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AIRCRAFT TURBOJET ENGINE TYPE РД-9Б

DESCRIPTION

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Chapter I

GENERAL

The PД-9Б engine (Figs 1,2,and 3) is a modern turbo-jet power plant designed for installation on fighters.

The engine design employs a high-pressure nine-stage axial-flow compressor, ten flow type combustion chambers, a two-stage gas-turbine, and an afterburner with adjustable jet nozzle.

Experience gained in the development of the early modifications as well as sound construction principles used in designing engine parts and units permitted the designers to choose the most rational forms of individual parts and to create an engine with low specific weight and high thrust.

The compressor rotor (Fig.4) consists of nine rigidly connected discs fitted with blades having aerodynamic profile. The discs and blades of the 2nd, 3rd, 4th, and 5th rotor stages are manufactured from an aluminium alloy, while the discs and blades of the 1st, 6th, 7th, 8th, and 9th stages are made of steel. The discs of the 1st and 9th stages are furnished with trunnions acting as compressor rotor bearings. The rear trunnion of the rotor incorporates a coupling which connects the compressor rotor to the turbine rotor and prevents the latter from axial movement.

The compressor rotor rides in two bearings. The front roller bearing takes up radial stresses, whereas the rear radial-thrust ball bearing takes up the axial load equal to the difference between the axial forces which originate during compressor and turbine operation. The bearings are force-lubricated.

Placed between the rotor stages are rows of stator vanes which serve to direct the air, thrown off the trailing edge of the rotor blades, to the required angle of attack and also

I. GENERAL DATA AND SPECIFICATIONS

Chapter I

GENERAL

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Placed between the rotor stages are rows of stator vanes which serve to direct the air, thrown off the trailing edge of the rotor blades, to the required angle of attack and also to convert part of the velocity head into pressure.

The stator vanes are secured in a 2-piece thin-walled compressor housing.

The air-flow section of the compressor is an annular duct with a narrowing flow-path area towards the exit, which provides for the required change of axial velocity of air passing through the compressor.

High rotational speed, considerable angle of turn of air passing through the blades as well as high standards of finish of the parts located in the air-gas path and minimum clearances between the ends of the blades - all these features provide for a considerable increase of air pressure in the compressor with a relatively high efficiency.

To ensure stable operation of the engine at intermediate duties, a provision is made in the compressor design for releasing the air, compressed in the first 5 stages, to the atmosphere. When the air is blown off after the 5th stage, the air mass drawn into the first stages of the compressor is considerably increased, and the possibility of surge is eliminated.

Air is blown off automatically by a special device, controlling opening and closing of the ports serving for air release at predetermined engine speed.

Ten cylindrical axial-flow type combustion chambers are arranged parallel to the engine axis between the compressor and the turbine, in the circular area formed by the rear housing and the bearing housing shield.

The design of the combustion chambers of the РД-9Б engine, subject to great thermal stresses, provides for proper fuel combustion process and small diameter of the engine.

The combustion chambers incorporate four flame igniters and ten duplex main burners.

The two-stage reaction turbine with high degree of gas expansion ensures great thermal drop at high efficiency.

The turbine rotor consists of a shaft, two discs coupled to each other by means of a load-carrying ring, and a number of blades. The blades of both turbine stages are manufactured of heat-resistant alloy.

The turbine rotor rests upon the rear force-lubricated roller bearing, and upon the coupling guarding the turbine against axial displacement.

In front of each turbine stage is installed a nozzle assembly directing gas flow against the turbine blades.

The nozzle assembly of the first stage is composed of 36 hollow cast vanes fastened to the outer and inner casings of the nozzle assembly. The vanes are fastened in such a manner as to provide for both the longitudinal and transverse play.

The vanes of the nozzle assembly, installed in front of the turbine second stage, are bolted to the compressor housing.

High degree of air compression, high efficiency of the compressor and turbine operation and proper fuel combustion in the combustion chambers ensure a relatively low specific fuel consumption.

The afterburner serves to augment the engine thrust for a short period of time by burning an additional amount of fuel, injected into the afterburner through 17 fuel nozzles. Resulting increase in the velocity of gas flow causes the engine thrust to increase by 25 per cent.

The adjustable jet nozzle of the afterburner provides for engine operation at various duties and improves its performance at the rated and cruising speeds.

Adjustment of the exhaust area of the jet nozzle is accomplished by changing the position of the swivel shutters. The shutters are controlled automatically by means of four hydraulic cylinders and a taper ring connected to the cylinder pistons and sliding on the external surface of the shutters.

For actuating the engine accessories and aircraft equipment provision is made for a drive gear box whose drives are rotated by the compressor rotor shaft through the medium of a gear train.

The РД-9Б engine incorporates the following systems: a starting fuel system serving to deliver starting fuel (gasoline) during engine starting; main fuel system, designed to supply main fuel when the engine runs at various duties; self-contained system of lubrication and cooling of the engine foto convert part of the velocity head into pressure.

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Modern automation, interlocking and warning systems are widely used in the engine design and facilitate engine operation.

Engine starting is accomplished automatically by pushing the starter button, as a result of which the automatic devices will control the delivery and ignition of the starting fuel as well as spinning of the engine turbo-compressor.

The main fuel system automatically controls the amount of fuel delivered during starting or engine operation at any of the stable and intermediate duties. Besides, the fuel system automatically maintains constant r.p.m. at any given throttle setting irrespective of aircraft speed or altitude. Due to this, engine control is accomplished by means of one control lever.

The engine electric equipment serves for energizing the starting system units, aircraft radio and navigation equipment, automatic devices, interlocking system, measuring instruments, and warning devices.

<u>Principle of Engine Operation</u>

The air drawn in by the compressor along the intake duct is compressed and directed to the combustion chambers in a continuous stream.

Some of the air delivered into the combustion chambers is consumed in the fuel combustion process, while the remaining portion cools the combustion chambers and is mixed with the combustion products to decrease their temperature to the required value.

The mixture of the fuel combustion products with the air, possessing high potential energy, is delivered to the nozzle assembly of the first stage, whence it is directed against the blades of the turbine first stage and further to the blades of the second stage.

The gases leaving the turbine enter the afterburner and after expanding in the adjustable jet nozzle are discharged to the atmosphere at high velocity.

Part of the gas potential energy is converted by the turbine to mechanical work used for driving the compressor and accessory units, while the remaining portion of the gas potential energy is converted to kinetic energy.

The amount of thrust developed by the engine is determined by the excess of the gas velocity over the speed of the aircraft and by the amount of gases ejected per second.

When the engine is running at augmented rating achieved by burning an additional amount of fuel, the gas flow is accelerated and the engine thrust is increased.

Chapter II

ENGINE SPECIFICATIONS

1. General Data

1. Designation РД-9Б
2. Engine type . . . . turbo-jet engine with afterburner
3. Compressor . . . . axial-flow nine-stage with automatic control of air blow-off behind 5th stage
4. Combustion chambers . . . . .axial-flow, individual, arranged in common housing
   (a) number 10
   (b) arrangement . . . . .along circumference
   (c) combustion chamber numbering . . . . .beginning with upper left-hand chamber counter-clockwise (as viewed from adjustable jet nozzle end)
5. Turbine . . . . .axial, two-stage
6. Jet nozzle . . . . adjustable (three positions)

Diameter of jet nozzle exhaust area:
   (a) with afterburner turned on, at starting, and at low throttle up to 4500 – 6500 r.p.m. . . . . . 498 $^{+}$ not less than 4 mm before closing of shutters $_{-3}$ mm
   (b) at maximum duty . . . . . . .442$\pm$7 mm
   (c) at other operating duties . . . . 465$\pm$7 mm
7. Sense of rotation of engine rotor . . . . .counter-clockwise (as viewed from adjustable jet nozzle end)
8. Overall dimensions of engine:
   (a) length of engine with afterburner . . . . 5555 mm
   (b) engine diameter (combustion chamber section) . . . . 665 mm
   (c) afterburner diameter . . . .636 mm
   (d) maximum height of engine complete with accessories . . . . 938 mm
9. Dry weight of engine with fuel and oil system unit . . . . . .695 kg^{+2} per cent
10. Guaranteed period of engine operation up to first overhaul . . . . 100 hours

2. Main Operating Conditions

11. Augmented condition:
   (a) engine rotor speed . . . . .11150$\pm$50 r.p.m.
   (b) temperature of gases aft of turbine[1]:

on ground

at ambient air temperature below +15°C — not over 650°C

at ambient air temperature amounting to or higher than

[1] In case gas temperature cannot be adjusted to within the indicated limits at altitudes of 10,000 metres to the practical ceiling, the temperature of gases aft of the turbine may reach 700°C.

$15^{\circ}C$ . . . . not over $680^{\circ}C$

during flight

maximum temperature of gases aft of turbine . . . . . . within $620 - 680^{\circ}C$

(c) period of continuous operation:

at altitudes of up to 6000 m. . . . . not over 6 min.

at 6000 m. or higher . . . . . .not over 10 min.

when climbing . . . . not over 5 min.

12. Maximum duty:

(a) engine rotor speed . . . .$11,150 \pm 50$ r.p.m.

(b) temperature of gases aft of turbine:

on ground . . . . not over $650^{\circ}C$

during flight . . . . not over $680^{\circ}C$

(c) period of continuous operation:

at altitudes up to 6000 m . . . not over 6 min.

at 6000 m. or higher . . . . . .not over 10 min.

13. Rated duty:

(a) engine rotor speed . . . . $11,150 \pm 50$ r.p.m.

(b) temperature of gases aft of turbine . . . . .not over $550^{\circ}C$

(c) period of continuous operation . . . . unlimited

14. Duty at 0.8 of rated thrust:

(a) engine rotor speed . . . .$10,400 \pm 50$ r.p.m.

(b) period of continuous operation . . . . .unlimited

15. Low throttle duty:

(a) engine rotor speed . . . . 4100^{+200} r.p.m.

(b) temperature of gases aft of turbine . . . . .not over $650^{\circ}C$

(c) period of continuous operation.. . . . . .not over 10 min.

16. Engine acceleration ability:

(a) acceleration period:

from low throttle duty to

rated duty . . . . 9 - 12 sec.

from low throttle duty to maximum duty . . . . 9 - 13 sec.

from low throttle duty to augmented duty . . . . .not over 15 sec.

from beginning of automatic regulation to rated duty . . . . 9 - 12 sec.

(b) permissible temperature of gases aft of turbine during acceleration check . . . . not over $750^{\circ}C$

(c) permissible momentary (3 -5 sec.) surge of speed during acceleration check . . . . not over 11,600 r.p.m.

(d) permissible momentary (3 - 5 sec.) surge of speed when afterburner is turned on and off . . . . not over 11,600 r.p.m.

(c) time period during which engine speed changes from maximum to augmented duty. . . . . not over 6 sec.

<u>Note</u>: When checking engine acceleration ability or reducing speed, the engine control lever should be shifted within 1.5 to 2 sec.

3. <u>Fuel System</u>

17. Fuel grade:

(a) main fuel used for engine operation at all duties . . . . fuel T-1 or TC-1

(b) starting fuel . . . . .clean aviation gasoline

18. Fuel booster pump:

(a) designation ШН-9

(b) type . . . . centrifugal, with constant-pressure valve

19. Main fuel pump-regulator:
    (a) designation HP-10A
    (b) type . . . . .plunger, with automatic devices ensuring metering of fuel under all operating conditions
    (c) beginning of automatic regulation of engine speed 8200±100 r.p.m.
20. Afterburner fuel pump-regulator:
    (a) designation HP-11A
    (b) type . . . . .plunger, with automatic devices ensuring fuel metering depending on conditions of aircraft flight with engine operating at augmented duty
21. Fuel pressure before fuel pumps HP-10A and HP-11A. . . . . .1.6-2.6 kg/sq.cm.
    for short periods . . . . up to 2.8 kg/sq.cm.
22. Main burner:
    (a) type . . . . .centrifugal, duplex
    (b) number 10
23. Afterburner fuel nozzle:
    (a) type . . . . .centrifugal
    (b) number 17
24. Fuel pressure before main burners . . . . not over 80 kg/sq.cm.
25. Fuel pressure before afterburner fuel nozzles . . . . .not over 90 kg/sq.cm.

4. Oil System

26. Type . . . . closed circuit, self-sustained, pressure lubrication
27. Oil grade . . . . .MK-8 or transformer oil
28. Oil consumption . . . . .not over 0.5 kg/hr
29. Pressure of oil in oil mains:
    (a) at low throttle . . . . .not less than 1 kg/sq.cm.
    (b) at maximum r.p.m. . . . . .4 - 4.5 kg/sq.cm.

__Note:__ Indicated data apply to test-stand conditions. When operating the aircraft, the indications of oil pressure warning mechanism 2СДУ5-1.3-3 should be taken into consideration (See Para.32).

30. Temperature of oil at engine inlet under all operating conditions:
    (a) minimum permissible . . . . . .-40°C
    (b) maximum permissible . . . . . .+85°C
31. Oil pumps:
    (a) pressure oil pump:
        type . . . . gear, single-stage
        number 1
        output under rated operating conditions, with counter-pressure amounting to 3 - 4 kg/sq.cm. and oil temperature 60 - 65°C . . . . .25 lit /min.
    (b) scavenge oil pump:
        type . . . . gear, three-section
        number 1
        output under rated operating conditions, with counter-pressure amounting to 1.0 kg/sq.cm. and oil temperature 70 - 75°C:
        section scavenging oil from compressor front housing . . . 50 lit /min.

section scavenging oil from middle support . . . . 22 lit/ min.
section scavenging oil from rear support . . . . 22 lit/ min.

32. Two-stage oil pressure warning mechanism:
designation 2СДУ5-1.3-3
type . . . . membrane type
purpose . . . . closes pilot lamp circuit when oil pressure in oil mains drops below $1.3^{+0.3}$ kg/sq.cm. with air blow-off ports open, or below $3_{-0.2}$ kg/sq.cm. with air blow-off ports closed

33. Fuel-oil unit, comprising oil tank, fuel-oil cooler and low-pressure fuel filter . . . . unit 317 A
(a) amount of oil in oil tank:
maximum . . . . $7.5^{+0.5}$ lit.
minimum amount at which engine operation is permissible . . . . 5 lit.

