DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

AND

FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

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NO. 512

CONTROL OF FIRES IN LARGE SPACES WITH INERT GAS AND FOAM PRODUCED BY A TURBO-JET ENGINE

PART 3. THE DESIGN AND OPERATION OF AN INERT GAS GENERATOR

by

G. W. V. STARK

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Fire Research Station.
Boreham Wood.
Herts.
('phone ELStree 1341)

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SUMMARY

The operation of an experimental inert gas generator based on a jet engine has led to an appreciation of ways in which its design and operation could be simplified. The desired controls of a prototype generator, incorporating additional devices for entraining air in the gas stream, and for generating high expansion foam, are described.

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PART 3. THE DESIGN AND OPERATION OF AN INERT GAS GENERATOR

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Introduction

Tests have been conducted at the Fire Research Station on an experimental inert gas generator based on a jet engine. This was designed and built by the National Gas Turbine Establishment after discussions with the Joint Fire Research Organization on the features to be incorporated.(1)

The present note describes the experimental generator and its operation, and puts forward modifications considered desirable in the light of the experience gained in its use.

Description

The unit is shown in Plate 1, and the general layout is given in Figure 1.

In operation, air enters at A and passes through a 7 stage compressor at B. Fuel, atomised by the compressed air, is burnt in the main jet burners at C. Additional fuel is burnt in the exhaust gases from the jet engine in the reheat section D. The exhaust gases are then expanded and cooled somewhat in the water jacketed section E, after which water is sprayed and vaporised into the gas stream from spray pipes on each side of the 180° bend in the unjacketed trunking at $F + F^1$. The humidified gas then passes to the coupled butterfly valves G, which can be operated to divert or proportion the gas stream between blow-off and supply outlets. Some water from F is supplied to a separate jet system to provide skin cooling of the unjacketed ducting.

The water supply to the cooling jacket E is obtained from mains if the pressure is adequate (40 - 60 lb/in^2 running pressure) or from a small auxiliary pump. After passing through the jacket, the pressure is increased to 100 - 120 lb/in^2 by 4 turbo-pumps driven by a small proportion of the air from compressor B.

The fuel for the engine, aviation kerosine, is contained in a 215 gal tank mounted above the 180° bend. The operating controls and instruments are mounted at one end of this tank (Plate 1).

The complete unit is mounted in a frame on a Ford 6 ton lorry chassis. Access to the control panel is from a platform about 6 ft long and extending some 4 ft from the side of the vehicle. The platform is stored under the generator when not in use.

Operation

Operating instructions and other data provided by the National Gas Turbine Establishment are summarised below.

The operating procedure for the experimental inert gas generator is given in Appendix I. The present operating procedure is similar but omits part due to the removal of the low pressure water cut-out. The electrical circuits are shown in Figure 3, the fuel system in Figure 4, and the water system in Figure 5. Checking procedures for failure to start and excessive engine temperature are given in Appendix II. General notes on running are given in Appendix III, and the procedure for an emergency stop, in Appendix IV.

Maintenance instructions are given in Appendix V. Although the experimental inert gas generator can be operated by one skilled man, the National Gas Turbine Establishment recommend three operators (Appendix VI).

Discussion

The experience gained in operating the experimental inert gas generator has led to an appreciation of the ways in which future designs can be simplified and so made more suitable for general use. Such a proposed unit should incorporate an air entrainment device to permit alteration in the properties of the delivered gas, and a device for manufacturing high expansion foam.[2]

Generator & Vehicle

The generator needs to be operated with the jet engine somewhat higher than the humidifying section, because if this is not done, water can run back into the engine. It is thus desirable to design the appliance so that the jet engine is above the level of the humidifying section. This could be achieved by constructing the unit with a fall from the jet engine to the inert gas outlet.

The jet engine in the experimental generator incorporates a fuel pumping system designed for aircraft use, which allows for attitude and altitude. A pumping system for ground use only need not be so complex, and a simple engine speed controlled pump should be adequate. It should also be possible to design a suitable engine with a less elaborate compressor, say for example a two stage compressor.

The reheat, or after-burner, section of the experimental generator is very compact, (overall length approximately 15 ins). Flame stability and efficiency of combustion here could be improved for example by increasing the diameter of, or lengthening the section.

Vaporisation of the water introduced in the humidifying section is incomplete, and about 10 per cent of the water is not vaporised in the generator. This is probably partly due to water from the spray pipes at F impinging on the trunking at the 180° bend and partly due to the short distance, between the spray pipes at F^1, (plate 1) and the outlet in which vaporisation can take place. This condition might be avoided by adopting a linear construction and placing the spray pipes at F^1 closer to those at F. (Fig.2). However, it might prove necessary to insert baffles to promote turbulence and so assist the vaporisation of water droplets. The length of a generator in linear form, with a reheat section twice the present length would be about 36 ft. The provision of a device for air entrainment could increase this length to about 40 ft. The use of a linear configuration would require a different system of transport to the one used at present. A suitable vehicle would consist of a trailer, towed by a separate road vehicle, e.g. Scammel "Mechanical Horse". Articulated vehicles of this kind are highly manoeuverable, but are also liable to uncontrollable movement under adverse conditions such as emergency braking.

If such a vehicle presents difficulties in fire situations, where there may be only limited access, a folded configuration would be necessary. In this case, some means should then be adopted to disrupt the wall films of water on the trunking after the intitial skin cooled section, and particulrly on the 180° bend, by means of corrugations, or squat baffles on the wall of the trunking. The removal of excess water would be more efficient if the drain cocks fitted to the inert gas trunking could be replaced by steam traps, to reject water while sealing against the loss of gas.

The water supply system could be improved, and simplified, by dispensing with the turbo-pumps and supplying water at high pressure throughout the water system on the generator. The high pressure water could be supplied by an auxiliary pump or a pump driven by the jet engine.

