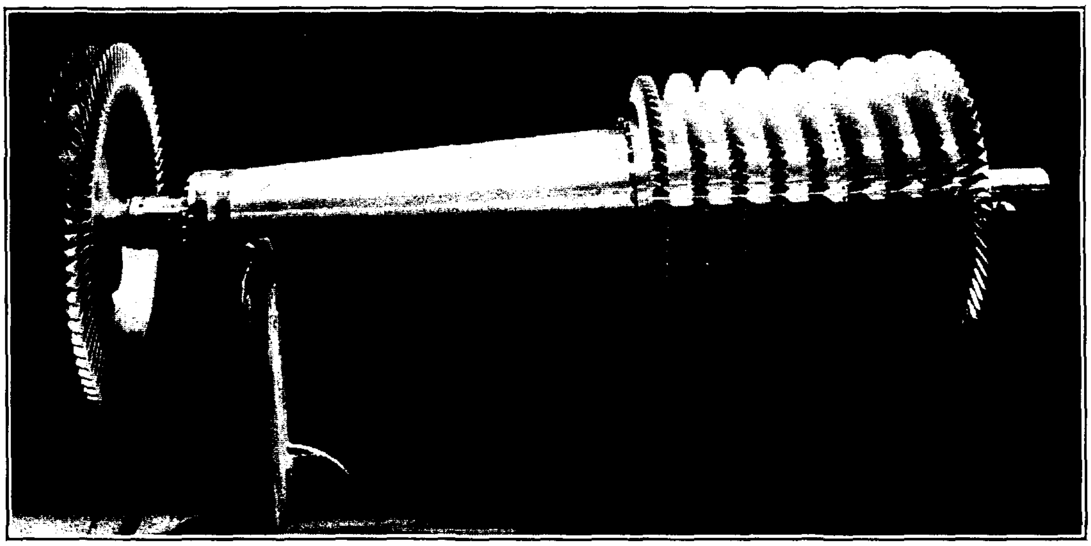

FIG. 2.—GAS GENERATOR—ROTOR

These bearings are lubricated by an oil mist, the oil being supplied from two feeds of a small eight-feed positive displacement pump. The oil so fed is entrained in air taken from the fifth stage of compression and is directed on to the bearing. The oil is not recirculated, but the quantity used is very small, being of the order of four pints per hour including oil for the power turbine bearings and auxiliaries. The bearings are cooled also by means of air taken from this stage of the compressor and led through the interior of the rotor to ventilating air passages formed in both rotating and stationary bearing housings.

On the casing of the compressor are mounted various auxiliaries including fuel pump, governor, tachometer generator, electric starting motor, and lubricating oil pump, together with fuel control and relief valves. A mechanical drive for the auxiliaries is taken from the forward end of the compressor shaft through bevel gear boxes and a vertical shaft.

The combustion chamber is of the annular type developed by Metropolitan-Vickers for jet propulsion engines, and is characterised by " straight through " flow. The chamber consists of two concentric walls containing an annulus, within which is mounted an annular primary chamber consisting of inner and outer walls. Air entering the chamber from the compressor is divided ; the smaller portion enters the primary chamber or zone of primary combustion through a series of holes on the upstream end of this chamber, and the larger part passes to the inner and outer annuli formed between the primary chamber and the containing walls. Pool gas oil is injected in a finely atomised stream into the primary chamber through 20 fixed orifice jets in an upstream direction. The high temperature products of combustion in the primary chamber are then mixed with the remainder of the air, which enters the chamber through a number of slots in the inner and outer walls of the primary chamber, resulting in a mixture at a temperature suitable for the turbine inlet. The sheet metal portion of the combustion chamber is of " Immaculate 5 " stainless steel which has excellent heat-resisting qualities and a coefficient of expansion approximating to that of aluminium alloy.

The turbine driving the compressor is of the two-stage type with a disc of molybdenum-vanadium steel carrying moving blading of " Nimonic 80 " alloy. A stub shaft is forged integral with the disc and is splined and locked into the end piece of the conical extension of the compressor drum. Each side of the turbine disc is cooled by a flow of air from the centre radially outwards, the air being taken from the compressor outlet.