5. Starting System

34. Type . . . . electric, automatic

35. Starting fuel pump (installed on aircraft):
(a) designation ПНР-10-9М

(b) type . . . . gear, with electric motor МУ-102А
(c) number . . . . 1 for two engines
(d) pressure of starting fuel . . . . 1.0 – 1.75 kg/sq.cm.
(e) pump output on ground with counter-pressure 2 kg/sq.cm., voltage across motor terminals 24 V, current 5 A . . . . 40 lit /hr

36. Starting atomizer
(a) type . . . . centrifugal
(b) number 4

37. Generator-starter:
(a) designation ГСР-СТ-6000А
(b) purpose . . . . at engine starting is used as starter; during engine operation functions as D.C. generator
(c) power developed at starting . . . . 3.5 h.p. (with voltage 21.0 V and current 200 A)
(d) power (when functioning as generator). . . . . 6000 W (with voltage 30 V)
(e) period of operation at starting . . . . 44.5 ± 0.5 sec. (31.5 ± 0.5 sec., if voltage of 24 – 48 V is used)
(f) permissible number of successive switchings at starting . . . . 5, followed by 30 min. cooling period

38. Starting panel (installed on aircraft) . . . . ПКС-6000Е (ПКС-

6000Н, if 24 - 48 V system is used)

39. Starter timing device (installed on aircraft). . . . . АВП-1БЕ (АВ5А, if 24 - 48 V system is used)
40. Number of engine startings without boost charging storage batteries: if 24 - 48 V system is employed - from two storage batteries 12 САМ-12; with 24 V system - from one storage battery 12САМ-28. . .not less than 3
41. Starting fuel consumption per one starting . . . . not over 0.5 kg
42. Permissible temperature of gases aft of turbine at starting . . . . .not over 850°C
43. Time of engine acceleration to low throttle speed at starting . . . . not over 80 sec. (60 sec., if 24 - 48 V system is employed)

6. <u>Ignition, Electric Equipment and Control Systems</u>

44. Type of ignition (engine and afterburner) . . . . spark, vibrating
45. Booster coil:
    (a) for engine:
        type КП-21БIМ
        number 1
    (b) for afterburner:
        type КПМ-1А
        number 1
46. Spark plugs . . . . .shielded
    (a) type СД-96
    (b) number 4

47. Afterburner spark plug:
    (a) type СП-02
    (b) number 1
48. Generator control equipment (installed on aircraft):
    (a) carbon-pile voltage regulator Р-25А
    (b) differential-minimum relay ДМР-400
    (c) stabilizing transformer Т-1Г
    (d) ballast resistor БС-6000
49. Afterburner automatic control box (installed on aircraft) . . . . . . КАФ-2 (КАФ-2А for 24 - 48 V system)
50. Compressor blow-off band control mechanism
    (a) type . . . . .hydraulic, piston type with centrifugal and magnetic valves
    (b) pressure of fuel in blow-off band control system . . . . . . not over 85 kg/sq.cm.
    (c) centrifugal valve . . . . controls band depending on engine r.p.m.
    (d) engine speed at which band opens air blow-off ports . . . . . .9700_{-100} r.p.m.
51. Adjustable jet nozzle shutters control mechanism:
    (a) type . . . . .hydraulic,piston
    (b) number of actuating cylinders 4
    (c) hydraulic fluid . . . . АМГ-10 oil
    (d) pressure of hydraulic fluid in control system . . . . 80 - 140 kg/sq.cm.
    (e) temperature of hydraulic fluid . . . . -40 to +60°C

52. Shutter control mechanism switches (installed on aircraft):
    (a) designation ГА-21
    (b) type . . . . solenoid operated slide valve
    (c) number . . . . .2 (per 1 engine)

53. Control panel:
    (a) designation ПУ-3
    (b) purpose . . . .(1) switches on and off maximum and augmented duties;
    (2) shifts shutters to augmented or rated position at engine speed of 4500 - 6500 r.p.m., when engine control lever is moved to "Stop" (Стоп) or "Rated"(Номинал) positions respectively;
    (3) switches stages of oil pressure warning mechanism 2СДУ-51.3-3;
    (4) makes possible cold operation of engine, with control lever set in "Stop" (Стоп)position;
    (5) switches electric system serving for corrosion-preventive treatment of engine

54. Warning and interlocking devices:
    minimum fuel pressure warning mechanism(in afterburner manifold) СД-3
    purpose. . . . . automatically switches off augmented or maximum duty when fuel pressure in aircraft fuel booster system drops below 0.3 kg/sq.cm.

    minimum fuel pressure warning mechanism (in afterburner manifold). . . . . . ДСД-2, membrane type
    purpose . . . .(a) prevents opening of jet nozzle shutters when afterburner is turned on in case excess fuel pressure in afterburner manifold exceeds total pressure of gases in afterburner by less than 0.2 kg/sq.cm.;
    (b) prevents jet nozzle shutters from being closed when afterburner is turned off in case excess fuel pressure in afterburner exceeds total pressure of gases in after-

burner by more than 0.2 kg/sq.cm.

hydraulic switch controlling fuel delivery by pump НР-11А (installed on aircraft) УГ-34/1

purpose . . . . automatically turns off afterburner when there is no hydraulic pressure in intermediate chambers of cylinders controlling adjustable jet nozzle shutters

limit switch of НР-10А pump hydraulic decelerator . . . . . .prevents switching on of maximum duty or of afterburner when engine speed is below 10,400±200 r.p.m., with engine control lever smoothly shifted to respective position

limit switch " Д " controlling compressor blow-off band . . . .(a) prevents shutters of jet nozzle from being open to augmented position at altitudes where engine speed at low throttle exceeds engine speed at which air blow-off band is open when throttling engine;
(b) makes it impossible to switch

on afterburner or maximum duty, if engine speed is lower than that at which band is closed at acceleration

7. Aircraft Accessory Units

55. Hydraulic pump (installed by Manufacturer on accessory drive gearbox):
(a) designation and type. . . . .623 (gear type) or 435ВМ (variable displacement, plunger type)
(b) number 1

8. Measuring Instruments

56. Tachometer (installed by Manufacturer):
(a) type . . . . .2ТЭ-15 with generator ДТ-3
(b) number . . . . .1 set (per 1 engine)

57. Thermometer for measuring temperature of gases aft of turbine (installed by Manufacturer):
(a) type ТВГ-11
(b) number of thermo-couples . . . 4, connected in series

II. ENGINE CONSTRUCTION

Chapter I

COMPRESSOR

The compressor of the РД-9Б engine is an improved modification of the early production models. The compressor is an axial-flow, nine-stage type, providing for high rate of air compression. The compressor is designed for compressing the air flowing into the combustion chambers. The first stage of the compressor is a supersonic one, for air velocity relative to the impeller blades reaches the value, higher than the speed of sound[1].

No provision has been made for air swirling at the entrance to the compressor.

The compressor rotor is comprised of nine discs and two trunnions. The external surface of each disc carries a set of blades fastened in dovetail grooves. The front and rear trunnions are fitted with a roller and a ball bearing respectively, the function of the bearings being to support the rotor.

The stator consists of three main units known as the inlet, middle and rear housings. The rear housing serves simultaneously as a housing for the combustion chambers. The middle housing accommodates eight guide vane assemblies, the ninth guide vane assembly being mounted in the rear housing. The stator guide vane assemblies serve to turn the air, as it leaves each of the turbine rotor stages, in the required direction, as well as to convert a portion of the velocity head to pressure.

[1] The subsequent stages of the compressor are not supersonic (though peripheral speed increases to some extent on the middle diameter of the impeller blades). This is due to the fact that temperature of air flowing through these stages is considerably increased as compared to the temperature of air at the first stage.

The external surface of the rotor drum and the internal surface of the middle housing along with the guide vanes form an annular air-flow path progressively decreasing towards the high-pressure exit. Reduction of the air-flow area is accomplished by increasing the diameter of the rotor drum, the diameter of the middle housing inner surface being uniform (except for the first stage, whose diameter exceeds the diameter of the following stages by 10 mm). Reduction of the compressor air-flow area is required to obtain changing of axial velocity of air at increased density.

Use of special profile rotor blades and guide vanes, thorough surface finish, reduced radial clearances between the rotor blades and the middle housing, as well as the use of labyrinth sealings between the stages - all these features provide for high degree of pressure increase ($\varepsilon = 7.14$), high efficiency ($\eta = 0.835$ at air consumption $G = 43.3$ kg/sec.) and relatively small dimensions of the compressor.

To provide for stable and surge-free operation of the engine at speeds lower than the rated, the compressor is equipped with a special automatic device controlling air blow-off after the fifth stage. Discharge of air (at a speed of up to 9700_{-100} r.p.m.) increases air consumption across the first two stages, which leads to increase in axial velocity of air flow across these stages and prevents slippage of air stream from the blades of the above stages operating at large M numbers. Discharge of air also decreases the volume of air passing through the last stages, thereby preventing them from acting as a turbine when compression ratio is low at speeds below the rated.

NOSE BULLET

To reduce hydraulic losses at air inlet to the compressor, provision has been made for the use of a special nose bullet (Fig.5) consisting of fairing A and support Б (Fig.6).

The fairing which covers the central drive of the inlet housing, forms, together with the stamped struts of the support and cast struts of the inlet housing, streamlined surfaces in the air-flow path on the way to the rotor blades of the compressor first stage. Besides, the nose bullet acts as an anti-icing device.

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No provision has been made for air swirling at the entrance to the compressor.

The compressor rotor is comprised of nine discs and two trunnions. The external surface of each disc carries a set of blades fastened in dovetail grooves. The front and rear trunnions are fitted with a roller and a ball bearing respectively, the function of the bearings being to support the rotor.

The stator consists of three main units known as the inlet, middle and rear housings. The rear housing serves simultaneously as a housing for the combustion chambers. The middle housing accommodates eight guide vane assemblies, the ninth guide vane assembly being mounted in the rear housing. The stator guide vane assemblies serve to turn the air, as it leaves each of the turbine rotor stages, in the required direction, as well as to convert a portion of the velocity head to pressure.

[1] The subsequent stages of the compressor are not supersonic (though peripheral speed increases to some extent on the middle diameter of the impeller blades). This is due to the fact that temperature of air flowing through these stages is considerably increased as compared to the temperature of air at the first stage.

The external surface of the rotor drum and the internal surface of the middle housing along with the guide vanes form an annular air-flow path progressively decreasing towards the high-pressure exit. Reduction of the air-flow area is accomplished by increasing the diameter of the rotor drum, the diameter of the middle housing inner surface being uniform (except for the first stage, whose diameter exceeds the diameter of the following stages by 10 mm). Reduction of the compressor air-flow area is required to obtain changing of axial velocity of air at increased density.

Use of special profile rotor blades and guide vanes, thorough surface finish, reduced radial clearances between the rotor blades and the middle housing, as well as the use of labyrinth sealings between the stages - all these features provide for high degree of pressure increase ($\mathcal{E} = 7.14$), high efficiency ($\eta = 0.835$ at air consumption $G = 43.3$ kg/sec.) and relatively small dimensions of the compressor.

To provide for stable and surge-free operation of the engine at speeds lower than the rated, the compressor is equipped with a special automatic device controlling air blow-off after the fifth stage. Discharge of air (at a speed of up to 9700_{-100} r.p.m.) increases air consumption across the first two stages, which leads to increase in axial velocity of air flow across these stages and prevents slippage of air stream from the blades of the above stages operating at large M numbers. Discharge of air also decreases the volume of air passing through the last stages, thereby preventing them from acting as a turbine when compression ratio is low at speeds below the rated.

NOSE BULLET

To reduce hydraulic losses at air inlet to the compressor, provision has been made for the use of a special nose bullet (Fig.5) consisting of fairing A and support Б (Fig.6).

The fairing which covers the central drive of the inlet housing, forms, together with the stamped struts of the support and cast struts of the inlet housing, streamlined surfaces in the air-flow path on the way to the rotor blades of the compressor first stage. Besides, the nose bullet acts as an anti-icing device.

The support is manufactured of sheet aluminium alloy and comprises cylinder 10 with four stamped struts 9 point-welded to the cylinder in four diametrically opposite directions. The stamped struts are double-walled. Individual components of the stamped struts are connected to each other by means of point- or continuous welding.

The upper strut of the support accommodates a pipe, threaded at the end, serving to supply air to the barostatic governor of the HP-11A pump. The lower strut houses a pipe for delivery of hot air from behind the ninth stage of the compressor to the inner cavities of the fairing and struts with the purpose of heating the walls of the nose bullet. The support cylinder houses flange 11 fastened by rivets and provided with eight holes.

The fairing is a double-walled ellipsoidal structure, manufactured from sheet aluminium. The fairing consists of outer wall 6 and inner wall 5 connected to each other through cylinder 7 by point-welding; besides, the inner wall is jointed at its base to the cylinder by continuous welding.

The front portion of the fairing outer wall mounts fairing tip 4 held in place by eight rivets. The tip is provided with radial grooves, machined on the inside, and a central hole accommodating the head of screw 3. The inner wall of the fairing has an annular groove at its base, which, along with cylinder 7, forms a manifold for the air delivered to the nose bullet for heating its walls. The front portion of the inner wall is flanged inward and separated by partition 2 secured by means of point-welding.

For delivery of hot air to the annular manifold and for by-passing it into the support struts, the fairing cylinder is provided with four holes. Hot air is delivered into the fairing interwall space through pipe 1 one end of which is secured to the flange of the inner wall annular groove, while the other end is fitted into the hole provided in the partition[1].

[1] Some of the air supplied via pipe 1 flows along the radial grooves of the fairing tip and into the intake duct of the compressor, to be thrown against the fairing outer wall by the air stream. Circulation of hot air between the walls of the fairing and the struts, as well as heating of the fairing outer surface by the air escaping through the radial grooves of the fairing tip prevent the nose bullet from icing.

Hot air delivered via the pipe passes through the flanged hole into the fairing interwall space from where it escapes through a number of holes provided in the middle portion of the inner wall.