The electrical requirements of the road vehicle and the jet engine equipment should all be at the same voltage, and could be supplied by the same storage battery, which could be charged to some extent by the road vehicle dynamo. However, auxiliary charging would be necessary, because of the large consumption of power for each electrical start of the jet engine.

The hydraulic actuating system for the coupled butterfly valves should be replaced by a mechanical system of operation. This would make it easier to control the proportioning of gas flow between blow off and supply, and reduce the equipment on the generator. Suitable mechanical systems would be rack and pinion, screw gear, or lever.

The position of the fuel tank on the prototype generator is unsatisfactory because (a) it presents a fire risk to the machine, and to personnel operating it, should it fracture, and (b) it reduces the roadworthiness of the vehicle by raising its centre of gravity. This could be avoided with either configuration of the inert gas generator by fitting the tank below the generator and within the dimensions of the vehicle. The tank could supply fuel to the generator and the diesel engine of the road vehicle.

The operating panel for the inert gas generator should be repositioned so as to give good visibility of the working parts of the generator and the delivery system for the inert gas or high expansion foam which remain within the dimensions of the vehicle. Suitable positions would be a rearward section of the cab of a non-articulated vehicle, or the intake end of a towed trailer (Fig. 2).

Auxiliary Equipment

The inert gas generator should be capable of being brought into use quickly. To do this, some ancillary equipment must be carried on the generator. The vehicle should carry (1) sufficient fuel for the unit to achieve control or extinction of a fire in a modular compartment, say 250,000 ft^3, (2) sufficient inert gas delivery ducting for the inert gas to be conducted into the premises in hazard, say 300 ft (3) foam generating attachments, (4) sufficient foam making detergent and a proportioning pump, or injector, to permit generation of high expansion foam for at least 10 minutes at 10000 ft^3/min. It is possible that items (2) and (3) which should be collapsible, could be combined as dual purpose ducting. (3)

It is estimated that an inert gas generator of the same capacity as the existing generator should carry 100 to 200 gallons of fuel (sufficient for 15 to 30 minutes running at full output), and at least 30 gallons of detergent. Since prolonged generation of inert gas or foam may be necessary, provision should also be made for connecting up reserve supplies of fuel and detergent.

Operation and Controls

A fully developed inert gas generator could be operated from a simple system of push button controls, the sequence of operations as given in Appendix 1 being automatically controlled by suitable servo systems. The controls should be designed to operate in sequence and should be:-

(1) Engine start. This control would start the engine and bring into action an automatic device to proportion the water flow to the gas stream and so control the outlet temperature to the appropriate level (100 - 120°C). The control system should fail to safe in the event of a failure of any part of the starting operation, so that the jet engine fuel supply was switched off, and the engine stopped, while maintaining the supply of water if possible.

(2) Engine Throttle. This control should be normally preset to the rated optimum operation of the appliance. An overiding manual control would be needed for situations where other operating conditions could be used with advantage.

(3) Reheat Start. This control should bring the reheat system into operation at the lowest rate of fuel consumption for flame stability. The water flow proportioning device or (1) should continue to control outlet temperature.

(4) Reheat Throttle. This control should be operable over the range of reheat fuel consumption that would give an oxygen concentration in the inert gas stream of from about 16 per cent to 2 per cent (vol). The automatic device at (1) above should continue to control the outlet temperature.

(5) Bypass Control. This should be a hand operated control to permit proportioning the inert gas flow between blow-off and supply outlets.

(6) Air entrainment control. This should be a hand control lever to adjust the amount of air entrained in the jet stream.

(7) Foam generation control. This should be a control to turn on the supply of foam compound. The proportioning of foam compound should be automatically controlled by engine speed, but this control would permit different expansion ratios of the foam produced to be selected.

Additional controls as indicated below would seem necessary.

(a) Master Switch
(b) Igniter Test button
(c) Fuel cock
(d) Water supply valve

Control (b) should operate in isolation so that an aural check can be made of the operation of the igniter without starting the jet engine.

The indicating devices considered necessary for monitoring the operation of the inert gas generator are:-

(i) Fuel tank contents gauge
(ii) Engine speed indicator
(iii) Oil pressure and temperature gauge
(iv) Water pressure gauge
(v) Vapourising water flow meter
(vi) Engine fuel pressure/flow meter
(vii) Reheat fuel pressure/flow meter
(viii) Engine rear bearing temperature gauge
(ix) Jet pipe temperature gauge
(x) Inert gas outlet temperature gauge
(xi) Delivered gas outlet temperature gauge
(xii) Foam compound solution flow meter

It would be advisable to have indicators for the flow rate and oxygen content of the inert gas. These should be so installed that readings could be taken before, and after air entrainment. These indicators, together with (x) and (xi) above would allow assessment of the operation of the generator, the expected time for the control of fires and hence the time at which it would be safe to allow firemen to enter the premises at which the appliance was used.

Fail-safe devices, as are fitted to the experimental generator, should be installed. These should operate at least on water failure and excess temperature of inert gas. Their operation should be indicated by warning lights which should also be fitted to indicate electrical completeness of circuits.

A crew of two Fire Service personnel should be able to operate such an equipped inert gas generator after a relatively short training period. Although such an appliance calls for a large number of controls, many of these are for safeguarding rather than operating the appliance. The operational controls are 1 to 7, and indicators (x) to (xii). The remaining controls and indicators are needed for testing, preparation, and performance rating of the appliance. An ergonomic excercise should ensure suitable positioning of controls for efficient operation.

Conclusion

The controls of the jet engine inert gas generator can be simplified, and its scope of use increased by incorporation of an air entrainment device and foam generating equipment.

Methods of incorporating these modifications in an inert gas generator of improved design are indicated. Such a generator should be suitable for use by a Fire Service crew.