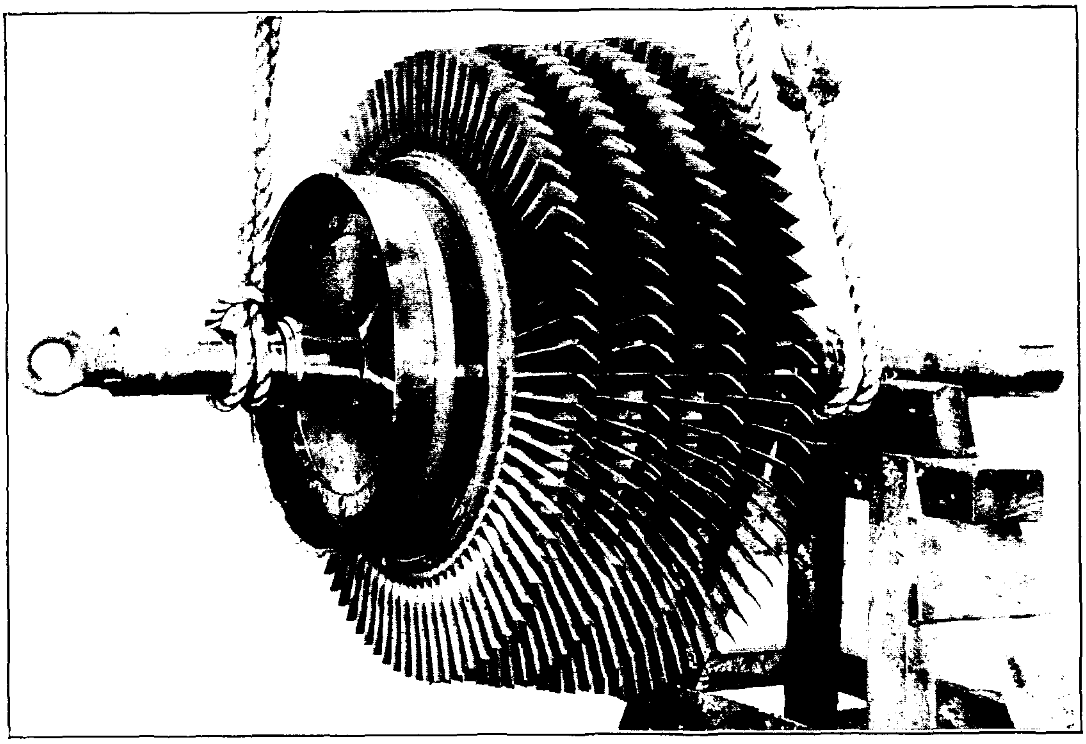

FIG. 3.—POWER TURBINE ROTOR

Power Turbine

The power turbine rotates independently of the compressor turbine. It has four stages with both fixed and moving blading of molybdenum-vanadium steel. The moving blades are mounted in axial serrations formed in a drum also of molybdenum-vanadium steel, and the fixed blades are dovetailed into circumferential slots machined in the stator casing (Fig. 4), which is made of forged mild steel.

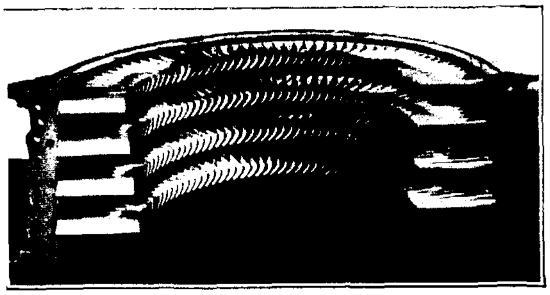

FIG. 4.—POWER TURBINE, FIXED BLADING

The drum is supported from the central shaft by two dished end pieces ; that at the after end is secured rigidly to the shaft, and that at the forward end is connected to the shaft through the medium of discs, which are flexible in an axial direction in order to deal with differential end expansion of the drum and shaft. The shaft itself is carried in two ball bearings ; the forward bearing is mounted in a spring loaded housing which floats axially to deal with expansion and is carried by a fabricated steel inlet branch through a number of struts of aerofoil section. The after bearing is similarly supported. A view of the power turbine rotor is shown in Fig. 3, and Fig. 5 shows the lagged power turbine cylinder with its exhaust casing. The after bearing is designed to take the axial thrust on the blading and is mounted in a spherical seating permitting slight angular movement. Both bearings are lubricated by oil mist and are air cooled similarly to the bearings of the compressor rotor, the oil supply being taken from the gas generator lubricating oil pump. The interior of the drum is cooled by a flow of air led through external pipes from the fifth stage of the compressor.

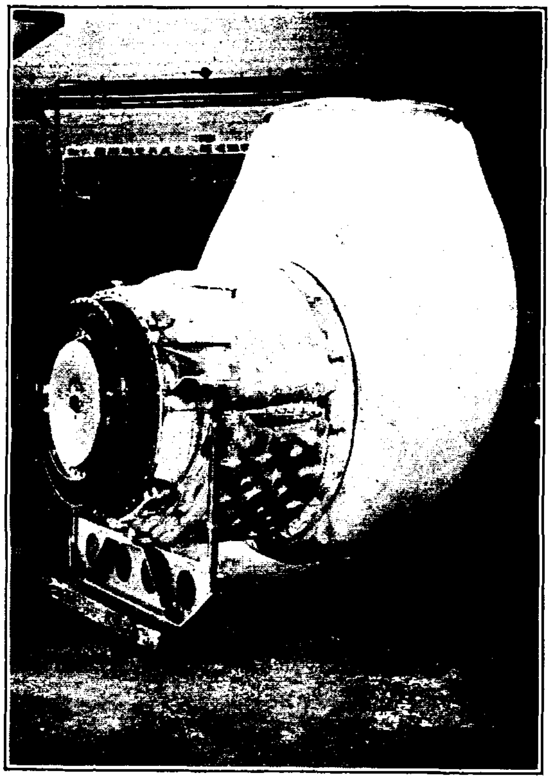

FIG. 5.—POWER TURBINE CYLINDER AND EXHAUST CASING

The gas generator outer casing is connected to that of the turbine by means of a bellows-type expansion piece. The hot gases on leaving the power turbine are passed through an outlet volute of fabricated sheet steel, turning the flow in a vertical direction to the exhaust.

Speed Reduction Gear

The gear is double helical single reduction. The drive from the power turbine is taken through a flexible quill shaft, which passes through a hollow pinion, to which it is attached at the end remote from the turbine. The pinion is carried in roller bearings without axial location.

A general view of the gear box is shown in Fig. 6 ; views of the box partly assembled are shown in Figs. 7 and 8.