The fairing is secured to the cover of the central drive by means of screw 3, passing through the central holes in the fairing tip and in the partition. The outer diameter of the cylindrical portion of the fairing base is centered in the support cylinder.

The fairing is held in a definite position relative to the support by a retaining lip, provided on the cylindrical portion of the fairing, and a respective recess in the support cylinder.

The support is fastened to the inlet housing by sixteen studs passing through the holes provided in the inner flange of the support and through the holes in the flanges of the stamped struts. The stamped struts of the support enclose oil and breather pipes, running along the front faces of the inlet housing struts.

When the engine is tested on a stand, a special diffuser is installed at the engine air intake. The diffuser is a component part of the test stand equipment set.

INLET HOUSING

The inlet housing along with the nose bullet form the entrance section of the engine air duct.

The inlet housing (Figs 7, 8, 9) is cast of magnesium alloy МЛ5 and consists of an outer ring and an inner box, coupled by means of four diametrically opposed hollow struts. The external surface of the ring carries bosses at the top, which have machined surfaces and are provided with threaded recesses. The bosses serve for mounting and securing the accessory drive gear box. The lower part of the ring is fitted with a boss whose inner cavity serves as an oil pan.

The inner box of the front case accommodates the central drive unit with centrifugal breather and scavenge oil pump, as well as the body of the compressor rotor front bearing with talc powdered surfaces for the collars of the rotating labyrinth sealings mounted on the front trunnion of the compressor rotor.

The inner cavities of the cast struts house vertical shaft 3 (See Fig.9) transmitting rotary motion to the drives of the accessory gear box, as well as engine oil and air system lines. The front outer side of the vertical strut mounts steel breather pipe 1 connecting the cavity of the centrifugal breather to the atmosphere through the central drive unit and the accessory drive gear box. The outer side of the lower vertical strut mounts pipe 4 through which oil is drawn from the oil pan of the front case. The outer side of the left-hand horizontal strut (as viewed from the air entrance end) accommodates pipe 9 through which oil is drawn from the rear bearing of the engine. Pipe 7 running along the outer side of the right-hand horizontal strut serves for evacuating oil from the medium bearing. The left-hand horizontal strut encloses pipe 11 along which oil is directed to the oil tank via pipe 8 and the fuel-oil cooler, while the right-hand horizontal strut houses a breather pipe, connecting the compressor-turbine shaft cavity to the centrifugal breather; besides, the right-hand horizontal strut has a channel to which air is fed via pipe 10 used for packing the labyrinth of the compressor front bearing. Pipe 2 runs along the drilled passage provided in the upper vertical strut; it serves for delivery of oil to the central drive unit and to the front bearing of the compressor rotor.

For cleaning the oil dripping into the oil pan, the inner cavity of the lower strut at the central drive side is fitted with gauze 5. The rear side of the oil pan is furnished with pipe union 6 serving to connect the oil return pipe line.

The rear flange of the inlet housing is coupled to the compressor middle housing by means of 24 bolts and nuts. The front flange of the inlet housing mounts 24 studs which serve to secure the nose bullet and the test stand diffuser.

MIDDLE HOUSING (Figs 10, 11)

The middle housing comprises a hollow cylinder accommodating eight stages of the stator vane assemblies. Apart from this, the middle housing serves as an intermediate link between the inlet and rear housings of the compressor.

The middle housing is a split structure consisting of front annular section A and rear annular section Б, the two sections being coupled with the help of 30 bolts of which ten are fitted bolts. The front annular section accommodates five rows of fixed guide vanes, while the rear section mounts three rows.

Both the sections consist of two halves with a common longitudinal joint in the vertical plane. This joint facilitates handling of the compressor rotor, when installing it in place.

The halves of the middle housing are held together with the help of six fitted bolts and sixteen coupling bolts arranged along the upper and lower longitudinal flanges.

The front section is manufactured from magnesium alloy МЛ7-1, whereas the rear one is made of steel 30ХГСНА.

The eight guide vane assemblies of the middle housing include 398 vanes; of these, 18 vanes are installed in the first stage, 22 vanes in the second stage, 26 vanes in the third stage, 60 vanes in the fourth stage, and 68 vanes in each of the fifth, sixth, seventh, and eighth stages.

The guide vanes of the first, sixth, seventh and eighth stages are constructed of steel 30ХГСА. The use of steel for the manufacture of these vanes is dictated by the fact that the vanes of the first stage are more than the other vanes exposed to the action of foreign particles, getting into the compressor with the air stream, whereas the vanes of the rear stages operate at high temperatures. The remaining stages are fitted with vanes made of forged aluminium alloy ВД17. To make the construction more rigid and strong some vanes in these stages are likewise made of steel (See diagram showing arrangement of steel vanes, in Fig.12).

The guide vanes have special streamlined profiles, and they are installed at definite angles relative to the engine axis.

The channeled portion of each vane in its upper part passes into a square plate and threaded trunnion (the cylindrical trunnions of steel vanes are provided with grooves accommodating locking rings). The inner surface of the middle housing has eight annular grooves designed to accommodate the square plates of the guide vanes. The vane plates fit into the respective annular groove thus causing the vanes to occupy definite positions and guarding them against rotation. The vanes are secured to the middle housing by nuts 6 (Fig.13), which are turned onto the threaded trunnions of the vanes, passed through the holes in the middle housing. To prevent air leakage through clearances, rubber packing rings 5 are installed where the vanes are jointed to the middle housing.

As the first three stages carry a small number of guide vanes, the annular grooves of these stages (between the plates of the guide vanes) are fitted with special inserts secured by screws. The inserts fill the annular grooves flush with the vane plates and the inner surfaces of the middle housing.

The guide vane assemblies are strengthened by half-rings 1 and 2 (See Figs 11 and 13) connecting the smooth cylindrical trunnions of the vanes pointing towards the centre line of the middle housing.

The half-rings enclose the vane trunnions and are fastened with bolts 6 or studs 3 and nuts 4 (See Fig.11). The half-rings are held from radial displacement by locking rings 3 (See Fig.13) installed into the grooves machined in the trunnions of the extreme steel vanes.

The external surfaces of the half-rings along with the outer surfaces of the rotor discs carrying the blades form the compressor air-flow path.

The inner surfaces of front half-rings 1 have talc coating which, together with annular collars provided on the rotor discs, make labyrinth sealings, preventing flow of compressed air from high-pressure stages to lower-pressure stages. The talc coating has been provided with the purpose of obtaining the least possible radial clearances in the labyrinth sealings, with the manufacturing procedure being reasonably simple. Besides, rubbing of the labyrinth collars against the talc coated surface during compressor operation does not cause scores or galling on the mating surfaces of the sealings. The inner surfaces of the middle housing, above the rotor blades of the first five stages, are talc coated with the same purpose in view.

The air blow-off ports are located aft of the fifth stage of the guide vanes, where the front section is coupled to the rear section. The air blow-off ports are closed with a steel flexible band controlled by a special mechanism.

The bolts coupling the flanges of the two sections are provided with L-shaped stops, limiting the travel of the steel band. The coupling flanges of the sections are provided with collars supporting the band. The collars provide for a higher specific pressure and a better fit of the band.

The front flange of the middle housing has a cylindrical recess which receives the centering collar of the front housing flange, while the rear flange of the middle housing has a centering collar fitting into the cylindrical recess provided on the rear housing flange. The middle housing is connected with the front housing by 24 bolts (of which six are fitted bolts), while connection to the rear housing is accomplished by the use of 52 bolts.

The lower rear portion of the middle housing left-hand half (looking forward) is provided with a pipe union through which some air from behind the eighth compressor stage is delivered to the front bearing to be used for packing its labyrinth sealing. A pipe union provided in the upper portion of the middle housing right-hand half serves for delivery of air from behind the eighth compressor stage to the automatic starter and to the acceleration valve of HP-10A pump.

In addition to various fuel, oil, air, and electric lines the external surface of the middle housing mounts the following equipment: mechanism for control of the air blow-off band, electric system servo-units, vent system tank, and three mounts for securing the engine to the aircraft.

REAR HOUSING

The rear housing (Figs 14, 15, 16) is one of the main units subjected to great stresses. It is designed to serve as an intermediate link between the compressor and the hot portion of the engine; it also serves for securing the combustion chambers and for mounting the guide vane assembly of the compressor ninth stage.

The rear housing consists of a number of individual welded units manufactured from steel 1X18H9T and combined in one assembly, making a rigid and light structure.

The outer wall of the rear housing forms the combustion chamber shell and is a thin-walled casing made of 1.8 mm thick sheet steel. The outer wall consists of stamped cone 5 (See Fig.16) and cylindrical band 6 jointed by means of continuous welding. Welded to the front face of the outer wall is rear housing outer ring 1. The outer ring serves for securing the rear housing assembly to the middle housing of the compressor, as well as for mounting vanes 3 of the guide vane assembly of the compressor ninth stage. To this end the cylindrical portion of the ring is provided with a number of through holes accommodating the guide vanes. Welded to the rear face of the outer wall is a flange serving to retain the combustion chambers and to secure the ring of the turbine first stage nozzle assembly. On the outside the combustion chamber shell carries 10 flanges for securing the main burners, four flanges for fastening the flame igniters, flanges for oil, air and vent lines, as well as some bosses for securing the fuel-oil unit and pipe line brackets.

The guide vane assembly of the compressor ninth stage consists of 68 vanes, made of steel 4X14H14B2M. Each guide vane passes in its upper part into a smooth or threaded trunnion, while the lower part of each vane ends in a square plate and a lug.

The upper trunnions of the vanes are fitted into the holes of the combustion chamber shell ring, while the lower plates rest upon rear housing inner ring 15 and are secured to it by means of lugs, bolts 17 and nuts 16. The guide vanes are secured to the outer ring by nuts 2 turned onto the threaded trunnions passed through the holes in the ring of the combustion chamber shell.

Thus, the guide vanes connect the outer and inner rings of the rear housing.

The inner ring of the rear housing is fitted with labyrinth ring 19 secured by means of radial dowels 18. The labyrinth ring along with the annular collars, provided on the rear trunnion of the compressor rotor, forms an air seal-

ing preventing air leakage from behind the compressor into the rear relief cavity formed by the outer wall of the rotor rear trunnion and the inner surface of bearing housing diffuser 20. Reduced leakage of air causes the pressure in this cavity to drop thereby reducing axial stresses imposed on the middle bearing. The air leaking into the relief cavity is evacuated through four ports on the diffuser housing, which receive the ends of special pipe connections 4, mounted on the tapered surface of the combustion chamber shell.

To build up and adjust pressure in the relief cavity to a definite value, which would facilitate operation of the air labyrinth sealing without imposing excessive axial stresses on the rotor, air escape from the relief cavity is throttled (special diaphragms with various clear openings are installed at the pipe connection outlets).

Welded to the rear side of the inner ring is the bearing housing assembly, welded from sheet steel 1X18H9T. The housing consists of diffuser 20 with two inner ribs 21, and bearing housing 7 proper, which comprises a cylinder with flange 10 mounting the housing of the rear bearing and the first stage nozzle assembly. Thus, the bearing housing serves as an intermediate link between the rear support and the load-carrying ring of the rear housing.

The outer surfaces of the diffuser housing and of bearing housing shield 9 make up the inner contour of the air-flow portion of the engine aft of the compressor.

To render the bearing housing more rigid, it is fitted with three ribs 8, secured by means of continuous welding.

The bearing housing accommodates oil supply pipe 12 carrying at its ends oil nozzles 11 and 22 which deliver oil to the centre and rear bearings of the engine. Pipes serving for removal of oil from the cavities of the middle and rear bearings are also arranged inside the housing.

The inner cavity of the bearing housing communicates with the atmosphere through the breather pipe and the centrifugal breather.

The oil and breather pipes are led in and out through special ports provided on the side surfaces of the combustion chamber shell.

COMPRESSOR ROTOR (Figs 17 and 18)

The drum of the compressor rotor is comprised of nine individual discs 2 (See Fig.18), front 1 and rear 13 bell-type trunnions, and 378 blades of special profile.

Among the advantages offered by this arrangement are small weight and adequate rigidity and strength of the construction. All the components of the compressor rotor are manufactured with great precision, as the rotor spins at high speeds and is subject to considerable stresses due to centrifugal forces. The blades of the first stage have to withstand centrifugal stresses amounting to 7 tons, while the blades of the ninth stage - the stresses amounting to 1 ton.

For reducing the weight of the unit the discs of the second, third, fourth, and fifth stages are manufactured from castings of aluminium alloy AK4-1, whereas the blades secured to these discs are made of forged aluminium alloy ВД17. The discs of the first, sixth, seventh, eighth, and ninth stages are made of construction steel 30ХГСА, while the respective blades are manufactured of steel ЭИ268 (Х17Н2).

The front and rear trunnions of the rotor are constructed of steel 40ХНМА.

Each disc is a ring with walls in the form of a diaphragm. The outer part of the ring has slanting dovetail grooves receiving the rotor blades.

The ring of each disc (except the fifth one) has a centering cylindrical band on one side, while the other side of the ring is provided with a groove receiving the centering band of the adjacent disc or of the trunnion. Machined on the tapered annular surfaces of the discs are circular ridges 9 contacting the talc coated surfaces of the inner half-rings of the guide vane assemblies.

To prevent corrosion the steel discs are zinc plated.

The discs and the trunnions are successively pressed on the cylindrical bands, and are coupled by hollow radial dowels 10 to form a non-detachable unit. To provide a means of escape for the air trapped in the cavities formed during pressing operations, and to vent the inner cavities of the rotor drum to the atmosphere, the discs have drilled passages of 1 mm in diameter.

The front trunnion of the compressor rotor mounts three labyrinth sealings 7 and front support roller bearing 6. The labyrinth sealings along with the talc coated surfaces of the front housing and the housing of the front bearing form the front relief cavity and the cavity into which air is supplied from behind the eighth stage of the compressor to be packed into the labyrinth sealing of the front bearing (See Fig.20).

The taper surface of the rear trunnion has a number of circular ridges, mating with the grooves of the rear housing labyrinth ring. The cylindrical surface of the rear trunnion mounts radial-thrust ball bearing 15 (See Fig.19) of the middle support. In front of the bearing there are some circular ridges mating with the talc coated surface of the centre bearing housing.