References

(1) D. J. Rasbash. Control of Fires in Large Spaces with Inert Gas and Foam produced by a Turbo-jet Engine. Part I - Introduction and Properties of Inert Gas and Foam.

(2) B. Langford, G. W. V. Stark, and D. J. Rasbash. Control of Fires in Large Spaces with Inert Gas and Foam produced by a Turbo-jet Engine. Part V - The Production of High Expansion Foams, F.R. Note No. 511.

(3) G. H. J. Elkins, G. W. V. Stark. Control of Fires in Large Spaces with Inert Gas and Foam produced by a Turbo-jet Engine. Part VI - Flexible Ducting for Conveying Hot Inert Gas. F.R. Note in preparation.

Acknowledgment

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APPENDIX I

Inert Gas Producer

Running Procedure Issue A

1 Initial checks

(1) Couple up hose from water hydrant to L.P. water inlet valve and turn on water at the hydrant.

(2) With fuel cock (engine) from fuel tank shut, switch on instruments with master switch and check fuel level in tank. Switch off master switch.

(3) Check that diffuser water jacket is primed by turning on L.P. cock and opening drain cock at the bottom of the jacket. Close drain and L.P. cock.

(4) Check air pressure (in accumulator) for operating blow-off butterflies and pump up to 400/500 p.s.i. in accumulator. Operate control lever opening and closing butterflies once and pump up accumulator again. The butterflies must be in the blow-off position for starting.

(5) Check engine controls for travel, ((a) throttle travel (b) high pressure valve travel). Reprime or reset if necessary.

(6) Open drain cock in middle of lobster back to drain system.

(7) Check air bottle pressures. Open valves on air bottles which provide air pressure to (a) pneumatic jack operating the H.P. water valve to turbo pumps and (b) pneumatic jacks operating fuel "cut-outs".

(8) Check engine oil tank for oil level. (Oil to Specification O.X.38).

(9) Check engine and reheat igniters aurally.

2 Starting

Note It is assumed that the batteries are fully charged up.

(1) Turn on fuel cock. Open cock on lubricating oil feed pipe.

(2) Switch on master switch on control panel. Note engine throttle and high pressure cock controls are at closed position.

(3) Switch on panel switch and press main start button switch; this will start the starter motor and rotate the engine. Open high pressure fuel valve control.

(4) Open L.P. water valve at the same time as (3). Unless there is 20 p.s.i. water pressure in water jacket engine fuel will not come on.

(5) When engine speed has increased switch on fuel primers, and immediately

(6) Open H.P. pneumatic water valve by pushing switch down, watch travel of pneumatic jack and when valve is open return switch to vertical position.

(7) When engine has started, switch off primers and panel switch; and control engine on throttle. For failure to start or excessive J.P.T. see Appendix II.

(8) As engine starts and approaches slow running, rev/min 5,500, open upstream H.P. water valve partially, noting temperatures at gas delivery and engine jet pipe temperature (J.P.T. 450/500 approximately)

(9) At the same time as (8) open L.P. water valve to full position, noting L.P. pressure and jacket temperature which must not exceed 60°C; the jacket pressure must not exceed 80 p.s.i. at any time.

(10) Close drain cock in lobster back.

3 Opening up

(1) Increase rev/min on throttle to 6,000 to 6,500. The H.P. water pressure in manifold must not be less than 30 p.s.i., otherwise reheat fuel will not be on.

(2) Open up pilot reheat fuel needle valve to fully open position, press reheat igniter button and turn on the Vickers cock. Reheat should come in, as indicated by change of note in gas delivery blow-off. Release button when reheat comes in. Just crack open the downstream high pressure water gate valve.

(3) Bring in main reheat fuel by opening Vickers cock with the needle valve just open. Ignition will be indicated by change in engine note or change in appearance of gas flow from blow-off outlet and increase in J.P. temperatures. If main reheat does not come in, shut Vickers cock and drop rev/min. Repeat operation of opening Vickers cock with needle valve just open. If main reheat comes in, open up needle valve and engine throttle together gradually, keeping J.P.T. as low as possible. Open upstream water gate valve to fully open position. Watch for increase in blow-off outlet temperature and control on downstream H.P. water control valve.

(4) At 11,000 engine rev/min and approximately 90 per cent of final reheat fuel flow, operate the blow-off control, slowly moving the butterflies to the "straight-through" position. Watch J.P.T. which should be approximately 550°C. Reduce reheat fuel if too high (650°C extreme limit).

(5) Increase engine rev/min on throttle up to required rev/min, adjusting the main reheat needle valve as engine rev/min are increased. 12,000 rev/min is the maximum rev/min allowed.

(6) When a steady reading of selected engine rev/min has been obtained, finally adjust reheat main fuel to keep J.P.T. between 620°C and 650°C, and adjust H.P. water control valves to maintain the outlet temperatures between 100°C and 120°C.

(7) Watch the fuel tank level gauge. With a full tank at start there should be enough fuel for 30 min running with reheat.

(8) The drain cock at the bottom of the blow-off unit can be left open as a means of draining excess water, if any.

4 Shutting down

(1) Close main reheat fuel needle valve slowly, at the same time partially close engine throttle to keep rev/min steadily dropping and start closing downstream H.P. water gate valve, keeping the gas delivery temperatures below 120°C.

(2) When engine rev/min have reached 10,000 rev/min and main reheat fuel has been reduced operate "blow-off" butterflies control lever to move over to "blow-off" position, and further close throttle to keep rev/min dropping. The downstream H.P. water gate valve should be closed steadily until fully closed.

(3) When engine rev/min have reached 8,000, close both main and pilot reheat fuel Vickers valve, closing engine throttle to keep rev/min dropping.

(4) Close main reheat needle valve. When engine rev/min have reached slow running rev/min 5,500, let engine settle for 30 seconds whilst the upstream H.P. water gate valve is partially closed.