It was necessary to provide means to permit the gas turbine propeller to rotate idly when the reciprocating engines alone were in service and thus

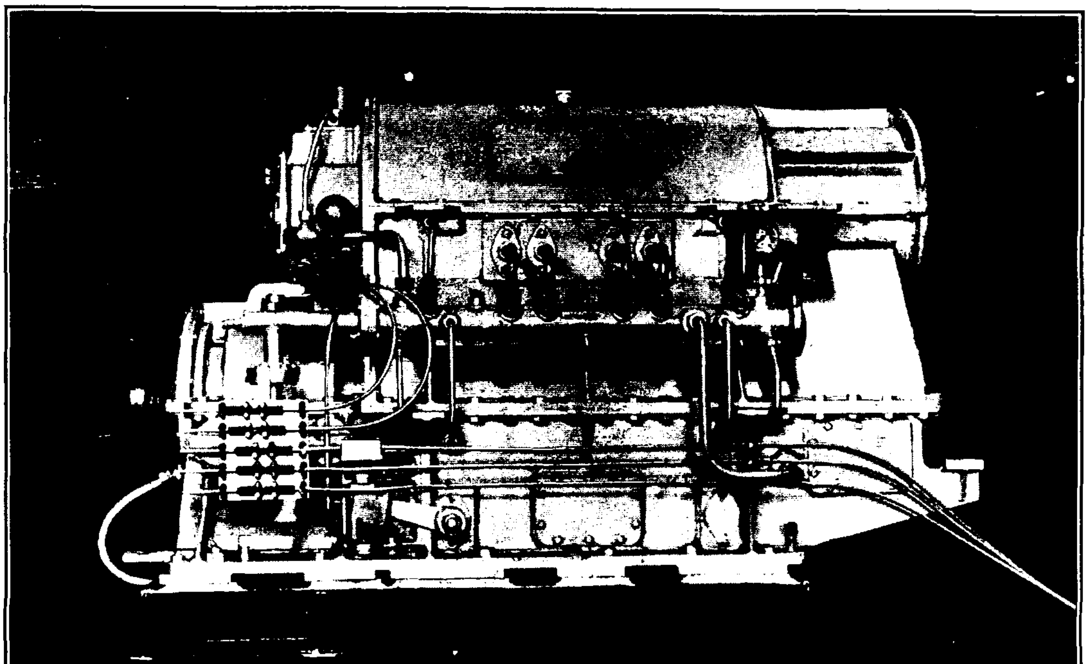

FIG. 6.—GEAR BOX—GENERAL VIEW

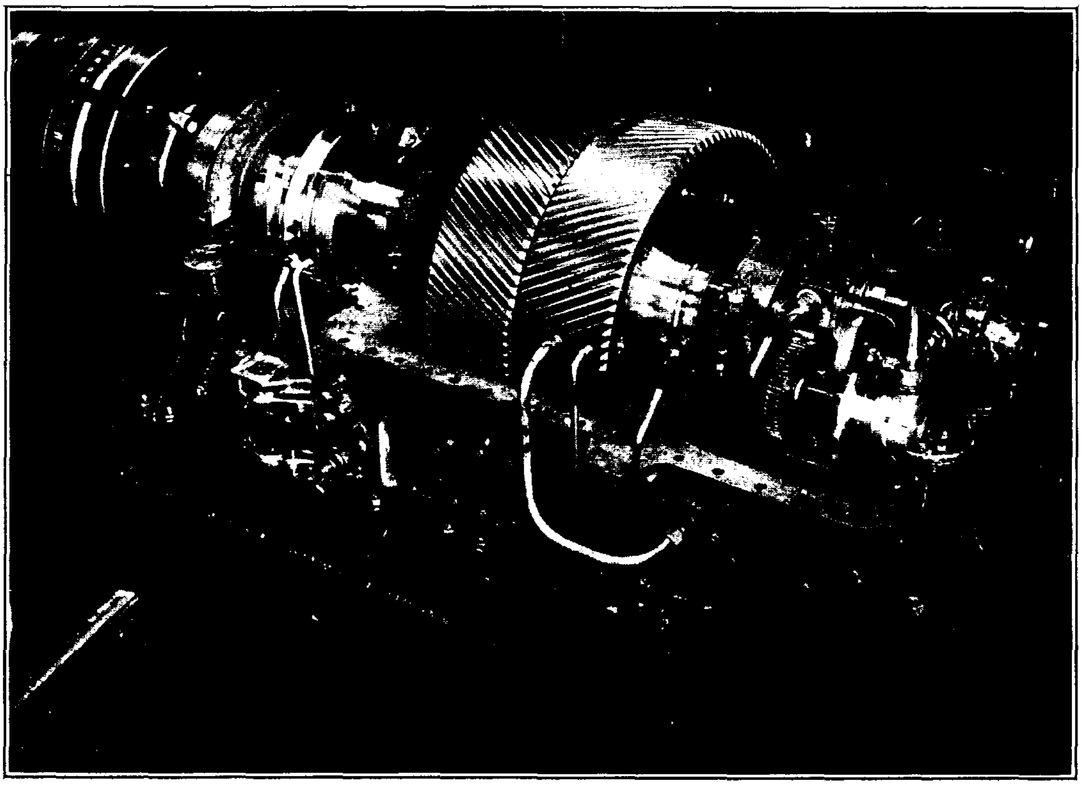

Fig. 7.—Gear Box showing gearwheel

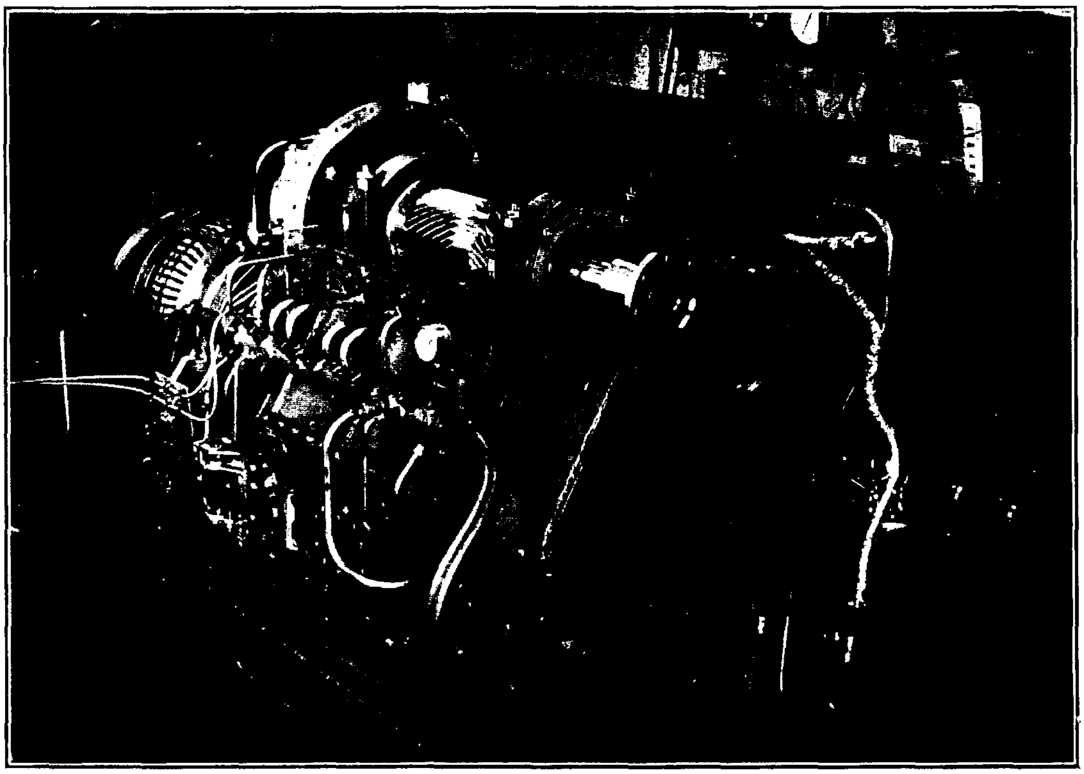