The rear trunnion incorporates coupling 4, which serves for preventing the turbine shaft from axial displacement, the splines of the turbine shaft being fitted into the inner splines of the rear trunnion. Dowels 5 guard the coupling against axial displacement and limit its turning. Riveted to the inner surface of the rear trunnion is spring catch 3, retaining the coupling in a fixed position. Simultaneously, the spring catch closes the hole in the trunnion through which a mounting wrench is inserted when coupling or uncoupling the compressor rotor and the turbine rotor.

In their cross section the blades of all rotor stages have perfect aerodynamic profiles finished with great precision, the blades of the first stage having wedge-shaped supersonic profile to 2/3 of their height.

The blades are installed at a definite angle relative to the rotor axis, to provide for optimum angle of attack of blade profiles relative to the stream of air at the engine maximum speed.

At the base the blades of all stages terminate in wedge-shaped dovetail locks (Fig.19). These locks are fitted into the slanting dovetail grooves of the discs, thereby ensuring a definite angle between the blade and the air flow: the lock also keeps the blade from radial displacement.

The blades are fitted into the disc grooves with a clearance of 0.005 to 0.035 mm, thus limiting tangential play of the blades to within 0 - 0.8 mm when measured at the height of 100 mm from the lock portion.

The first disc mounts 29 blades, the second - 17, the third - 28, the fourth - 33, the fifth - 52, the sixth - 52, the seventh - 53, the eighth - 59, and the ninth - 55.

The number of blades and the density of the grid they form correspond to distribution of load among the compressor stages.

The blades of the first seven stages are secured in the grooves of the discs by means of steel split locking rings 11 (See Fig.18) installed into special recesses provided in the discs and in the lock portion of these blades. The locking rings are held in place by special dowels, which are flanged after being fitted in.

The blades of the eighth and ninth stages are fastened in the grooves of the discs with the help of individual retaining locks 12. To this end, the grooves in the discs are provided with special milled recesses whose contours correspond to the shape of the retaining locks. The blades are held in place by the nibs of the retaining locks, bent over the butt ends of the blade lock portion (See Figs 18 and 19).

With the engine in operation the compressor rotor sets up considerable axial stresses taken up by the centre bearing. To reduce these axial stresses, a special relief system has been provided which is designed as follows: the ring portion of the seventh disc has a number of drilled radial passages through which a portion of air from behind the sixth stage of the compressor is delivered inside the rotor. The inter-disc cavities communicate with one another through the holes provided in the disc walls, due to which pressure is equalized throughout the compressor rotor. Similar holes are provided on the tapered surface of the rotor front trunnion.

As the inner cavity of the compressor communicates with the front relief cavity through the holes in the taper wall of the front trunnion, different pressures are created which act on the wall of the rear trunnion from within the rotor, and on the trunnion outer wall from the rear relief cavity side (See Fig.21). The difference between pressure values gives rise to an axial force which opposes the stresses created by rotation of the compressor rotor. This results in a considerable reduction of the axial stress imposed on the centre bearing.

The centre bearing is relieved of the axial stresses also due to the axial effort developed by the turbine in the direction opposite that of the axial effort of the compressor, as well as due to the axial force created by the pressure difference of the air acting on the walls of the front trunnion: from cavity 3 (See Fig.20), into which air is delivered from behind the eighth stage of the compressor, and from inside the rotor drum.

The compressor rotor assembly is subjected to dynamic balancing on a special balancing machine, with an accuracy of 5 gr-cm at each support. The required accuracy of balancing is attained by selecting blades of appropriate weight and by installing them into proper disc grooves during rotor assembly, as well as by removing metal from the rear trunnion (in place Б) or by installing weights on the front trunnion under the bolts securing the labyrinth sealing in place A (See Fig.18).

ENGINE ROTOR BEARINGS

The compressor and turbine rotors are supported by antifriction bearings, the compressor rotor resting upon the front roller bearing and centre ball bearing, and the turbine rotor shaft resting on the rear roller bearing.

The front roller bearing (Fig.20) takes only radial stresses. Inner ring 8 with the rollers and the cage is an integral unit, while the outer ring is an individual part fastened inside front support 2 with the help of a locking ring.

The inner ring of the front bearing is tightly fitted onto the cylindrical band of the rotor front trunnion and is secured with nut 6, which is retained by plate lock 5. The inner ring has two collars holding the rollers and cage in a definite position. Outer ring 7 has no collars and allows the rotor to move in the axial direction relative to the housing, thus making up for manufacturing errors (within the limits set in the drawing) and for thermal expansion.

Lubrication and cooling of the bearing is accomplished by the use of an oil jet delivered through a calibrated orifice provided in oil nozzle 4. The bearing is sealed by means of a two-stage air labyrinth sealing comprised of two rows of circular ridges, rotating together with the front trunnion of the rotor and fixed talc-coated surfaces of the front support housing.

A special pipe line and a drilled passage serve to deliver air into the interlabyrinth space from behind the eighth stage of the compressor; the air prevents oil from being thrown into the relief cavity.

The centre radial-thrust ball bearing (Fig.21) guards the engine rotor against axial displacement and takes up axial and radial stresses. The bearing consists of inner ring 13, ball 12, cage 3, and split outer ring 4. The inner ring of the bearing is mounted on the cylindrical band of the compressor rotor rear trunnion and is fastened by nut 9 retained by plate lock 11. The split outer ring is enclosed in middle support housing 5, which is secured to the bearing housing by means of bolts and nuts; in addition it is fastened by nut 8, locked by plate lock 7.

The middle support has a labyrinth sealing, consisting of circular ridges machined on the rear trunnion, and talc coated surface of the bush welded to the middle support housing. Installed between the face of the bearing inner ring and the rear trunnion collar is slinger ring 2 which along with the labyrinth sealing prevents oil from being thrown into the rear relief cavity. The bearing is cooled and lubricated by a jet of oil which is delivered through the calibrated orifice of oil nozzle 10. The oil nozzle incorporates a gauze filter for oil cleaning.

The rear roller bearing (Fig.22) takes up only radial stresses imposed on the turbine rotor.

In its construction the rear bearing is similar to the front bearing. Inner ring 12 with rollers and the cage is fitted onto the cylindrical band of turbine shaft bush 14 where it is fastened by round nut 11, retained by plate lock 1. The outer ring is installed in rear support housing 4 which is secured to bearing housing 7 with the help of bolts 5, nuts 8 and locking ring 3.

The outer ring has no collars and allows the turbine rotor to move axially thus making up for thermal extention and manufacturing errors within the permissible limits set by the drawing.

The rear support is furnished with a two-stage air labyrinth formed by two rows of circular ridges machined on labyrinth 15 and on the turbine shaft bush, and of talc coated surfaces of the bushes welded to the housing of the rear support. The labyrinth sealings do not allow hot air from the space before the turbine to penetrate into the rear support.

To by-pass hot air leaking through the upper labyrinth sealing, the interlabyrinth space is connected to the rear relief cavity by six pipes arranged between the bearing housing wall and shield 6.

Cooling and lubrication of the bearing is accomplished by the use of oil nozzle 2. The nozzle has two calibrated orifices one of which serves to spray oil onto the bearing, while the other, of a smaller diameter, is pointed towards the turbine shaft and delivers oil for cooling purposes. The middle and rear supports installed on the flanges of the bearing housing, form a common cavity which communicates with the centrifugal breather via a special pipe.

Used oil drips into the sumps of the bearing housing whence it is drawn by the two stages of the scavenge oil pump (installed in the front housing of the compressor) connected with the sumps by two drain tubes.

AIR BLOW-OFF BAND CONTROL SYSTEM

To provide for stable operation of the engine at intermediate duties, a portion of the air compressed in the first five stages of the compressor is blown-off into the space between the engine and the inner surface of the fuselage skin.

The air is discharged through a number of ports arranged along the joint between the front and rear sections of the compressor middle housing.

The blow-off ports are closed with a band which is controlled automatically through a hydraulic system (Fig.23) operated by the fuel, supplied from the pressure line of the HP-10A fuel pump.

The air blow-off band control system is comprised of a centrifugal valve and a band control mechanism.

The centrifugal valve (Fig.24) is designed for automatic control of the air blow-off band. Structurally it consists of a sensing unit and a valve proper: the sensing unit determines the engine speed at which operation of the air blow-off band control mechanism takes place, while the valve controls delivery of fuel to and its drainage from the band control mechanism. The sensing unit consists of housing 1 with bush 2 pressed into it. Bush 2 accommodates hollow shaft 3, actuated by the accessory drive gear box through cylindrical toothed wheel 24, mounted at the shaft end; the other end of the shaft carries centrifugal weights 4. The shaft accommodates slide valve 11 capable of travelling along the shaft axis. The slide valve end mounts the ring with ball bearing 6, and spring retainer 10. Resting against retainer 10 is spring 9 which forces the slide valve to the lower position. The other end of spring 9 rests against retainer 7 fitted with adjusting screw 8. The adjusting screw serves for changing the tension of the spring which determines the speed of the engine at which operation of the air blow-off band control mechanism takes place. When the screw is turned in, the control mechanism operates at a higher speed, when the screw is turned out the control mechanism operates at a lower speed. With the adjusting screw turned through 360°, the speed at which the band control mechanism operates changes by 300 to 4[illegible] r.p.m.

The valve comprises housing 13 with bush 14 pressed into it. Shifting inside the bush are valve seats 15 and 22 with valves 19 and 21. Rod 20 is installed between the valves. Valve 19 with seat 15 is pressed against the rod by spring 16. The other end of the spring is pressed against retainer 17 with cover 18.

Valve 21 with seat 22 is pressed by spring 16 through rod 20 to membrane 23. On the other side the membrane is acted upon by spring 12. The centrifugal valve has five pipe unions.

With the engine in operation, oil is continuously delivered through pipe union B and filter 25 from the oil pressure line, while fuel is delivered from the pressure line of the HP-10A fuel pump via pipe union Б and filter 26.

Fuel delivery pipe union Б is fitted with a throttling jet with the orifice diameter amounting to 0.8 mm. Pipe union A serves for fuel delivery to the blow-off mechanism, while through pipe union Г fuel is directed to the vent system. Pipe union Д with filter 27 serves for oil delivery from the magnet valve.

The centrifugal valve is secured to the accessory drive gear box with the help of a quick-detachable ring.

The air blow-off band control mechanism (Fig.25) consists of a blow-off mechanism, two sectors and two brackets.

The blow-off mechanism comprises cylinder 2, steel piston 4 with rubber cup 3 and distance ring 19.

The piston is acted upon by spring 5, whose opposite end rests against cover 7 with bush 9.

The cover is manufactured from magnesium alloy МЛ5 and is secured to the cylinder by six studs 6. Bush 9 accommodates rubber packing ring 8 which prevents oil leakage through the clearance between the piston rod and the bush.

Fuel, leaking into the space between the piston and the cover, is drained through the hole provided in the cover and through pipe union 18. Piston rod 4 is coupled to driving sector 12 through tip 10 with the help of pin 11. Driving sector 12 is engaged with driven sector 13.

The sectors rotate in needle bearings 15; the sectors proper serve as outer rings of the bearings, distance sleeves 14 being used as the inner rings.

Sectors 12 and 13 are connected to the lugs of air blow-off band 16. The band control mechanism is secured to the middle casing of the compressor by means of hinges and brackets 1 and 17.

The air blow-off band control system functions as follows.

When the engine speed is increased, centrifugal forces developed by weights 4 (See Fig.24) overcome the force of spring 9 and cause slide valve 11 to move to the position at which oil is supplied to the cavity of membrane 23 via duct a.

Due to pressure of oil on the membrane, the valve seat and valve 21 move to the right and actuate rod 20 thus causing valve 19 with seat 15 to move and to open duct б for fuel to be supplied to pipe union A. Then fuel via pipe 2 (See Fig.23) is directed to the cylinder of the blow-off mechanism and shifts piston 5 with cup 4 to the right; this causes the piston rod to turn toothed sectors 7 and 8 thereby tightening the band, which closes the air blow-off ports. When the engine speed is decreased, slide valve 11 (See Fig.24) is forced by spring 9 in the opposite direction thereby cutting oil supply to the membrane cavity. Oil from the membrane cavity via duct a and hole B provided in slide valve 11 is fed into the cavity of the centrifugal weights whence it is drained into the accessory drive gear box through two grooves machined in bush 2. Spring 16 forces valves 19 and 21 to the left (to position shown in Fig.24) thus cutting fuel supply from the pressure line of the HP-10A fuel pump to the blow-off mechanism cylinder. Simultaneously, fuel is drained from the blow-off cylinder through duct г; under the action of spring 6, piston 5 (See Fig.23) shifts to the left and discharges fuel from the cylinder into the vent system; in this case the piston rod turns the toothed sectors in the opposite direction; this causes the band to loosen, as a result of which an annular clearance is formed between the compressor middle housing and the blow-off band, providing exit for the air. To obtain a uniform annular clearance between the air blow-off band and the compressor middle housing, with the band open, and to eliminate vibration of the band, provision has been made for the use of stops on the compressor middle housing, which limit band movements both in radial and axial directions. To ensure remote control of the blow-off mechanism irrespective of the engine speed, provision has been made for additional oil delivery into the membrane cavity of the centrifugal valve via magnetic cock 1 (See Fig.23) and pipe union Д (See Fig.24).

The magnetic cock (Fig.26) consists of cock housing 1, magnet housing 5 and plug connector case 8. The cock housing has two pipe unions: pipe union "a" - for delivery of oil into magnetic cock from the oil pressure line, and pipe union "б" - for delivery of oil from the magnetic cock into the membrane cavity of the centrifugal valve. The housing accommodates piston 3

provided with two holes, 1 mm in diameter, serving for oil passage into the piston. The circular groove of the piston mounts packing ring 14. The piston is forced to the extreme left-hand position by spring 4, with the packing ring pressed against the cock housing seat.