(5) Shut engine fuel high pressure valve and close water H.P. valve by operating switch on panel: when valve is closed return switch to the vertical position. Switch off main instrument panel switch. Open drain cock in lobster back as quickly as possible.

(6) At the same time as (5), all water valve, H.P. and L.P. are to be closed. The time of the engine run down is to be checked with a stop watch, this should not be less than 80 sec from time of closing engine H.P. fuel valve. Note and record duration of run.

(7) Open all drain valves, 7 in all, to completely drain the water system.

(8) Close fuel Vickers valve and close engine oil tank cock.

(9) Shut off the water at hydrant.

(10) If frost is likely, the machine should be put under cover.

APPENDIX II

Procedure if (i) engine fails to start or (ii) excessive J.P.T. is obtained on starting. Normal J.P.T. 500/550°C. Excessive J.P.T. 620/670°C.

(a) Close throttle and high pressure control.

(b) Let engine run down and stop.

(c) Investigate possible causes of (i) and (ii), i.e. restricted air inlet to engine. Blow-off butterflies in wrong position. Excessive fuel being delivered to engine.

APPENDIX III

General notes on running

(1) If the H.P. water pressure drops below 30 p.s.i. the reheat safety cut-out will come in and "cut" the reheat fuel which will result in an increase in engine rev/min. Both main and pilot reheat Vickers cock must be closed and main reheat needle valve closed. The throttle must be closed to compensate and when H.P. water pressure is correct the operation of bringing the reheat in section 3-1 to 3 carried out.

(2) If the L.P. water pressure in the diffuser jacket falls below 20 p.s.i. the engine safety cut out will come in and "cut" the engine fuel supply, stopping the engine. Both engine throttle and engine high pressure fuel valve must be closed, also the H.P. water turned off as quickly as possible at the hand operated gate valves and H.P. water valve switch on panel moved to "closed" position; when valve is closed return switch to vertical position.

(3) Careful observation is to be made for any "hot spots" on (1) engine tail pipe (2) reheat portion and (3) just upstream of the transverse jet tubes.

(4) Avoid sudden changes in engine conditions especially increasing of rev/min or reheat.

(5) A running log must be kept to include all necessary engine data i.e. rev/min, J.P.T. oil pressure, oil temperature, R/bearing temperature, compressor delivery and burner pressure.
At each engine stop the run down time, i.e. time from shutting H.P. cock to engine stopping, must be logged. This is to check freedom of engine rotating parts.

APPENDIX IV

Emergency Stop

(a) Move blow-off control to blow-off position.

(b) Shut off reheat fuel. Close pilot and main reheat Vickers cocks.

(c) Close both throttle and shut off cock levers.

(d) Close engine fuel cock (Vickers).

(e) Close low pressure inlet water valve.

(f) Open drain cocks.

APPENDIX V

Maintenance

(i) Grease the turbo pumps with grease to specification DTD 825 after every 5 hrs running. 12 ccs to main bearing and 2 ccs to tail bearing.

(ii) Charge up the three 12v batteries after 10 starts.

(iii) Remove, clean and replace all water injection jet tubes, at intervals to be determined as the result of experience.

(iv) Check Viper engine turbine tip clearances after 25 hrs running. Tolerance allowed is 0.046 in. to 0.060 in.

(v) Recharge air bottles after every 5 hours running.

(vi) Prime throttle and high pressure valve controls after 25 hrs running.

(vii) Grease the bearings of the blow-off butterflies after 5 hrs running. Use D.T.D. 825 as in (1) above.

(viii) Check auxillary gearbox oil level periodically and top up when necessary with oil to specification C.600.

(ix) Remove and clean all engine burners after 25 hrs running.

(x) Remove and clean water and fuel filters (2) after 25 hrs running.

APPENDIX VI

Duties of operators on Inert Gas Producer

Operator No. 1

1.0 General

This operator will be in charge of the whole unit. He will issue all instructions over the intercom to the Nos. 2 and 3 operators.

2.0 Duties

2.1 All initial checks as given in Section 1 of "Running Procedure".

2.2 The starting, controlling and shutting down of the Viper engine and keeping the J.P.T. at reasonable values.

2.3 Supervising operators 2 and 3.

3.0 Starting, controlling and shutting down

3.1 Detail instructions on starting, etc. are given in "Running Procedure". It is only necessary to add that the instructions over the intercom to operators 2 and 3 must be concise and as short as possible.

3.2 The duration of each engine run together with a seconds check of engine run down, (i.e. time from closing engine high pressure cock control to engine stopping) must be logged for every run, see Section 4, sub-paragraph 6 of "Running Procedure".

Operator No. 2

1.0 General

The injection water system (high pressure) is under his control.

2.0 Duties - starting and running

2.1 As soon as engine commences to rotate on the starter, depress switch operating h.p. water valve. If possible watch travel of rod to see that the jack has operated.

2.2 When engine has started (i.e. when fuel primers have been switched off) open left-hand gate valve one turn.

2.3 Put outlet thermocouple switch in No. 1 position.

2.4 Keep outlet temperature below 120°C by means of the left-hand gate valve until this valve is fully open, then,

2.5 Open up right-hand control valve noting flow indicated by pressure shown on gauge.

2.6 Continue opening the right-hand valve to maintain outlet temperature at approximately 80°C to 90°C.

2.7 When "bypass blow-off" has been closed and the butterflies moved to "straight through" position move thermocouple switch to 2 - 6 position in turn to check distribution of temperature at the extreme outlet. Adjust the downstream valve to maintain as even a distribution as possible.

2.8 The final position will be (when full reheat fuel is on) that the left-hand valve will be fully open, and the right-hand valve fully open or nearly so.

2.9 When steady running conditions are obtained the following readings are to be logged every ten minutes:-

R.P.M.