Fig. 8.—Gear Box—top cover removed, showing pinion

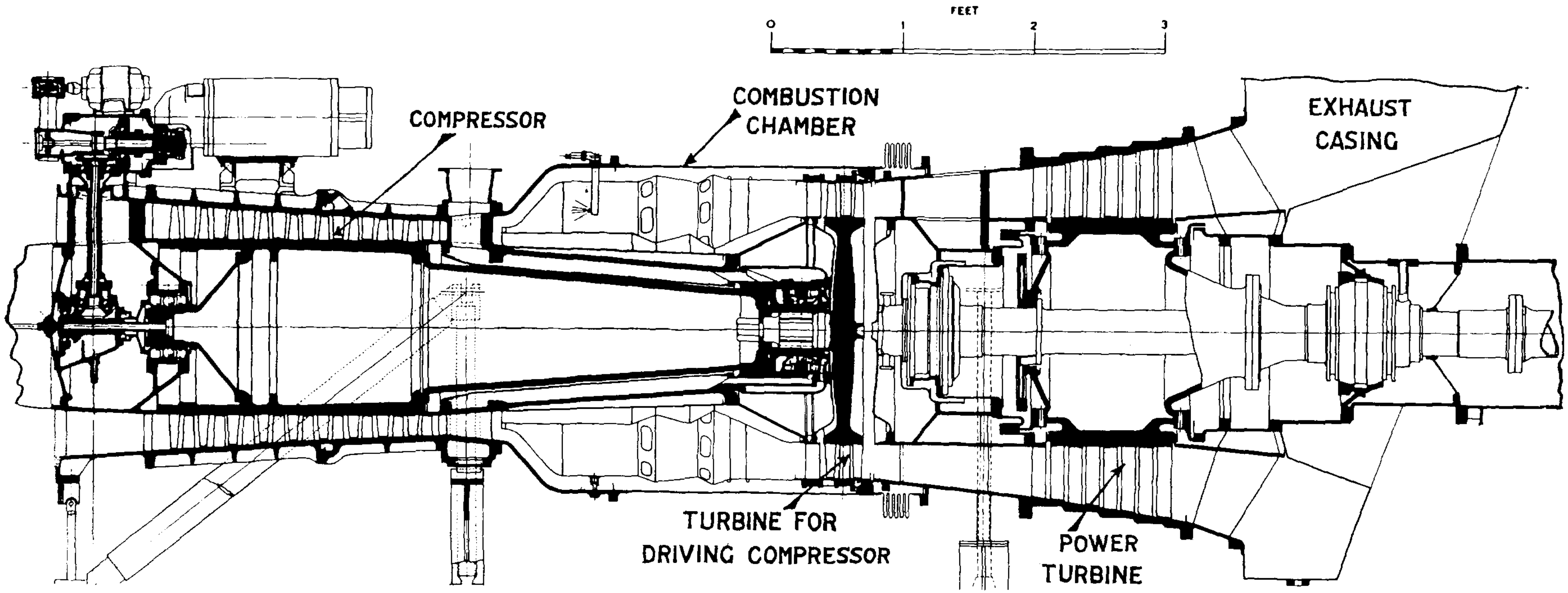

FIG. 9.—DIAGRAMMATIC SECTION OF GAS TURBINE UNIT

avoid motoring the power turbine rotor with consequent blade windage losses. To fulfil this purpose the gear incorporates a Sinclair self-synchronising clutch mechanism developed by the Hydraulic Coupling and Engineering Co., Ltd.