Piston 3 is coupled to packing ring 14 and core nut 13 with the help of hollow screw 2. The nut has a recess for connection to the core, which is shaped in the form of a needle. At one end the core is recessed to receive packing disc 12, while the other end is provided with a 4.5-mm diameter hole accommodating spring 10. To prevent oil or air locks, and to provide for easy movement of the core, the space between the core and the coil is connected to the piston cavity via the central hole of the core and the recess connected by 1-mm diameter hole.

The core is accommodated inside coil 6 and is forced by spring 10 to the extreme left-hand position; the packing ring rests against the face of screw 2.

The coil is fitted into the electromagnet housing. Resistance of the coil winding at a temperature of +20°C amounts to not less than 15 cm. The coil terminals are soldered to the contact pins of plug connector union 7. Plug connector ВШ-4 is secured with four screws to the flange of its case, which is held to the magnet housing by nut 9.

The magnetic cock operates as follows: oil, continuously fed during engine operation to pipe union "a" via the oil pressure pipe line, enters the piston cavity through two holes. As the hole in the screw is closed by packing disc 12 of core 11, forced by spring 10 against screw 2, oil exerts pressure on the piston. Under the force of oil and springs 4 and 10 the piston is tightly held against the valve housing seat, thereby preventing oil from escaping into pipe union "б" and consequently into the membrane cavity of the centrifugal valve when the magnetic cock is cut out.

When the magnetic cock is cut in, current is supplied into the magnet coil, causing the core to shift to the right (as far as clearance A permits) and to uncover the hole in the screw thereby supplying pressure into the piston cavity. On its further travel the core overcomes the force of springs 4 and 10, displaces the piston with the packing ring and opens the passage for oil from pipe union "a" to pipe union "б" and further to the membrane cavity of the centrifugal valve.

With the magnetic cock cut off, springs 4 and 10 force the core and the piston into the initial position (closing). The magnetic cock is mounted on a bracket and secured by two straps. The bracket is secured on the studs of the НР-10А fuel pump.

On an aircraft powered by two engines, the magnetic cock is automatically cut in to close the air blow-off band of the running engine, when the second engine is being started. This arrangement has been provided in view of the fact that air escaping from under the band of the running engine interferes with the normal operation of the compressor of the engine being started.

Chapter II

COMBUSTION CHAMBER

The combustion chamber is designed for heating the air delivered by the compressor.

The combustion chamber is an important engine unit subjected to great thermal stresses as considerable amount of fuel is burnt within a comparatively small space.

Specific thermal stress, that is thermal stress referred to air pressure at the combustion chamber inlet, amounts to 49 millions of Cal.

COMBUSTION CHAMBER CONSTRUCTION

The engine is fitted with 10 individual cylindrical combustion chambers (Fig.27) of the straight flow type mounted circumferentially between the rear housing and the shield (Fig.28).

The combustion chamber (Fig.29) consists of snout 2, swirler 9, liner 4, flame tube 5 and flange 6.

Snout 2, constructed of sheet alloy ЭИ602 is butt welded to combustion chamber liner 4 by argon-arc welding. The snout mounts a cylindrical collar accommodating swirler 9 secured by means of point welding. Swirler 9 consists of outer shell 1, five shaped vanes 8 and bush 7. All the swirler components are fabricated of sheet alloy ЭИ435. Each of the swirler vanes has four lugs point-welded to the outer shell and to the swirler bush. The swirl vanes are curved to 72°. To prevent wear, the inner surface of swirler bush 7 is chrome-plated, as it accommodates main burner 1 (See Fig.28) supporting the combustion chamber. The main burner being a free fit in the swirler bush, the combustion chamber is capable of axial travel to compensate for thermal expansion.

Combustion chamber liner 4 (See Fig.29) fabricated from alloy ЭИ602 is a cylinder with a spherical front portion.

As the combustion chamber liner has to withstand very high temperatures, its external surface carries longitudinal ribs making for better heat dissipation and increasing its rigidity. Scattered all over the entire surface of the liner are small and big diameter holes serving to obtain the required gas temperature before the turbine and to cool the combustion chamber walls.

The liner has two by-pass holes accommodating bushes 7 and 9 (See Fig.28) manufactured from alloy ЭИ435 . The bushes are coated with aluminium to prevent them from burning out. One of the bushes 7 is fitted with a lock serving to retain by-pass connection 8, made of sheet alloy ЭИ435 . Bushes 7 are provided with special lugs which prevent the connection from dropping out during transportation of individual combustion chambers as well as during engine assembly and disassembly.

Four by-pass connections 11 form a kind of a tee-piece one end of which accommodates flame igniter 10, which ignites fuel in two adjacent combustion chambers simultaneously. Other by-pass connections 8 have slots on their surfaces serving to cool down the connection.

The mounting diameters of the by-pass connections are face-hardened by the electric spark method, to reduce wear during operation. All by-pass connections should be capable of free swinging inside bushes 7 and 9 of the combustion chamber liners.

By-pass connections 8 and 11 serve for equalizing gas pressure as well as for proper flame propagation.

Secured to liner 4 (See Fig.29) by means of continuous welding is flame tube 5, constructed from 1.5-mm thick sheet alloy ЭИ602.

The flame tube, cylindrical in shape where it is coupled to the combustion chamber liner, gradually assumes a trapezoidal shape. The flame tube carries flange 6, made of alloy ЭИ435 and secured by means of argon-arc welding. The flange has a collar which is arranged between the flanges of rear housing 3 (See Fig.28) and nozzle assembly 4 thus guarding the combustion chamber against axial displacement. Ring 5 to

which the combustion chambers are secured with bolts, keeps them from radial displacement.

To reduce peening to a minimum, combustion chamber flange 6 (See Fig.29) is coated with a layer of copper. To prevent crack formation, the inner and outer surfaces of the combustion chambers are subjected to electric polishing.

FUEL COMBUSTION PROCESS

Air packed by the compressor into the combustion chamber is divided into two streams.

The primary stream of air used in the fuel combustion process enters the combustion chamber through the swirler and the holes provided in the front portion of the liner. In passing the swirler the primary air stream is violently thrown against the liner walls by centrifugal forces.

A zone of reduced pressure created in the front part of the combustion chamber causes a small portion of hot gases to flow back towards the burner, which results in a rise of temperature in the front part of the liner; this makes for better fuel evaporation and improves mixing of fuel with air. Besides, the streams of hot gases flowing in the reverse direction provide for reliable ignition of fresh mixture within a wide range of excess air coefficient change (from $\alpha \approx 3.5$ to $\alpha > 100$).

The secondary air stream, comprising about 70 per cent of the entire air flow, is supplied into the combustion chamber through several rows of holes provided in the liner. This air mixes up with the hot gas stream thus cooling it to the required temperature.

The arrangement and diameters of the holes provide for obtaining the required gas temperature before the turbine, and are governed by the law of gas temperature change depending on the height of the turbine blades.

The combustion chamber walls are cooled on the outside by the secondary air stream, which forms an insulating layer between the walls of the combustion chambers, rear housing 3 and shield 6 (See Fig.28).

The secondary stream of air entering the combustion chamber through the holes in the liner isolates the inner surface of the combustion chambers from hot gases.

Chapter III

TURBINE

The gas turbine is designed for driving the compressor rotor and the engine accessories.

As distinguished from the earlier production models, the РД-9Б engine employs a two-stage turbine providing for considerable temperature difference at comparatively low speed and small dimensions. It is capable of delivering power sufficient for actuating the high-pressure compressor (power consumed by the compressor amounts to about 17,000 h.p.) and the engine accessories.

The turbine comprises a two-disc rotor and nozzle assemblies of the first and second stages. The rotor discs accommodate blades locked in their grooves.

The rotor rides in a roller bearing and is connected to the compressor rear trunnion by means of a coupling.

The turbine rotor is driven by the gas stream flowing from the combustion chambers through the nozzle assemblies and thrown against the turbine blades. The function of the nozzle assemblies is to increase the velocity of the gas flow and to direct it against the rotor blades at an angle preventing dangerous impact. Besides, the nozzle assembly of the first stage acts as a rigid load-carrying structural member supporting the turbine rotor through the inner support and the housing of the rear bearing.

The gas flow issuing from the combustion chambers carries a great amount of potential energy. In the space limited by the vanes of the first stage nozzle assembly the gas expands (at the expense of heat content) which causes an increase in the absolute velocity of gas flow. Further drop of gas temperature and further gas expansion takes place in the ducts formed by the turbine rotor blades; this results in acceleration of gas velocity relative to the turbine blades. The similar process takes place in the second stage of the turbine.

The difference between gas heat content before and aft of the turbine accounts for the temperature drop; the higher the temperature drop, the greater the power delivered by the turbine.

Thus, in the process of gas expansion potential energy of the gas flow is converted into kinetic energy which is consumed in driving the turbine and compressor rotors (the flow section of the turbine is diagrammed in Fig.30).

The turbine of the РД-9Б engine is of the combination impulse-reaction type. This means that the circumferential force acting upon the rotor blades depends on the active force of the gas stream flowing from the nozzle assemblies, as well as on the reactive force developed by the gas flowing between the rotor blades.

The rotor blades are acted upon by the centrifugal force arising in the gas stream and directed along the radius of the passage curvature. As a result, a circumferential force is created on the rotor blades. This force, applied at some distance (radius) from the rotation axis, creates torque used for driving the compressor rotor and the engine accessories.

The blades are arranged on the turbine rotor in such a manner that the curved surfaces of two adjacent blades form a passage somewhat narrowing towards the trailing edges. Therefore, in flowing through such passages the gas stream acquires additional speed (relative velocity of the gases increases). Accelerated gas flow sets up a reactive force, which creates additional torque.

As the flow section of the turbine is exposed to high temperatures, all the turbine components are constructed from heat-resistant materials. Besides, all load-carrying components are cooled with air (See Fig.87).

Normal functioning of the turbine calls for minimum possible clearances according to the respective drawing. Clearances in excess of the specified values result in loss of power, whereas too close clearances may lead to engine failure, as rotating parts will catch on stationary parts.

Fig.31 shows turbine clearances subject to checking.

TURBINE ROTOR (Figs 32 and 33)

The turbine rotor consists of shaft 5 (See Fig.33), discs 14 and 20 of the first and second stages respectively, load-carrying ring 17, labyrinth 12, shaft bush 11, baffle 21, and fastenings.

The disc rims are provided with fir-tree grooves accommodating blades 16 and 18.

The main rotor components (except the blades) of the engine in question are connected with the aid of radial dowels and make one non-detachable unit. This feature provides for rigidity of the rotor and reduces its weight.

Hollow shaft 5 is forged from steel 40XHMA. The rear end of the shaft passes into a tulip-shaped flange, which is press fitted into the bore of the first stage disc circular projection. The shaft is connected to the disc by means of 19 radial dowels 13, which transmit torque from the discs to the shaft. The dowels are locked in the disc, which does not allow them to drop out due to centrifugal forces. The outer surface of the other shaft end has involute splines 3 which come into engagement with the inner splines of the compressor rotor rear trunnion thereby transmitting the torque to the compressor rotor. In addition to the splines, the front end of the shaft is furnished with four lugs 2 designed to take up the axial loads of the turbine rotor; two holes 1 serve to accommodate the guide of the mounting wrench, used for engagement and disengagement of the coupling (detailed description of the coupling is given below).

The turbine shaft mounts labyrinth 12 and bush 11. The labyrinth is secured by means of nine threaded dowels, while the bush is held in place by three dowels. The projecting ends of the dowels are clipped off flush with the external surfaces of the labyrinth and bush, and are punched to prevent loosening. The turbine shaft bush carries oil slinger 10 and roller bearing 9, held in position by nut 7.

The nut is retained by plate lock 6 whose lug is bent into the nut slot. The lock is inserted into one of the three recesses machined in the shaft bush, and is held from axial

displacement by a recess provided in ring 8, installed between the inner ring of the roller bearing and the nut. The ring is held from rotation by two lugs engaging the bush recesses.

Machined on the external surface of the shaft bush are circular grooves, which in combination with labyrinth 15 (See Fig.22) and the housing of rear support 4 form a labyrinth sealing of the rear support.

To reduce heat transfer from the shaft to the bearing, the mounting surface of the shaft bush has 42 longitudinal grooves, while the bush diameter accommodating the roller bearing is furnished with four circular grooves.

Ring 4 (Fig.33) is installed on the external surface of the shaft where the involute splines terminate.

The ring has two circular grooves accommodating bronze rings which combine with the internal surface of the middle support nut to form a sealing, isolating the inner cavity of the compressor rotor from the bearing housing cavity.

Discs 14 and 20 of the first and second stages respectively, as well as load-carrying ring 17 are constructed from forgings of heat-resistant steel ЭИ481. The discs of the both stages are provided with fir-tree grooves machined in their rims. The grooves serve to accommodate the rotor blades. The first stage disc carries 76 blades, the second stage disc - 64. The blades of the first stage disc (See Fig.34) are locked in their grooves by locks 15 (See Fig.33); the lugs of the locks fit into the blade recesses, while their ends are bent over the disc rim. The blades of the second stage disc are retained on the one side by shield A, made integral with load-carrying ring 17, and on the other side by bent ends of T-shaped plate locks 19. The locks are fitted into the fir-tree grooves of the disc. The collars of the locks resting against the front face of the second stage disc do not allow the locks to shift axially towards the afterburner. The ends of the locks bent over the rear faces of the blade roots prevent them from moving in the opposite direction (See Figs 33 and 35).

The rear side of the first stage disc is provided with a circular projection, whose internal surface is bored to receive the centering band of the load-carrying ring. A similar projection of larger diameter is machined on the front side of the second stage disc. The discs are held together by the load-carrying ring press-fitted into the bores of the circular projections by 20 radial dowels installed in the load-carrying ring-to-first stage disc joint, and by 32 dowels fitted in the load-carrying ring-to-second stage disc joint. These dowels shrink-fitted in place are designed to retain the mating components and to transmit torque to the turbine shaft. The dowels are held in position by the material of disc projections rolled over to prevent them from coming out due to centrifugal forces.

To protect the blade roots and the fir-tree grooves of the second stage disc from hot gases, the load-carrying ring is provided with shield A (See Fig.33), made integral with the ring. The upper projection of the shield has three circular ridges which combine with the lower rear plates of the second stage nozzle assembly vanes to form a labyrinth sealing preventing leakage of hot gases flowing through the nozzle assembly.