<u>Pressures</u>:	L.P. water, H.P. water (2) compressor delivery, burner,
<u>Temperatures</u>:	jet pipe temperature (3) outlet temperatures (5) jacket temperature

3.0 <u>Shutting down</u>

3.1 As soon as bypass butterflies are moved to "blow-off" position move outlet thermocouple switch to No. 1 position.

3.2 As reheat main is being reduced, close the downstream water valve, maintaining the temperature at outlet as steady as possible.

3.3 As soon as downstream water valve is closed, commence closing the upstream valve. A little more speed in closing this valve will be found necessary.

3.4 When the engine H.P. fuel control is closed, quickly close the upstream water valve and move H.P. water switch on panel to up position which cuts off the L.P. water to the turbo-pumps. When valve closed move switch to vertical position.

3.5 Open drain cock in lobster back, or instruct someone at ground level to do so by an agreed signal.

<u>Operator No. 3</u>

1.0 <u>General</u>

The L.P. water control valve, bypass blow-off control and reheat fuel are under his control.

Operator No. 1 will give the necessary instructions for any major operation, i.e. "reheat on"; "close blow-off" etc.

2.0 Duties - starting and running

2.1 Turn on L.P. water gate valve to prime diffuser water jacket and ensure that 40 p.s.i. is showing on gauge. Unless at least 20 p.s.i. is shown the automatic cut-out will keep the engine fuel shut-off to the engine pump.

2.2 Check

(a) reheat Vickers cocks are in off position

(b) pilot reheat needle valve fully open

(c) main reheat needle valve fully closed.

2.3 Check that butterflies are in the blow-off position for starting and that pressure in the accumulator is between 400 p.s.i. and 500 p.s.i. Pump up if necessary.

2.4 Bring in pilot reheat when instructed by operator 1, first by opening Vickers cock and pressing reheat igniter button. Release button when indications show that pilot reheat is alight.

2.5 Bring in main reheat when instructed by operator 1 by opening Vickers cock to full and just cracking needle valve until float in rotameter just moves.

2.6 Progressively bring in main reheat as rev/min are increased to instructions by operator 1 who will be observing jet pipe temperatures as he opens up the engine.

2.7 Operate the bypass blow-off when instructed by operator 1.

2.8 Finally set up main reheat to instructions of operator 1.

2.9 When steady running conditions are obtained the following readings are to be logged every ten minutes.

R.P.M.	
Pressures	engine oil, outlet static, jet pipe total, reheat pilot, reheat main.
Temperatures	engine oil, rear bearing
Flows	reheat pilot, reheat main, water.

3.0 Shutting down

3.1 When instructed by operator 1 move bypass butterflies to "blow-off" position. Prior to this operation, check that pressure (air) in accumulator is between 400 p.s.i. to 500 p.s.i. Pump up if necessary.

3.2 Steadily close reheat main needle valve, keeping synchronized with operator 1 who will be controlling the rev/min. (Note: As reheat is shut-off the engine rev/min will rise.)

3.3 Close both reheat main and reheat pilot Vickers cocks when instructed by operator 1 (i.e. "reheat off").

3.4 When engine is back at slow running, commence to shut off L.P. water; i.e. close valve wheel one turn.

3.5 As soon as engine high pressure fuel control is put to "closed" position, close L.P. water valve as quickly as possible to stop water flooding the engine.