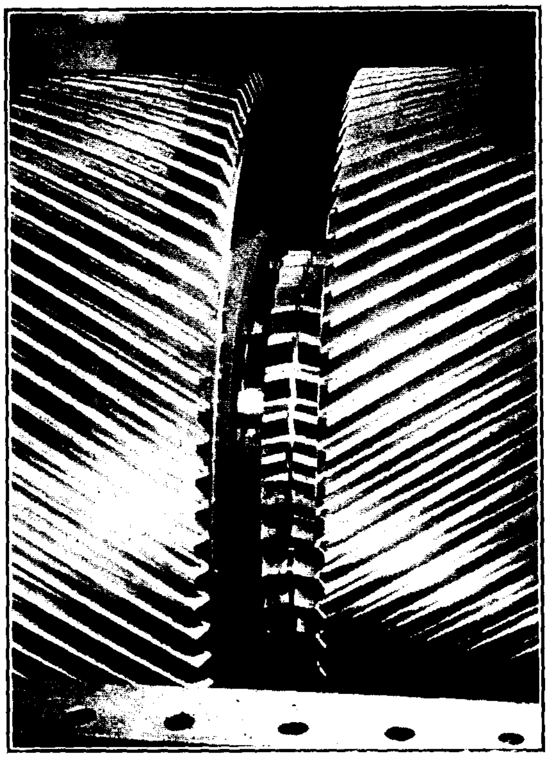

FIG. 10.—TOOTHED ENGAGEMENT RINGS OF SELF-SYNCHRONISING CLUTCH

The low speed gear wheel is in two halves with one helix formed on each, and both portions are free to slide axially on the shaft. The principle of operation of this mechanism is that loads on the driving teeth cause the two single helical wheels to be drawn together and held in that position ; the main drive is then transmitted from the wheels to the shaft through the engagement of two sets of internally and externally toothed rings mounted on the wheels and shaft respectively. These toothed rings may be seen in Fig. 10. When the driving power is cut off and the propeller shaft continues to be rotated by the trailing of the propeller, the helices cause the wheels to slide apart and the toothed rings disengage.

In this disengaged position the teeth of the internally toothed rings mounted on the gear wheel pass over a series of spring-loaded pawls, which provide the initial resistance that, when power is restored, causes the wheels to be brought back into full engagement with the shaft. In order to avoid continuous duty of the pawls over long cruising periods and also to prevent the gear from running into engagement when the vessel goes astern (*i.e.* when the rotation of the gas turbine propeller shaft is reversed), provision is made to draw the wheels further apart until the internally toothed ring is clear of the pawls. This is effected by means of bell crank levers which carry slippers engaging collars formed on the side faces of each of the gear wheels. The low speed shaft is carried in roller bearings and is provided with a Michell thrust block to deal with the propeller thrust.

The gear case is fabricated from mild steel plate and is split horizontally on the axes of the two shafts with the bearing keeps secured to bottom half.

The lubricating system for the gears provides cooled oil circulation for the gear teeth, thrust block, gear bearings and clutch mechanism. The oil pump for this duty is a Rotoplunge automatic reversing pump, which pumps oil in one direction only irrespective of the direction of rotation of the driving shaft. This pump is gear-driven from the propeller shaft and delivers through Auto-klean strainers to the oil cooler, across which is a thermostatically controlled by-pass to ensure that the cooled oil temperature does not fall below a fixed minimum.

A spring-loaded low-pressure oil trip is provided which cuts off the fuel supply to the gas generator and shuts down the whole unit in the event of the pressure of the oil supply to the gear box falling below a safe value. Further, this trip is arranged so that it is impossible to reset it, unless the clutch mechanism has been moved to the " pawls engaged " position and the clutch is thus in a condition to engage when power is applied to the gear box. By such means