A labyrinth sealing aft of the first stage blades is formed by the ridges machined on the circular projection of the first stage disc and by the lower front plates of the second stage nozzle assembly vanes.

For passage of cooling air delivered by the compressor the first stage disc is provided with 8 holes, and the second stage disc - with 2 holes, the latter holes being partially covered by baffle 21 installed on the rear wall of the disc (See Chapter VII) and held in place by six dowels.

The rotor first and second stage blades are fabricated from forgings of heat-resistant alloy ЭИ617. Each blade consists of a fir-tree type root serving to secure the blade in the disc groove, and a curved tip. The root portions of the blades of both stages have similar dimensions in their cross-section. The tips of the blades of each stage are of different length, the profiles of the concave sides being formed by two conjugated arcs of different radii, passing to a straight line at the trailing edge of the blade. The profiles of the convex sides are formed by complex curves, plotted in compliance with the predetermined co-ordinates in various sections of the blade.

To obtain the required entry and exit angles of gas flow the blades are twisted lengthwise.

The desired configuration of blades is ensured by machining them with the use of profiling devices. The blade tips are ground in assembly, for which purpose the entire blade set is secured in the disc or in a special fixture.

To prevent brushing of the blades against the inner surfaces formed by the plates of the vanes of the second stage nozzle assembly during engine operation (due to reduced radial clearances), the upper thin edges of the blades are cut at an angle of $(1^{\circ}20')^{+30'}$: the blades of the first stage are cut over a length of 20 ± 2 mm, the blades of the second stage over a length of 15 ± 2 mm.

The external surfaces of blades are thoroughly machined and finished to ∇∇∇ 9.

The blades are arranged on the disc periphery in such a manner that the blades fitted into diametrically opposed grooves of the disc have almost equal weight.

In securing the root portion of the blade in the disc groove, provision has been made for tangential play which allows the blade to be self-adjusted under the influence of centrifugal forces developed during turbine operation.

The turbine rotor assembly is subjected to dynamic balancing on special balancing machines. Dynamic disbalance of the rotor should not exceed 8 gr-cm. Disbalance is eliminated by removing metal where the disc body merges with the rim to a depth of not more than 0.5 mm, on the entire circumference; balance may also be adjusted by rearranging the blades on the disc.

Turbine rotor balancing with regard to the right-hand support is carried out with the rotor mounted in its own bearing; balancing with regard to the left-hand support is done by the use of a fixture incorporating a special bearing.

COUPLING

The turbine and compressor rotors are connected by means of splines, transmitting the torque, and a coupling which locates the turbine shaft axially.

Axial forces arising during compressor rotor operation are directed forward, whereas axial forces developed on the turbine are directed rearward. Connection of the turbine and compressor rotors by means of a coupling provides for algebraic summation of these forces with resultant reduction in the axial load taken up by the centre bearing; this arrangement aids in operation of the compressor unloading system described above and ensures more favourable operating conditions for the middle support.

Connection of the turbine and compressor rotors is accomplished as follows.

Coupling 1 (Fig.36) comprises a stepped bush, fabricated from steel 18XHBA. The front part of the coupling has a toothed sector used for turning the coupling with the help of a special wrench, and two slots for locking the coupling in the mounting and operating positions. Machined on the rear part of the coupling are four lugs directed towards the coupling axis and designed to be attached to the turbine rotor shaft. The inner diameter of the coupling serves for centering the turbine shaft shank.

The coupling is installed in the rear trunnion during assembly of the compressor rotor.

Four dowels 5 locate the coupling axially and limit its rotation around the axis. The coupling is retained during assembly and operation by plate spring 2 engaging the respective recess in the coupling sector.

The rear trunnion of the compressor rotor has internal helical splines, one of which is cut off (See Fig.36, CC section); the forward end of the turbine rotor shaft mounts strip 6, which, in conjunction with the cut-off spline, provides for the required position of the rotors relative to each other during their connection. The shank of the turbine rotor shaft fits into coupling 1, the coupling projections entering the shank grooves. When the coupling is turned through 45°, its projections engage those of the shaft thereby keeping the turbine shaft from axial displacement relative to the rear trunnion of the compressor rotor.

Prior to installing the turbine rotor the coupling is fitted into the rear trunnion in a position allowing plate spring 2 to enter the recess of the mounting stop. After the turbine rotor is installed the coupling is turned, with the aid of mounting wrench 4, to a position corresponding to the operating stop; this causes the plate spring to be released.

After the coupling is turned and the wrench is removed, the plate spring secures the coupling in the operating position.

FIRST STAGE NOZZLE ASSEMBLY

The first stage nozzle assembly (Figs 37 and 38) consists of outer ring 4 (See Fig.38), inner support 1, 36 vanes 2, 36 outer shoes 7, 36 inner shoes 9, 18 coupling bolts 3 with distance tubes 8, shield 12, and the shoe fastenings.

The passages in the nozzle assembly are formed by the side surfaces of the vanes and the external surfaces of the outer and inner shoes. The total clear opening area amounts to 557 – 562 sq.cm.

Outer ring 4 of the nozzle assembly is manufactured from steel 1X18H9T and comprises a thin-walled rim with two flanges. To make the rim lighter, some furrows are machined on the outer surface of the flanges. The front face of the outer ring has a centering band, and the rear face – a groove. Drilled on the external surface of the ring are 72 holes for bolts securing the outer shoes, and 18 holes for the coupling bolts; besides, the front face of the ring has 180 oblique drillings for passage of cooling air. There are 60 groups of such drillings, each group consisting of three drillings.

The inner support is fabricated from steel 1X18H9T. It is a tapered circular wall, whose larger diameter is developed into a cylindrical rim, while the inner diameter forms a flange provided with 16 holes; of these holes 10 serve for securing the inner support to the bearing housing, and 6 for passage of pipes by-passing air from the rear support labyrinth sealing to the relief cavity. The front portion of the rim is provided with a circular groove accommodating the centering projection of the combustion chamber ring; the rear portion where the wall merges with the rim carries 12 lugs, serving to fasten the shield on its larger diameter. The cylindrical surface of the inner support rim has two rows of through holes for the bolts securing the inner shoes, as well as a number of threaded holes for the coupling bolts. The tapered wall of the inner support is provided with eight holes serving for supply of cooling air into the cavity formed by the walls of the inner support and shield 12.

The hollow vanes of the nozzle assembly (Fig.39) are precision-cast from heat-resistant alloy AH300. Each vane is uniformly profiled on its entire height; the required contour is formed on the convex side by a complex curve plotted according to pre-set co-ordinates, and on the concave side by an arc. To provide for the required clear opening area when mounting the nozzle assembly, the vanes are divided into two groups. The groups differ by the length and radius of the vane trailing edge. The upper and lower end faces of the vanes are milled to provide inlet and outlet for the air cooling the inner cavities of the vanes. The outer and the inner shoes are precision-cast from heat-resistant alloy ЭИ437 with subsequent machining. The side surfaces of the shoes are made to suit the contours of the concave and convex sides of the nozzle assembly vanes. To minimize contact with the mating parts (outer ring and inner support) and to form cavities for free passage of the cooling air, the contact surfaces are given a special shape. Each of the shoes has two threaded holes serving to fasten the shoes to the internal surface of the outer ring or to the rim of the inner support. The shoes are secured to the above parts with bolts which are locked with plate locks. The side walls of the installed and fastened shoes form nests serving to secure the nozzle assembly vanes. The vanes are fitted into the shoe nests with a clearance provided all around the nest contours; besides, the vanes are capable of free radial movement within 1.15 to 1.7 mm, to allow for thermal elongation during engine operation.

Shield 12 (See Fig.38) is a welded structure, consisting of a wall fabricated of sheet steel 1X18H9T, and two machined flanges, point-welded to the wall. The large flange of the shield has 12 lugs serving to connect the shield to the lugs provided on the inner support. The small flange is designed to couple the shield to the inner support flange.

The shield wall has two rows of flanged holes for passage of air cooling the turbine rotor components.

Outer ring 4 is connected with inner support 1 by means of 18 coupling bolts and distance pipes passing through the inner cavities of guide vanes.

The front flange of outer ring 4 serves to couple the first stage nozzle assembly to the flange of the combustion chamber housing, the joint being secured with 60 bolts, of which 18 are fitted bolts. The rear flange of the outer ring is used

for connection to the second stage nozzle assembly. Inner support 1 of the nozzle assembly is fastened to the flanges of the bearing and rear support housings by 10 bolts, the nozzle assembly shield being secured at the same joint.

SECOND STAGE NOZZLE ASSEMBLY
(Figs 40 and 41)

The second stage nozzle assembly comprises a set of 42 profiled vanes 4 (See Fig.41) bolted circumferentially inside shroud 1.

Second stage nozzle assembly shroud 1 is fabricated from a forging of heat-resistant steel IX18H9T, and comprises a thin-walled rim with two flanges. The internal surface of the shroud is slightly tapered, with the diameter somewhat increasing towards the rear flange. The front part of the shroud is fitted with a band serving to centre the second stage nozzle assembly relative to the first stage nozzle assembly. The external surface of the rim carries two thickened bands with holes for the vane securing bolts. Drilled in the lower section of the rear band are holes of a smaller diameter, serving to connect the vent system pipes; the upper part of the rear flange is milled to receive the centering bolt of the releasable ring.

The solid vanes of the second stage nozzle assembly (Fig.42) are precision-cast from heat-resistant alloy AH300. Each profiled vane is provided with upper and lower plates at its ends. The contours of the convex and concave sides of the vanes are formed by the curves plotted in compliance with the pre-set co-ordinates. The thickness and chord of the profiles are not uniform over the vane length. The upper plate of the vane is rectangular in shape. Its contact surface is corrugated to reduce heat transfer from the vanes to the nozzle assembly shroud. The front and rear end faces of the upper plate are milled to allow passage of cooling air in both directions. The bosses of the upper plates are provided with two threaded holes each. The holes accommodate bolts 2 (See Fig.41) holding the vanes to the shroud. The bolts are retained by plate locks (washers) 3.

Vanes 4, secured to shroud 1, are subjected to treatment on the diameters formed by the upper and lower plates. The upper plates of the vanes serve as belts for the first and second stage blades of the turbine rotor, while the lower plates form the surfaces of the labyrinth sealings.

The front flange of nozzle assembly shroud 1 is secured by means of 48 coupling and 6 fitted bolts to the rear flange of the first stage nozzle assembly outer ring. The rear flange of the second stage nozzle assembly is coupled to the afterburner diffuser with the use of a releasable ring.

As the second stage nozzle assembly shroud has no joint in the axial plane, turbine assembly is carried out as follows: the first stage nozzle assembly is secured to the flange of the combustion chamber housing; then the turbine rotor is installed in position(with the blades of the second stage disc removed), following which the second stage nozzle assembly is mounted and the blades of the second stage disc are fitted in their proper places on the disc.

Chapter IV

AFTERBURNER

The afterburner (Fig.43) with its fuel nozzles is arranged aft of the turbine. Fuel burnt in the afterburner causes a rise in the temperature of gases before the jet nozzle, which results in acceleration of gas flow and, consequently,in augmentation of engine thrust.

Fuel burnt in the afterburner increases the thrust of РД-9Б engine approximately 25 per cent.

The afterburner consists of three main units: a diffuser, a middle pipe and an adjustable jet nozzle.

DIFFUSER

The diffuser (Figs 44, 45, and 46) comprises a widening duct, serving to decelerate gas flow to a value, ensuring stable burning of fuel in the afterburner.

The diffuser (See Fig.46) consists of outer wall 6, inner wall 7, five fairings 4, front fuel manifold 14, rear fuel manifold 13, flange 15, flame arrester 8, spark plug 3, and hood 5.

Outer wall 6 of the diffuser is made of 0.8-mm thick sheet steel ЭИ602 . The end faces of the outer wall carry flanges, fabricated from steel IX18H9T and secured by means of continuous welding. The flanges have cutouts serving to secure the releasable rings.

The diffuser outer wall mounts nine pipe unions for thermocouples, two pipe unions for intake of total gas pressure, five blind bushes for securing the fairings, and two flanges for fastening the fuel manifold pipes and the spark plug.

A lug for installation of a locking device is spot-welded to the outer wall surface near every pipe union.

To render the structure more rigid, 1.2-mm thick strips 21 are welded into the outer wall, under the pipe unions, bushes, and flanges.

The entire outer wall of the diffuser is made more rigid by two bands, manufactured from sheet steel IX18H9T and fastened by means of arc welding.

The bands are provided with flanged holes to ensure ventilation of the space between the hood and the outer wall.

As a rule, gas temperature is measured by employing only four pipe unions, the remaining pipe unions being plugged.

Diffuser inner wall 7 is made in the form of a truncated cone, manufactured of 1-mm thick sheet steel IX18H9T.

The front end face of the inner wall mounts flange 16 made of steel 1X18H9T and secured by continuous welding. The flange has 20 threaded holes used for bolting down diffuser flange 15 fabricated from steel 1X18H9T. The nozzles of the front fuel manifold enter the cutouts provided in the diffuser flange. Welded to the rear end face of the inner wall is end plate 10 made of 1-mm thick sheet steel ЭИ435.

The end plate has a hole surrounded by six welded bosses with threaded holes for attachment of rear fuel manifold flange 12. Bush 11, mounted in the centre of the end plate serves to accommodate afterburner spark plug 3. The rear face of the end plate carries six welded bosses with threaded holes designed to secure flame arrester 8 and rear fuel manifold 13.

The inner wall has two oval ports, with the edges flanged for rigidity. The pipes of the fuel manifolds pass through port A, port Б accommodating afterburner spark plug СИ-02.

Twenty holes arranged in two rows on the diffuser inner wall serve to secure the latter to the five fairings. Afterburner spark plug 3 is fastened to the outer wall flange by two hemispherical covers 18; fitted between the covers is adjusting shim 17.

The pipes of the fuel manifolds are fastened to the outer wall flange by two hemispherical covers 19 enclosing hemispheres 20. To reduce heat transfer to the fuel manifold pipes, the hemispheres are provided with circular grooves.