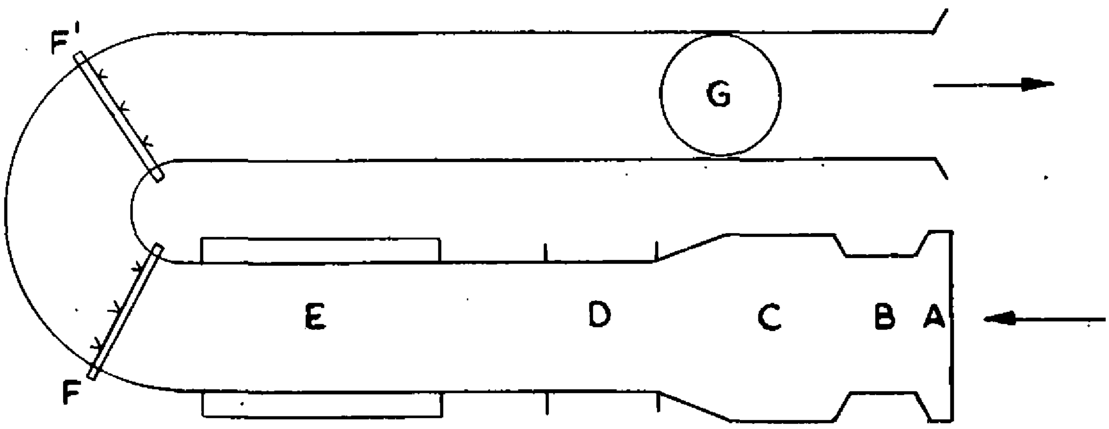

FIG. 1. GENERAL LAYOUT OF EXPERIMENTAL INERT GAS GENERATOR

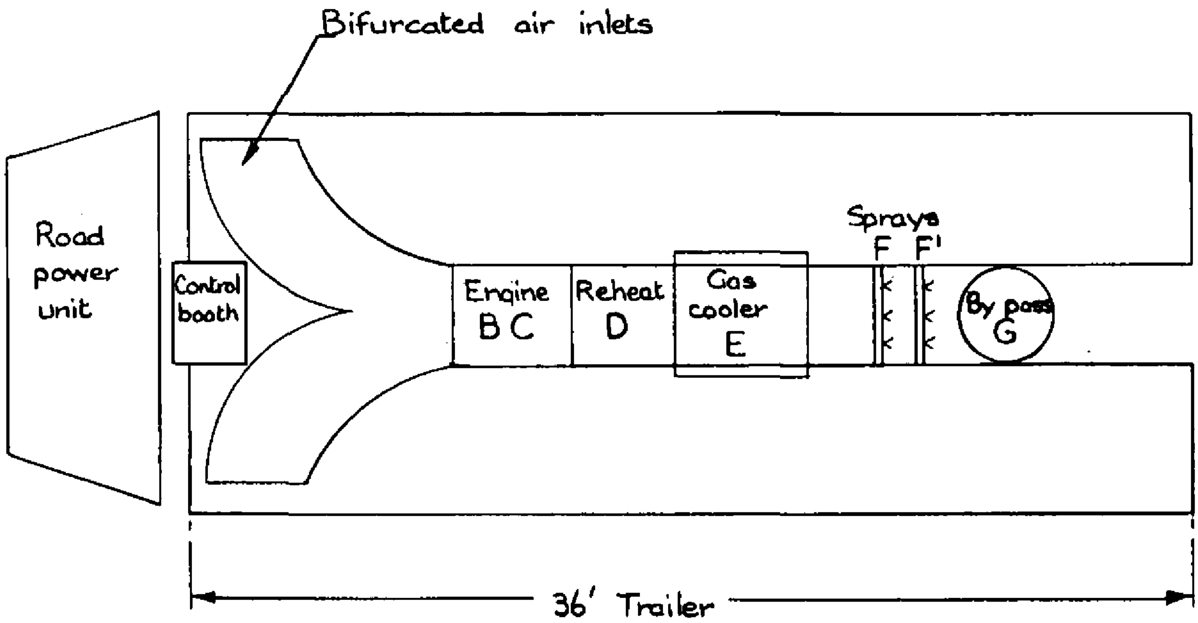

FIG. 2. LINEAR LAYOUT OF PROTOTYPE INERT GAS GENERATOR

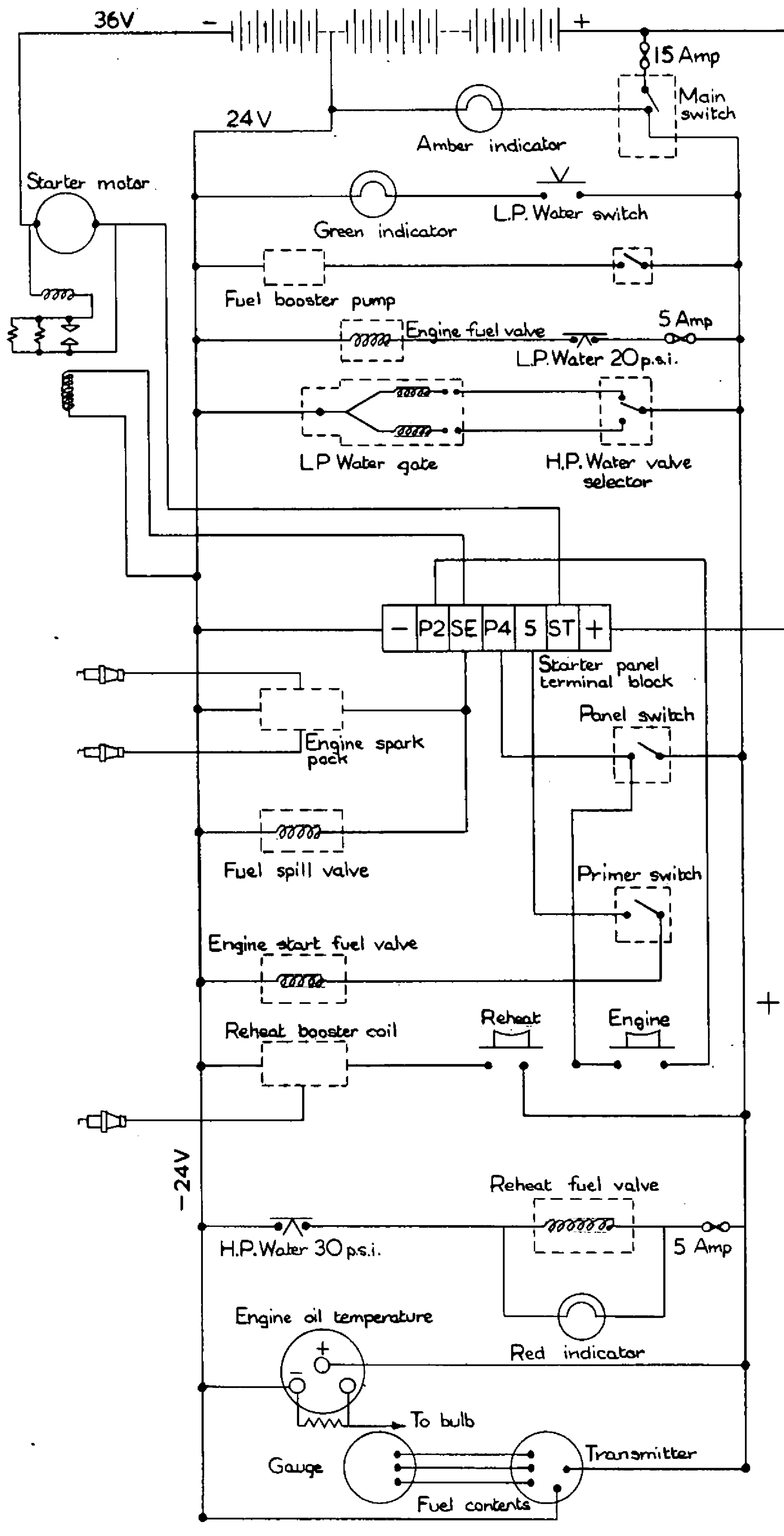

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FIG. 3. ELECTRICAL CIRCUIT DIAGRAM FOR EXPERIMENTAL INERT GAS GENERATOR