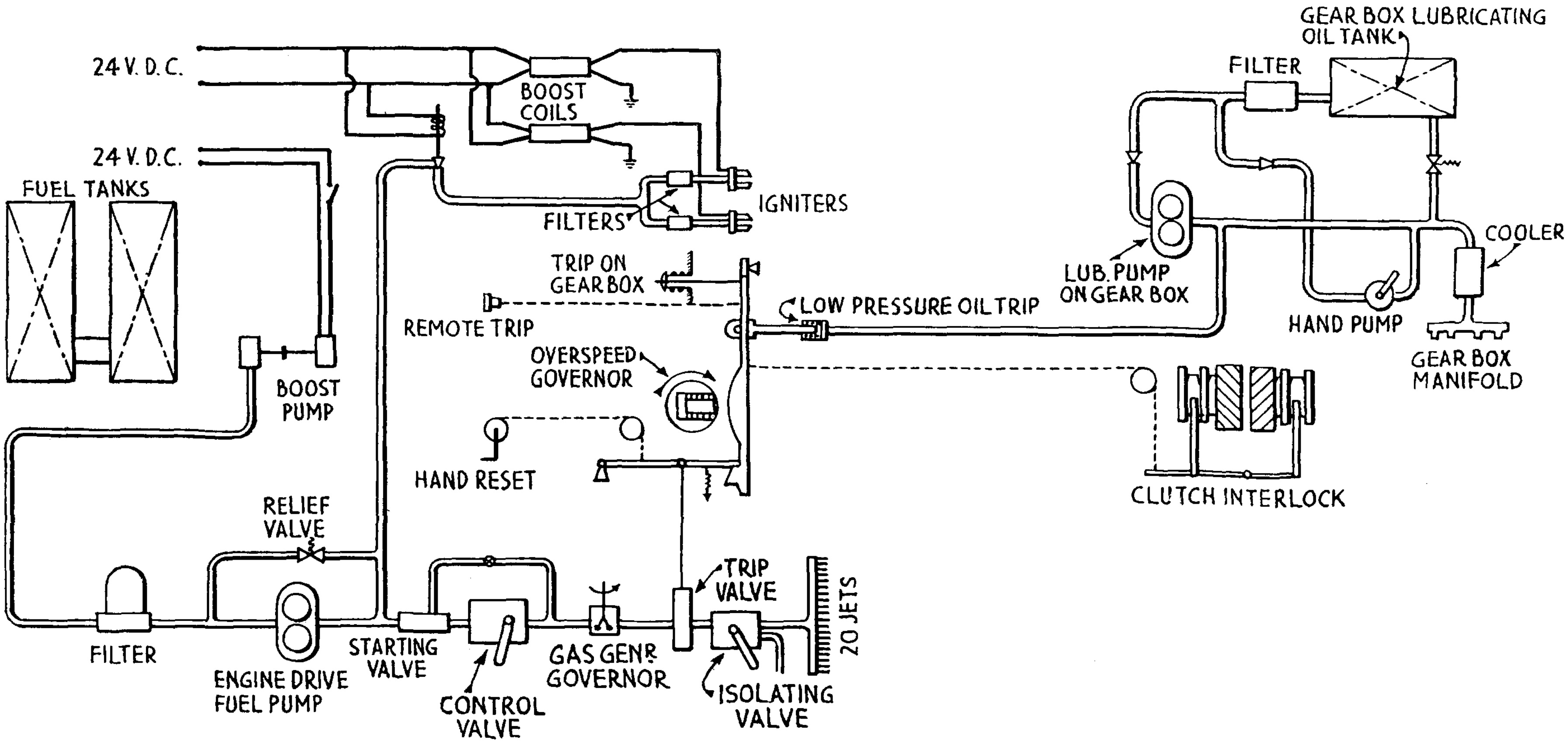

Fig. 11.—Diagram of Fuel System

the needless over-speeding and retripping of an unloaded power turbine is prevented.

When the vessel is cruising, the trailing of the gas turbine propeller rotates the oil pump at a speed sufficient to maintain an oil pressure in excess of the tripping pressure, so permitting the starting up of the gas plant. Under test bed or dock trial conditions, however, the propeller would be at rest, and a hand pump is provided to enable sufficient oil pressure to be established to allow the starting of the plant.

As the gas plant is out of service for long cruising periods, the ball and roller bearings of the plant might, if the rotors remained stationary, suffer damage due to the vibration of the internal combustion engines. With the gas turbine propeller trailing, the oil drag between the gear slow speed shaft and the gear wheel bushes is sufficient to cause slow rotation of the gear wheels, pinion and power turbine rotor, but as the gas generator rotor has no mechanical connection with the propeller shaft a separate inching motor is provided for this element. This motor is of 1/16 H.P. and drives through a double worm reduction gear.

Control System

The control system of the gas plant is shown diagrammatically in Fig. 11. The control of the power output is effected solely by regulation of the fuel quantity admitted to the combustion chamber of the gas generator. This fuel quantity and the prevailing atmospheric conditions dictate the speed at which the gas generator will run and so determine the gas flow rate and the temperature and pressure at the inlet to the power turbine ; these in turn determine the power output.

The gas generator portion of gas turbine plant has a minimum running speed known as the idling speed, from which or from any higher speed it is possible to make rapid acceleration to full speed. On starting up, external means are required to bring the speed up to the self-sustaining speed (which is less than the idling speed) but beyond it control is effected solely by the regulation of fuel admission.

To bring the gas plant into operation, the rotor of the gas generator is run up by means of a 24-volt D.C. electric starting motor to about 800 to 1,000 r.p.m., so establishing conditions for the satisfactory lighting up of the combustion chamber. The ignition is effected electrically. A solenoid valve when energised permits fuel to pass from the main fuel pump delivery to igniter jets formed with each of two ignition plugs, spark ignition taking place through the medium of a boost coil. When ignition has taken place some power assistance is received from the turbine, but at this low speed it is insufficient alone to drive the compressor. It is therefore necessary to continue the motor drive until a speed of about 2,000 r.p.m. is reached, when the machine becomes self-sustaining. The motor is then switched off, and the unit accelerates to the idling speed under the control of an automatic starting valve. This starting valve is servo-operated and is designed to ensure that the fuel flow into the combustion chamber gradually increases in step with the pressure build-up, so that the gas generator accelerates at a safe rate.

The main throttle or control valve consists essentially of a tapered needle moving in an orifice, the movement of the needle being servo-operated and automatically controlled to give a rate of acceleration that is as high as possible consistent with freedom from risk of stalling of the compressor. This valve is actuated from the control desk by a rack-and-pinion mechanism.

The maximum operating speed of the gas generator is controlled by an overspeed governor, which prevents the speed from exceeding the selected