Spherical joints between the spark plugs, fuel manifold pipes and the outer wall eliminate stresses arising during installation as well as due to thermal expansion.

Flame arrester 8 secured to the diffuser inner wall serves to obtain a stable flame torch. Flame arrester 8 is a welded structure, manufactured from 1.2-mm thick sheet steel ЭИ602. It consists of a ring, a cone, five ribs and a flange. The ribs are secured to the ring and the cone by means of argon-arc welding. The flange has six holes for fastening the flame arrester to the diffuser inner wall. Clamps 9 serving to secure the rear fuel manifold are fitted through the cutouts in the flange during installation. To prevent wear of the rear manifold fuel nozzles, the flame arrester cutouts are fused with alloy ЭИ435.

To straighten the flow of gases issuing from the turbine, the diffuser is provided with five hollow fairings 4. The profile of each fairing is uniform through its entire height.

The fairing wall is manufactured from 1-mm thick sheet steel ЭИ435. The upper part of the fairing wall is fitted with a cover secured by continuous welding, while the lower part carries a strip. The cover and the strip are provided with ports. The fuel manifold pipes and the afterburner spark plug pass through the ports of different fairings.

The fairing is retained in the outer wall by pin 2 welded to the fairing cover. A clearance of not less than 1 mm is provided between the fairing cover and the diffuser outer wall, to make for thermal expansion of the fairing.

Butt-welded to the lower part of the wall and the strip of the fairing are two supports manufactured from steel IX18H9T. Each support has two threaded holes for screws securing the fairing to the diffuser inner wall. Such connection of five fairings to the outer and inner walls of the diffuser permits the inner wall to expand freely relative to the outer wall during engine operation. To provide for thermal insulation, the outer wall of the diffuser is covered by hood 5. Hood 5, fabricated from 0.5-mm thick sheet steel IX18H9T is comprised of upper and lower halves. It is rendered more rigid by longitudinal and lateral corrugations provided on both the halves. The hood ends are reinforced with rolled-in wire. The hood is provided with flanged ports accommodating the bushes, pipe unions, afterburner spark plug and the fuel manifold pipes. Three bosses riveted to the hood serve to secure the vent pipe clamps. The hood halves are coupled by two clamps 1.

Gases containing oxygen not used up in the combustion chambers are delivered from the turbine into the widening duct of the diffuser. In passing through the duct the gas flow is straightened by the fairings, while its velocity decreases. When flowing past the truncated cone formed by inner wall 7 and end plate 10, as well as past circular flame arrester 8 the gases are violently swirled and are well mixed with fuel injected against the gas flow by 15 fuel nozzles arranged in the two fuel manifolds, accommodated in the diffuser.

Ignition of the gas-fuel mixture is accomplished by setting fire to the mixture in the region adjacent to the centre of end plate 10, where spark plug СП-02 is arranged, and where fuel is injected by two nozzles of the rear fuel manifold.

Apart from favouring adequate gas-fuel mixture formation, zones of violent gas swirling provide for reduction of gas flow velocity thereby ensuring stable and effective combustion of fuel.

The primary flame produced behind the flame arrester propagates throughout the entire diffuser, in which the gas stream is intensively mixed with fuel; the fuel is injected through 15 fuel nozzles of the two fuel manifolds arranged in the diffuser.

MIDDLE PIPE

The middle pipe, located between the diffuser and the adjustable jet nozzle, serves to direct the gases to the adjustable jet nozzle. The middle pipe is 1680 mm long, its overall diameter is 640 mm.

The middle pipe (Fig.47) consists of a shell and a shroud. Shell 6 is a cylindrical structure manufactured from 1-mm thick sheet steel ЭИ602.

The end faces of the middle pipe carry two flanges fabricated from steel IX18H9T and secured by means of continuous welding. The front flange serves to connect the middle pipe to the afterburner diffuser with the use of quick-change ring 1.

Rear flange 8 of the middle pipe shell has 60 holes uniformly spaced around the circumference and serving for connection with the adjustable nozzle middle pipe. The edges of the rear flange are provided with milled recesses.

To render the middle pipe shell more rigid, nine bands 4 made of sheet steel ЭИ435 are secured to it by continuous welding. Four of the bands have flanged holes for ventilation of the space between the shell and the shroud of the middle pipe.

Each of the remaining five bands has two drilled holes, designed for equalizing pressure of the air trapped within the band, with the atmospheric pressure.

For thermal insulation, middle pipe shell 6 is housed inside shroud 7 fabricated from 0.3 mm thick sheet steel IX18H9T.

Shroud 7 consists of three parts - front, middle and rear, each made up of an upper and a lower halves. The upper and lower halves are coupled together by four clamps 12. Besides, to provide additional means of fastening the shroud components, four lugs 9 are fitted, serving to fasten the shroud components with the aid of wire.

The upper halves of the shroud carry six bosses 5 provided with threaded holes for fastening the clamps of the vent pipe that runs along the middle pipe of the afterburner.

Circular corrugations provided on all components of the shroud tend to increase its rigidity. Besides, wire is rolled in both ends of the front component of the shroud and in one end of the middle and rear components.

Cooling of the middle pipe shell is effected through flanged holes provided in the shroud.

Attachment of the middle pipe complete with the adjustable jet nozzle to the diffuser is accomplished by the use of quick-change ring 1. The external surface of front flange 2 is given a spherical shape of a large diameter, which allows displacement of the middle pipe axis relative to the engine axis after installation of the quick-change ring. Quick-change ring 1 of steel IX18H9T consists of two halves held together by two bolts. The two flanges of the lower half mount fuel trap 11 made of sheet steel IX18H9T. In its lower part the fuel trap has welded pipe union 10 serving to discharge fuel dripping through the hole in the lower part of the quick-change ring during unsuccessful starting or when removing corrosion-preventive compound from the engine.

Rigidity of the fuel trap is increased by wire rolled in its edges.

ADJUSTABLE JET NOZZLE

The adjustable jet nozzle (Figs 48 and 49) aids in operating the engine at normal, maximum and augmented ratings.

The adjustable jet nozzle consists of a rear pipe shell, eight shutters, a taper ring, four actuating cylinders, pipes of the hydraulic system controlling the shutters operation, an actuating cylinder shroud, and an ejecter.

Rear pipe shell 2 (See Fig.49) is a welded structure consisting of three sections - front, middle and rear; each of the sections is fabricated from sheet steel ЭИ602.

Welded to the front cylindrical section of the rear pipe shell is flange 1 manufactured from steel IX18H9T and serving to secure the adjustable jet nozzle to the afterburner middle pipe. The flange has 60 holes uniformly spaced around the circumference; 52 of these holes are threaded and the remaining eight holes receive fitted bolts centering the adjustable jet nozzle when coupling it to the afterburner middle pipe. The flange edges are milled between the holes.

To render the front section of the rear pipe shell more rigid, three bands of sheet steel ЭИ435 are welded to its surface.

Two extreme bands 5 are provided with flanged holes for ventilation of the space between the rear pipe shell and the shroud. Middle band 3 has two holes for venting the space between the band and the shell. Welded to the lower part of the rear pipe front section is strap 22 mounting a flange with a pipe serving to drain fuel in case of unsuccessful starting or when removing corrosion-preventive compound from the engine.

The middle section of the rear pipe comprises a truncated cone secured to the front and rear sections by means of continuous welding. The external surface of the middle section carries four brackets 6 made of steel IX18H9T and designed for mounting the actuating cylinders. The brackets are secured by point welding.

Welded to the rear cylindrical section of the rear pipe is shutter flange 9, made of steel IX18H9T. The flange mounts eight pairs of lugs to which eight shutters 18 are hinged.

For fastening the actuating cylinder casing relative to the rear pipe shell, the shutter flange is fitted with four bosses having holes to receive centering bolts 19, screwed into actuating cylinder casing 21.

The shutter flange mounts the guides of the actuating cylinder retainers.

Fastening of the afterburner on the aircraft is accomplished by the use of two hangers bolted to the shutter flange.

The adjustable jet nozzle shutter (Fig.50) is of a box shape which makes for increased rigidity of the shutter and facilitates its cooling. The edges of the adjacent shutters overlap one another and make a tapered outlet section with the exit area approaching a circle at any position of the shutters.

The adjustable nozzle shutter consists of outer wall 1, inner wall 2, rib 3, recess wall 5, angle 4, left-hand hinge 7, and right-hand hinge 6. The surface of shutter outer wall 1 is given a spherical shape and is chrome-plated to reduce wear.

Outer wall 1 and rib 3 are provided with flanged holes for passage of shutter cooling air. The shutter components are fastened together by means of point welding.

Shutter position determining the diameter of the jet nozzle exit area depends on the position of the taper ring against which the shutters are pressed by the flow of gases.

Taper ring 11 (See Fig.49) is manufactured from steel IX18H9T and is hinged with the help of four bolts to the rods of the actuating cylinders, for which purpose four pairs of lugs are provided on the taper ring.

To reduce friction between the shutters and the taper ring, the latter is fitted with copper strips coated with a layer of graphite.

The front section of the rear pipe shell is covered with shroud 4 made of 0.3-mm thick sheet steel IX18H9T.

Shroud 4 consists of two halves held together by two clamps 23; each of the shroud halves is welded up of three sections. To ensure additional rigidity, circular corrugations are provided on the shroud; besides, wire is rolled in at the ends of the shroud halves. A port is provided at the bottom of the lower half, serving to mount the vent pipe. Cooling air is passed through flanged holes provided in the shroud.

The rear section of the rear pipe shell is protected by actuating cylinder casing 21, fabricated from sheet steel IX18H9T.

Actuating cylinder casing 21 is a welded structure consisting of upper and lower halves, held together by five bolts at each of the casing sides. The actuating cylinder casing has stamped recesses serving to accommodate the actuating cylinders, hydraulic system pipes, and the bolts locating the casing relative to the rear pipe shell.

For securing the ejector, the shields of the actuating cylinders, and the vent pipe, the actuating cylinder casing has bosses with threaded holes, fastened by means of point-welding. Riveted to the upper half of the casing is a bracket mounting three adapters and a boss with a threaded hole receiving the vent pipe clamp.

The actuating cylinder casing has 32 holes, 30 mm in diameter, with the edges flanged for rigidity. These holes serve for passage of cooling air, sucked by ejector 15, into the space between the casing and the rear pipe shell. The air drawn by the ejector cools the rear pipe shell and the shutters.

The ejector (Fig.51) is a welded structure made up of three sections. Each of the ejector sections is manufactured from sheet steel IX18H9T.

The front section has 10 holes serving to secure the ejector to the actuating cylinder casing. Fastened to the ejector are four shields 10 (See Fig.49) of the actuating cylinder rods.

Welded to the lower part of the ejector are pipe union 17 designed for draining condensate, and two lugs 20 serving to fasten the afterburner pan when mounting the engine on the aircraft.

The middle section of the ejector has flanged ports for passage of air cooling the shutters and the actuating cylinder piston rods.

The required rigidity of the ejector is ensured by a circular corrugation and band 14 provided on the middle and rear sections respectively.

Clamp 12 secured to the ejector by two bolts serves for fastening vent pipe 13.

Secured to the brackets of the jet nozzle rear pipe are four shutter actuating cylinders 8.

Each actuating cylinder (Fig.52) consists of cylinder 8, two pistons 7 and 9, sleeve 1, packing bush 6, adjusting bush 15, thrust nut 5 with bush 13, shank 12, union nut 14, and adjusting nut 11. Cylinder 8 is fabricated from steel 12X2H4A.

The internal surface of the cylinder is case hardened to minimize wear. The rear piston rod guide has four circular grooves accommodating rubber cups 10 serving to seal the rod of rear piston 9. The cylinder surface mounts six pipe unions designed for supply and return of hydraulic fluid. The rear portion of the cylinder is threaded to receive a split nut used for adjustment of the jet nozzle diameter at the maximum rating, and a projection serving to hold the actuating cylinder against turning or misalignment.

Front piston 7 and rear piston 9 of the actuating cylinder are made of steel 38XMЮA. The circular grooves of the pistons accommodate rubber packing cups. The piston rods are hollow; the diameter of the front piston rod is equal to 12 mm; the diameter of the rear piston rod is 17 mm.

The rod of the front piston mounts thrust washer 3, while the rod of the rear piston is fitted with shank 12 which is hinged to the taper ring of the adjustable jet nozzle shutters.

The hole provided in the shank accommodates a spherical bush. The rod of the rear piston has two flats near the threads, used for application of a wrench, when adjusting the jet nozzle diameter at the augmented rating.

Packing bush 6 is fabricated from steel 40XHMA. The external and internal surfaces of packing bush 6 have circular grooves receiving rubber packing cups. The packing bush is provided with eight diametrically arranged holes, two of which accommodate retainers 16.

Screwed into the packing bush is thrust nut 5 with bush 13. The thrust nut has two 2-mm holes for passage of hydraulic fluid. There are two recesses at the end of the nut, accommodating the projections of adjusting bush 15. Adjusting bush 15, manufactured from steel 18XHBA, is used for adjustment of the jet nozzle diameter at the nominal rating. The adjusting bush has two grooves receiving rubber packing cups. Machined at the front end of the adjusting bush are longitudinal recesses, one of which accommodates retaining screw 2, turned into the hole of sleeve 1. Sleeve 1 of steel IX18H9T has a collar and two ports on the side surface. Union nut 14 rests against the collar thereby pressing the sleeve to the cylinder. The adjusting bush is accessible through the port. Fitted between the end faces of the packing bush and the sleeve collar is rubber packing gasket 4. Inserted into the sleeve hole is a spherical bush, serving to hinge the actuating cylinder to the bracket provided on the shell of the jet nozzle rear pipe. All the four actuating cylinders are connected by means of pipes serving for delivery and return of hydraulic fluid. The actuating cylinders operate synchronously.

Connection of the actuating cylinders by the hydraulic system pipes is diagrammed in Fig.53.

To avoid a sudden rise of gas pressure aft of the turbine with resultant engine surge, closing of the shutters when passing from the augmented to the nominal rating is accomplished slowly. The shutters are opened quickly, when passing from the maximum to the augmented rating. For this purpose the hydraulic system is equipped with return valve 3.