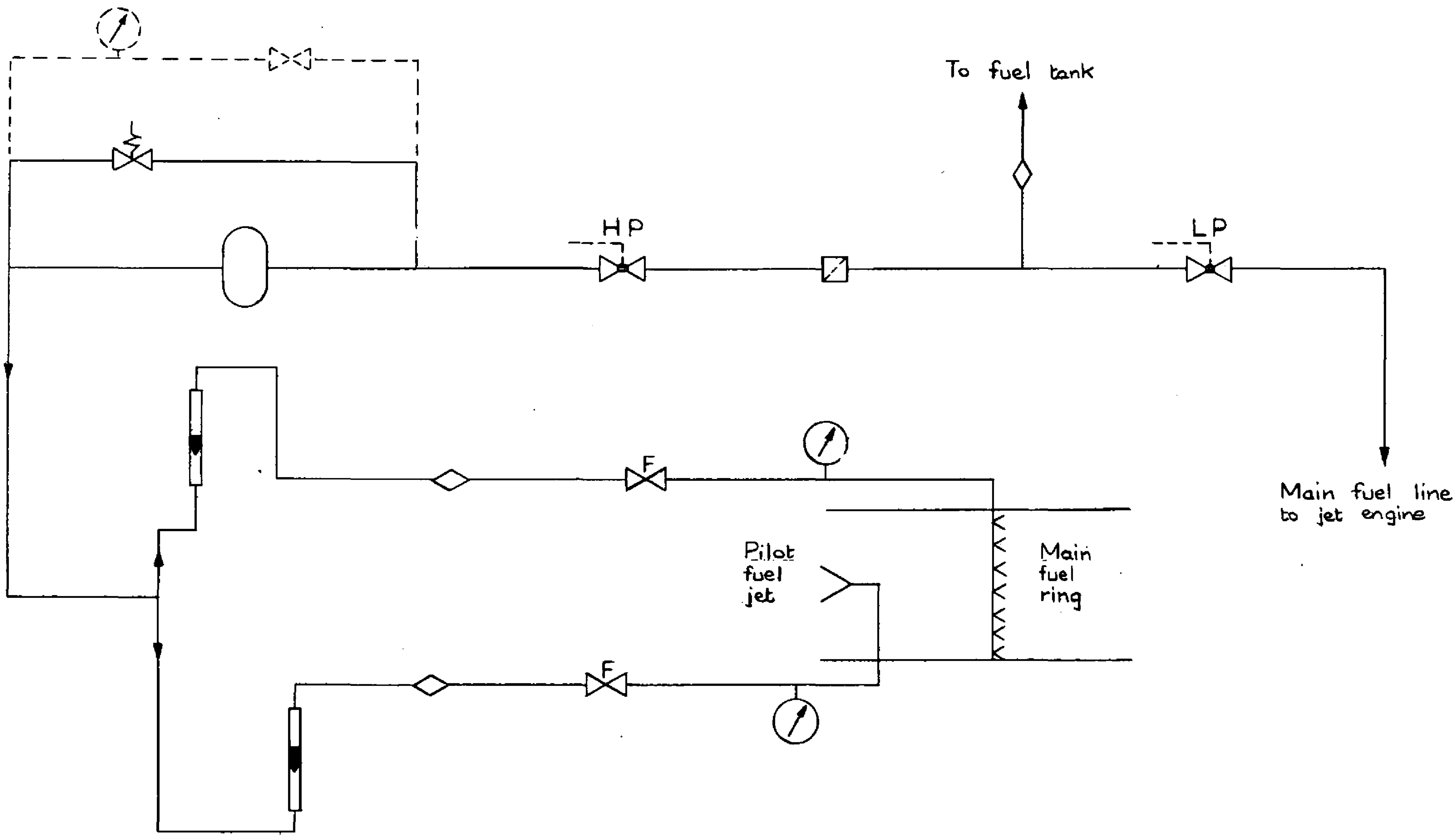


FIG. 4. FUEL CIRCUIT DIAGRAM FOR EXPERIMENTAL INERT GAS GENERATOR

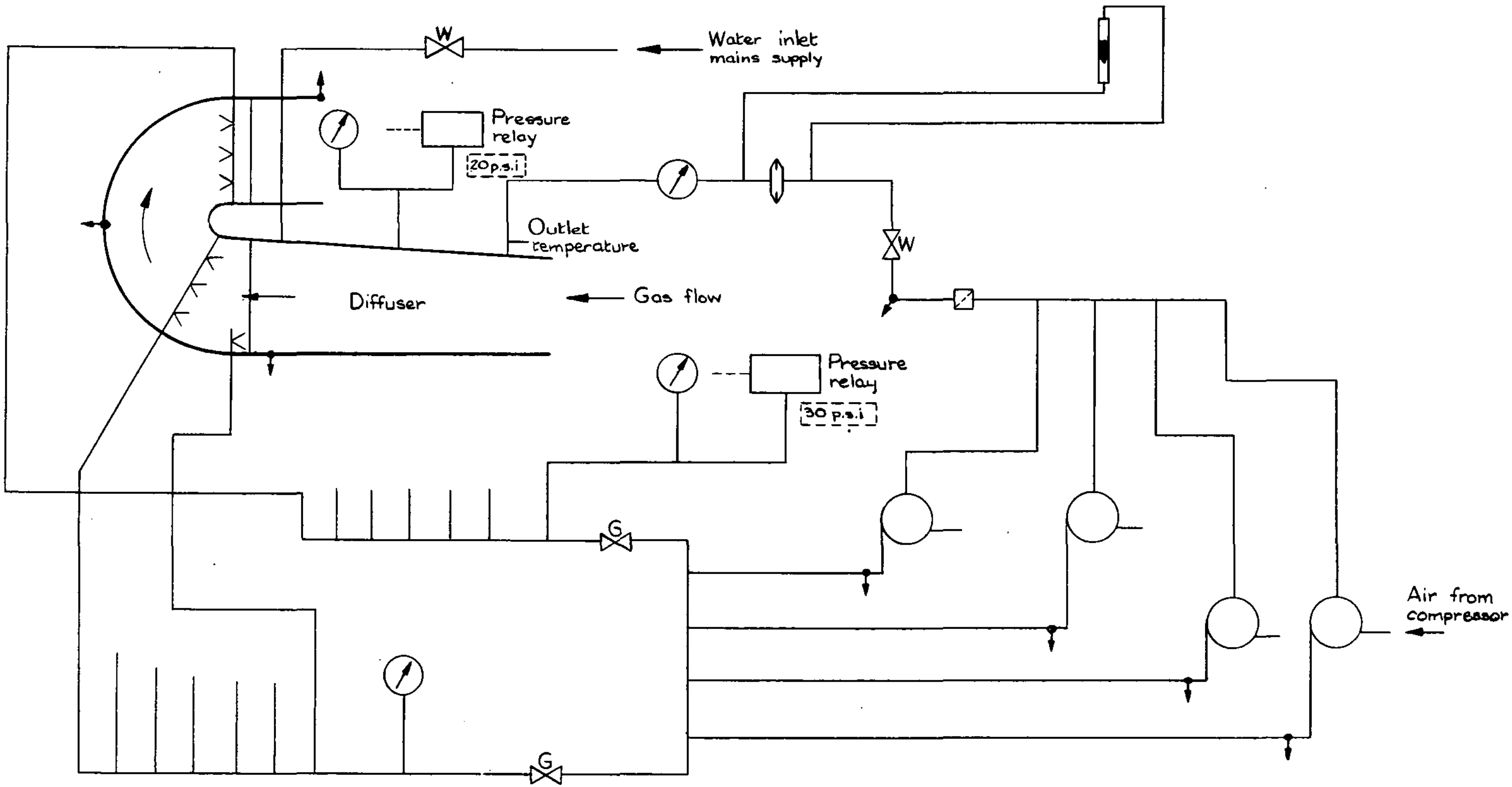