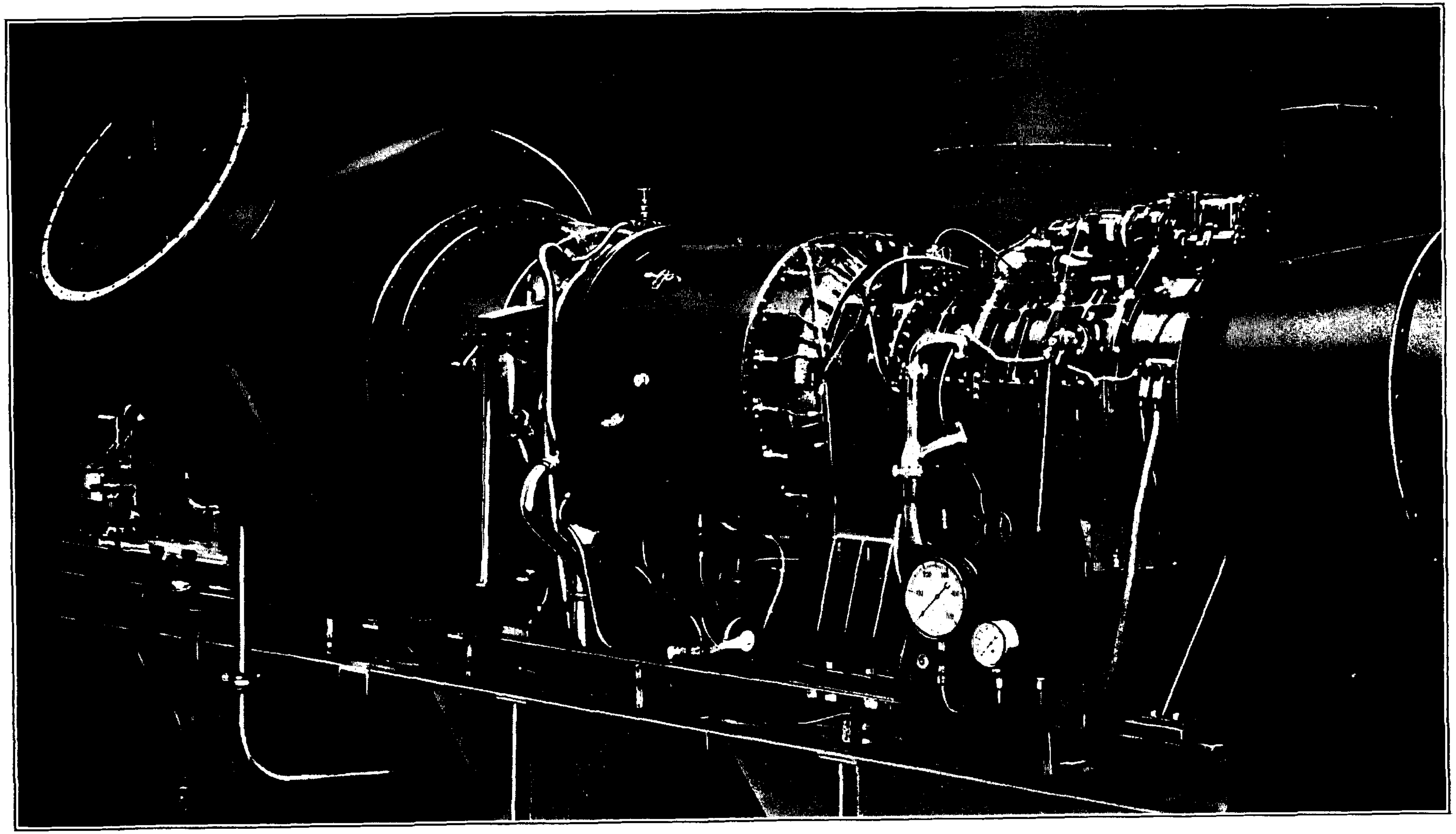

Fig. 12.—Assembly of complete unit on bench test, viewed from gas generator end

maximum value by the automatic throttling of the fuel admission to the combustion chamber.

The operating speed of the power turbine, which is mechanically separate from the compressor turbine, is normally dictated by the relation between power input from the gas generator and power absorption by the propeller, but an emergency trip governor of the bolt type is provided ; which, when the speed exceeds the designed maximum operating speed by 11%, acts on the fuel supply to the gas generator to shut down the entire gas unit.

The time for starting up the gas generator from cold and running up to the idling speed of 3,000 r.p.m. is of the order of 45 seconds.

Control Desk

The control desk contains equipment for the remote control of starting, regulation, and shutting down of the gas plant.

The electric starter is provided with a multipoint starting switch having an indicating lamp to show when the ignition circuit is closed and a main control lever to regulate fuel admission for the range " idling " to " full speed."

From the desk it is also possible to operate the trip that cuts off fuel and so shuts down the plant immediately : the trip lever may also be reset from the desk before restarting. There is also push-button starting and stopping for the inching motor of the gas generator and an operating lever for the clutch mechanism as already described.

Electric interlocks ensure that the electrical starting circuits are dead unless the trip lever is reset and the main control lever is in the idling position. It is possible, with the trip reset, to run the engine up to about 1,200 r.p.m. but without subsequent ignition, and this procedure may be used to check the mechanical conditions from time to time. Further electrical interlocks provide that the operation of the main switch shuts down and automatically uncouples the inching motor and that the control desk trip lever must be in the " stop " position before the inching motor can be started.

Bench Tests

Prior to acceptance tests on the gas turbine for shipboard installation an experimental unit was subjected to extensive bench testing. These bench tests commenced in April, 1946. For the purpose of the tests the whole unit comprising gas generator, power turbine and reduction gear was mounted on a fabricated bedplate and coupled to a dynamometer for load measurement. The assembly of the plant on bench test is shown in Figs. 12 and 13.

On account of the atmospheric conditions normally prevailing at the test house, air filtering apparatus was installed to prevent unduly rapid deterioration of the compressor performance by blade fouling. Experience with jet engines has shown that such fouling takes place in the smoke-laden atmosphere of an industrial district, but not in the clean air encountered in flight and expected at sea.

The dynamometer was of the Heenan & Froude Dynamatic type and was coupled to the slow-speed gear shaft by a flexible coupling of the Bibby type. The fuel was supplied through a Purolator filter under a small pressure head by an electrically driven boost pump, the flow being measured by timing the flow through a graduated tank.

The running of the plant on bench test was very smooth and free from vibration, notwithstanding the lightness of the supporting structure, and this can be attributed to the careful dynamic balancing of the rotating parts. The noise emitted at full load compared favourably with that expected from a marine petrol or Diesel engine of the same power.

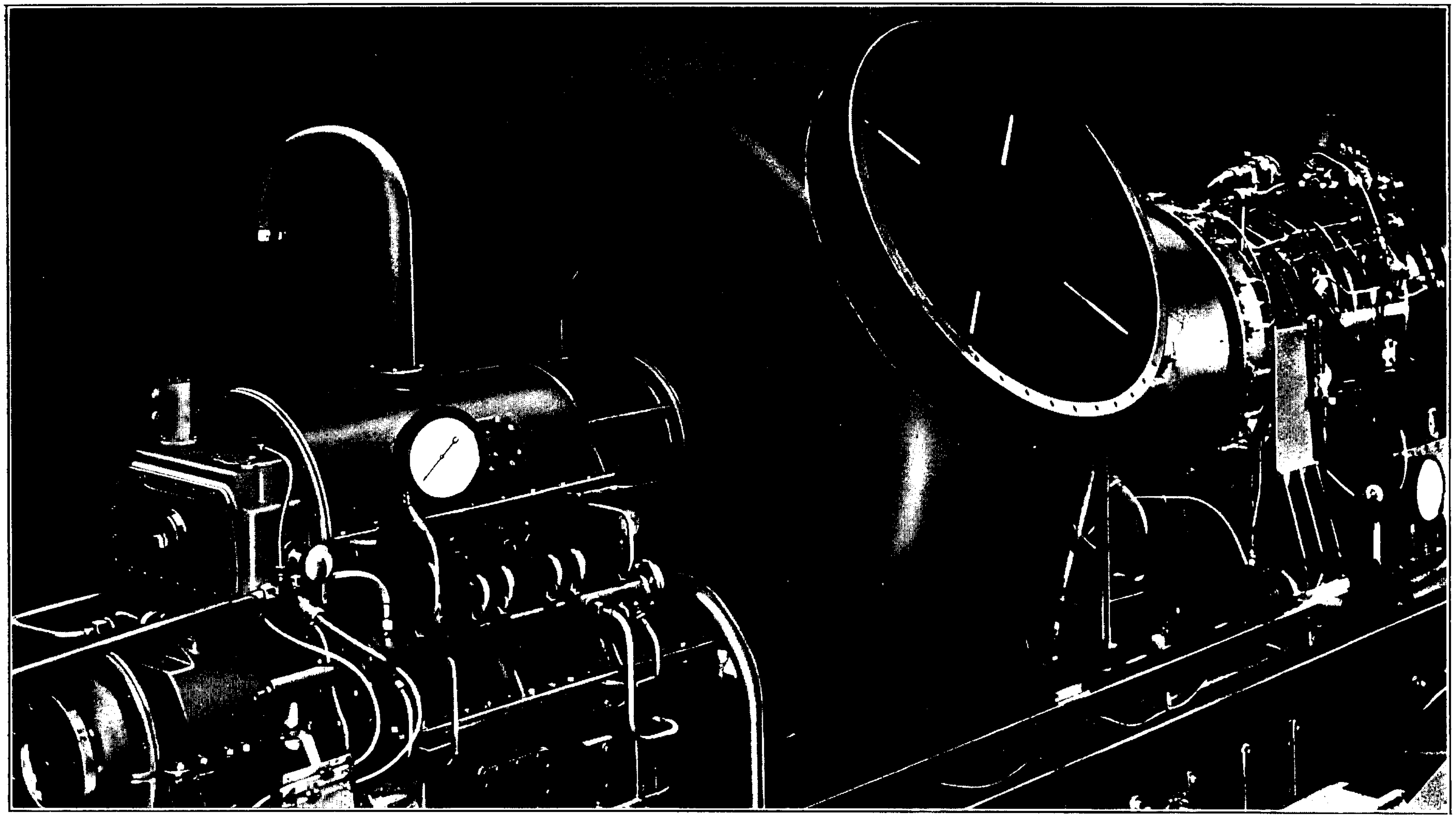

FIG. 13.—ASSEMBLY OF COMPLETE UNIT ON BENCH TEST, VIEWED FROM POWER TURBINE END

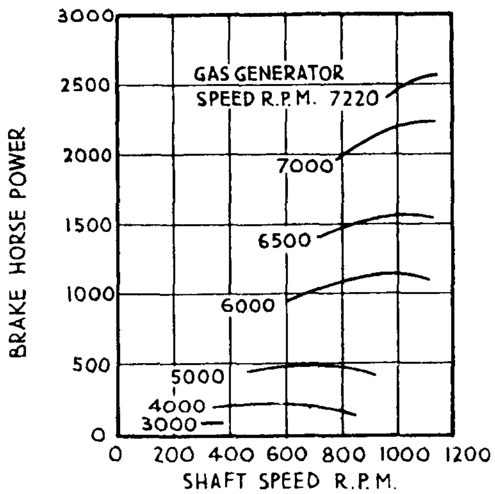

FIG. 14

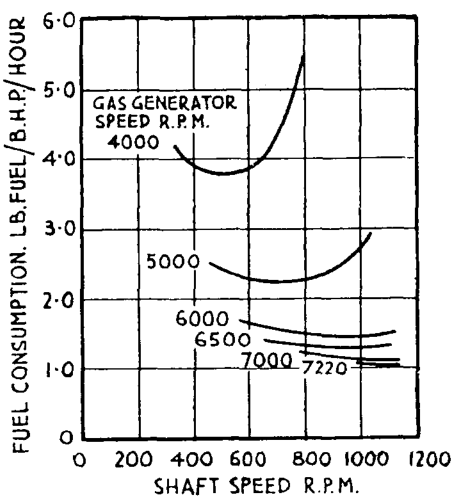

FIG. 15

The lack of mechanical connection between the rotors of the gas generator and power turbine enables the latter to adjust itself easily to the power-speed characteristics of the load, and during bench tests a range of power turbine speeds was explored for various levels of gas power output from the gas generator, *i.e.*, for various constant speeds of rotation of the latter.

The characteristics of the complete unit, as obtained on bench tests, are shown in Figs. 14 and 15. The first shows the power output of the power turbine and the shaft speed corresponding to various speeds of the gas generator, and the second shows the specific consumption (*i.e.* lb. of fuel per B.H.P. hour) and the shaft speed, again corresponding to various gas generator speeds. Pool gas oil was used for the bench tests.

It will be noted that an output of 2,550 B.H.P. was obtained at the designed shaft speed of 1,087 r.p.m. with a gas generator speed of 7,220 r.p.m., and that the specific consumption corresponding to these speeds and output was 1.06 lb.