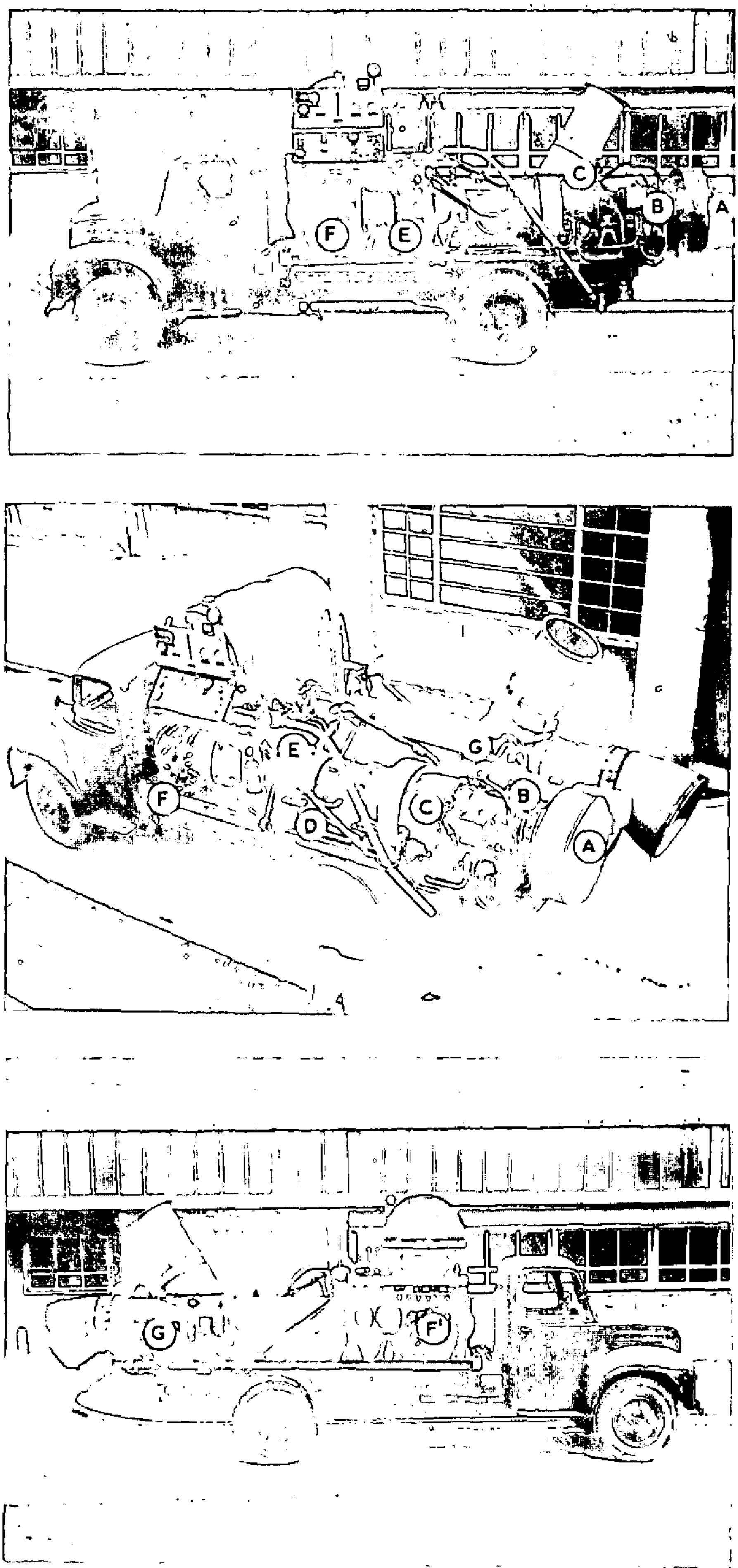


FIG. 5. WATER CIRCUIT DIAGRAM FOR EXPERIMENTAL INERT GAS GENERATOR



THE PROTOTYPE INERT GAS GENERATOR

PLATE 1