The return valve (Fig.54) consists of body 3, a throttling unit, valve 4 with seat, valve spring 2, and plug 9. The recess of body 3 accommodates seat 10, which is press-fitted with a negative allowance of 0.01-0.05 mm; pressed to the seat by spring 2 is valve 4 hinged to seat 11 with the help of a dowel.

Seat 11 is provided with a drilled passage for hydraulic fluid; the passage communicates with two diametrically opposed holes.

One end of spring 2 works against seat 11, the other - against thrust ring 1, which is retained in the return valve body by locking ring 12.

The return valve throttling unit consists of case 5 and a set of washers 6 (with eccentrically arranged holes) between which distance washers 7 with central holes are installed.

Hydraulic fluid flows through two holes in the throttling unit case.

The throttling unit screwed into the return valve body bore is retained by plug 9, which is pressed to the return valve body by union nut 8.

Filter 9 and jet 10 (See Fig.55) are installed at the junction between the return valve and the actuating cylinder. Jet 10 is so selected as to ensure opening of the shutters within 1.2 to 2.5 sec., when passing from the maximum to augmented rating (See Table 1).

Table 1

Selection of Jets

Group	Diameter, mm
А	1.25
Б	1.00
В	0.8
Г	0.6
Д	0.7
Е	0.5

When changing from the augmented rating to the maximum rating, hydraulic fluid is fed to the actuating cylinders through throttling units 11. In order that shutter closing should be accomplished within 5 to 7 sec., when changing from the augmented to maximum rating, proper throttling units should be selected (See Table 2).

Table 2

Selection of Throttling Units

Throttling unit No.	Capacity, cu.cm /min.
2	700
3	1000
4	1200
5	1600
6	1400

Time period within which the shutters shift from the normal rating to the maximum rating position (2.5 to 5 sec.) is ensured by selection of proper jets 13 installed into the middle pipe unions of the actuating cylinders (See Table 3).

Table 3

Selection of Jets

Group	Diameter, mm
Б	2.0
В	1.75
Г	1.5
Д	1.25
Е	1.0
Ж	0.8
И	0.6
Л	0.7
М	0.5

To achieve a more effective cooling the actuating cylinders are covered by shields 7 (See Fig.49). The shields are made of aluminium alloy АМцАМ. Rivited to each of the shields are four steel angles with holes, serving to fasten the shield to the actuating cylinder housing.

To facilitate engine starting and to improve engine operating conditions at low speed, the adjustable jet nozzle shutters remain in the maximum open position (in the augmented rating position) up to the speed of 4500 - 6500 r.p.m.; in this case hydraulic fluid pressure is trapped in cavity A (See Fig.55), while pistons 2 and 4 are shifted to the extreme right-hand positions.

With the engine control lever moved forward, at an engine speed of 4500 to 6500 r.p.m., control panel ПУ-3 switches over the supply of the ГА-2I unit solenoids, thereby shifting the slide valves of the ГА-2I units and reversing hydraulic fluid flow to the pipe unions of the actuating cylinders.

Hydraulic fluid from pipe union II of ГА-2I unit No.2 is delivered through throttling unit 11 into cavity Б, under rear piston 4 of the actuating cylinder.

Simultaneously, hydraulic fluid from interpiston cavity B of the actuating cylinder is returned through hollow front piston 2 into pipe union I of ГА-2I unit No.2.

Hydraulic fluid pressure causes the front piston to shift until nut 1 on the piston shank comes up against bush 14 of thrust nut 15, whereas shifting of the rear piston is limited by front piston 2.

Adjustable jet nozzle taper ring 7 fastened to rear piston shanks 6 moves axially causing shutters 8 to close until the jet nozzle exit diameter corresponds to the normal rating.

Further shifting of the engine control lever (to the maximum rating position) causes control panel ПУ-3 to switch over the electric circuit of ГА-2I unit No.1; as a result, the slide valve of ГА-2I unit No.1 will be shifted to a position, at which hydraulic fluid from cavity A of the actuating cylinder will be directed to the return line.

Rear piston 4 with shank 6 moves further until it comes up against adjusting nut 5, thereby changing the position of the taper ring. As a result, shutters 8 close to a position corresponding to the maximum rating.

With the engine control lever shifted to the"Afterburner" (ФОРСАЖ) position, control panel ПУ-3 will switch over the electric circuit of the ГА-2I units, which will change the positions of the slide valves correspondingly.

Cavity Б located under rear piston 4 will be connected to the return line via pipe union II of ГА-2I unit No.2, whereas pipe union 1 of the same unit will deliver hydraulic fluid into interpiston cavity B; the resultant hydraulic pressure will force rear piston 4 to the extreme rear position, thereby shifting taper ring 7 and releasing shutters 8. The shutters will be opened by the outgoing gases, thus ensuring an exit diameter corresponding to the augmented rating.

If shifting of the engine control lever to the "Afterburner" (ФОРСАЖ) position does not cause hydraulic pressure to be supplied to the hydraulic system controlling adjustable jet nozzle shutters, no fuel will be delivered by the НР-11А pump to the afterburner fuel nozzles. This type of interlocking is accomplished by the use of hydraulic switch УГ 34/I.

When the engine control lever is moved towards the low throttle position, the adjustable jet nozzle shutters will change their position in the reverse sequence.

The afterburner is secured to the second stage nozzle assembly shell with the aid of a quick-change ring (See Fig.4). The quick-change ring consists of two halves, held together by four bolts. Each half is manufactured from steel IX18H9T. The lower half of the quick-change ring mounts the fuel sump made of sheet steel IX18H9T. The sump accumulates the fuel drained through the holes in the lower half of the quick-change ring during unsuccessful starting or when removing corrosion-preventive compound from the engine. This fuel is discharged to the atmosphere via the pipe connected to the pipe union provided on the fuel sump.

The quick-change ring is held against rotation by a retainer engaging the cutouts provided on the flanges of the diffuser and the second stage nozzle assembly shell.

CHARACTERISTIC FEATURES OF AFTERBURNER WITH PRECOMBUSTION IGNITION

РД-9Б engines of the fifth series are provided with precombustion (carburettor) ignition of the afterburner, which ensures reliable change-over to the augmented rating at altitudes of up to 15,000 m.

The diffuser of an afterburner with precombustion type ignition (Fig.56) incorporates the following additional parts and assemblies: flame igniter 5, spark plug 4, distance piece 6, fuel-air mixture delivery pipe 2, adapter 3, and busbar 1. Flame igniter (Fig.57) is welded of sheet alloy ЭИ602; it consists of outer cone 2, inner cone 1, cup 3, nozzle 4, cone 6, and end plate 5.

The flame igniter is secured along with distance piece 6 by bolts 9 (See Fig.56) to the inner wall of the diffuser, its axis registering with that of the afterburner. Flame arrester 8 is fastened to distance piece 6 by bolts 7. The flame igniter pipe union mounts fuel-air mixture delivery pipe 2, while the flame igniter flange carries spark plug СД-I08A secured by two bolts.

Voltage to the flame igniter spark plug is supplied by booster coil КПМ-IA via adapter П-11 secured to the outer wall of the diffuser and arranged inside the diffuser fairing, and further through busbar 1. Afterburner ignition is

accomplished by means of a torch, formed in the flame igniter as a result of burning of the fuel-air mixture delivered into the flame igniter from the carburettor.

Carburettor 3 (Fig.58) is a tee-piece arranged at the joint between the middle and rear compressor housings; air is delivered to the carburettor from the 9th stage of the compressor.

Fuel supplied from the main fuel manifold via magnetic valve 1 and metered by throttling unit 2 is injected into the air stream by nozzle 4. The resultant fuel-air mixture is fed by the carburettor into the flame igniter, where it is ignited by spark plug СД-I08A ; the flame torch thus formed is ejected through the central hole into the zone of afterburner rear manifold fuel nozzles. The carburettor uses fuel from the pipe connected with the main fuel manifold, for which purpose the pipe carries a pipe union. Further, fuel is fed to magnetic valve 1 (See Fig.58) through the tank, which is secured to the compressor air blow-off band control mechanism (Fig.59). The magnetic valve is similar in construction to the magnetic valve employed in the engine starting fuel system.

The precombustion type of ignition called for an alteration of engine electric circuit: control panel ПУ-3 has been fitted with an additional wire, connected to pins 1 and 2 of the respective plug connector. The wire is connected in such a way that when control panel cam Ф operates, current is fed both to spark plug СД-I08A and to the solenoid of the magnetic valve. Consequently, fuel-air mixture is delivered into the flame igniter simultaneously with supply of voltage to the spark plug.

To prevent the engine from spinning at high altitudes the НР-10А fuel pump is fitted with a minimum pressure valve. As the minimum output of the pump is controlled by the minimum pressure valve, the stop limiting minimum angle of inclination of the wobble plate has been eliminated. Besides, to improve engine acceleration ability, the engine speed at which the НР-10А pump starts to regulate automatically fuel feed has been changed from 8200±100 r.p.m. to 9000±200 r.p.m., while the speed at which the hydraulic decelerator limit switch operates has been changed from 10,400±200 r.p.m. to 10,900±100 r.p.m.

Control panels ПУ-3 and the НР-10А pumps with the above modifications, installed on the РД-9Б engines of the fifth series are marked ПУ-3Б and НР-10А, series " Л", respectively.

Chapter V

ACCESSORY DRIVES

ENGINE MECHANICAL DIAGRAM

(Fig.60)

The engine and aircraft accessory drives comprise the following individual units: 1) the nose portion of the inlet housing; 2) the accessory drive gear box; 3) the two-speed drive with the starter-generator.

Arrangement of all the driven accessories, direction of rotation and the respective gear ratios are given in Table 4.

Table 4

Nos	Name of unit	Designation	Gear ratio	Direction of rotation	Place of installation
1	2	3	4	5	6
1	Starter-generator	ГСР-СТ-6000А	1.25; 2.778	Left-hand	Accessory drive gear box
2	Regulating pump	НР-10А	3.125	Right-hand	Accessory drive gear box
3	Regulating pump	НР-11А	3.125	Right-hand	Accessory drive gear box
4	Oil unit	–	4	Left-hand	Accessory drive gear box
5	Hydraulic pump	Unit 623 or unit 435ВМ	4.5	Right-hand	Accessory drive gear box

1	2	3	4	5	6
6	Tachometer generator	ДТ-3	4	Left-hand	Oil unit
7	Booster pump	ЦН-9	1.25	Left-hand	Accessory drive gear box
8	Centrifugal valve	-	1.765	Left-hand	Accessory drive gear box
9	Centrifugal breather	-	0.76	Right-hand	Compressor inlet housing nose portion
10	Scavenge oil pump	-	2.55	Right-hand	Compressor inlet housing nose portion

Notes: 1. Direction of rotation is given when looking from the drive end.

2. The gear ratio expresses the relation of engine speed to unit speed.

$$i = \frac{n_{engine}}{n_{unit}}.$$

When the engine is being started, torque from the starter is transmitted through the friction clutch to the spur gear (Z=22) which is in constant mesh with the ratchet gear (Z=41) of the centrifugal dog clutch. Rotary motion from the ratchet gear is transmitted through three dogs to the clutch body made integral with a gear (Z=22). The gear imparts motion to a driven gear (Z=41), which has inner involute splines receiving the central shaft of the accessory drive gear box, the other end of the central shaft fitting into a bevel gear (Z=20). Besides the internal splines receiving the shaft, the bevel gear (Z=20) has two more bands of splines, inside and outside. The internal splines receive the driving gear (Z=15) of the hydraulic pump drive. The gear (Z=54) has two ball supports arranged in a special adapter, and splines serving for connection to the hydraulic pump shank. The external splines of the gear (Z=20) are designed to mount the central gear (Z=16) which imparts rotary motion to the left-hand and right-hand gear trains of the accessory gear box.

Left-hand gear train. The central cylindrical gear (Z=16) through an intermediate gear (Z=27) rotates the gear (Z=40) of the HP-11A fuel pump drive. The gear (Z=40) is mounted on the splines of the driving gear (Z=25) of the oil unit drive. The gear (Z=25) actuates the gear (Z=32) of the oil unit, and the tachometer generator drive. The tachometer generator is installed on the flange, provided on the oil unit housing, and is rotated by the shaft fitting into the square hole provided in the driving shaft of the oil pump.

Right-hand gear train. Rotary motion is transmitted from the central gear (Z=16) through an intermediate gear (Z=27) to the gear (Z=40) of the HP-10A fuel pump drive (the fuel pump shank fits into the internal splines of the gear). The gear (Z=40) of the HP-10A fuel pump drive through an intermediate gear (Z=22) rotates the gear (Z=16) of the ЦН-9 booster pump, which is mounted on two ball supports. On one side the gear of the booster pump drive is splined internally to receive the booster pump shank, while on the other side it is provided with a tooth rim (Z=17) which drives the centrifugal valve.

Compressor and turbine drive. The bevel gear (Z=20) imparts rotary motion to the driven bevel gear (Z=20) having internal involute splines designed to receive the vertical shaft of the compressor inlet housing nose portion drive. The other end of the vertical shaft fits into the internal splines of the gear (Z=20) which is enclosed in the compressor inlet housing nose portion. The gear (Z=20) transmits rotation to another gear (Z=16) which is located by a dowel on the driving shaft of the compressor inlet housing nose portion. The nose portion shaft is made integral with the bevel gear (Z=18), which drives the three-stage oil scavenge pump through another bevel gear (Z=46).

The involute splines of the drive shaft shank mount the drive gear (Z=50) of the centrifugal breather drive and the coupling. The drive gear (Z=50) transmits rotary motion to the centrifugal breather through another gear (Z=38).

The coupling transmits rotation to the engine compressor and turbine with the help of external splines, through the front trunnion of the compressor rotor.

When the engine accelerates to 2550 - 2900 r.p.m., the dogs of the ratchet clutch come out of engagement. From this moment on, the engine rotor, accessory drive gear box and the two-speed drive are rotated by the turbine. This throws in the roller clutch and the torque is transmitted directly to the starter, with a gear ratio 1 = 1.25. The starter begins to operate as a generator.

COMPRESSOR INLET HOUSING NOSE PORTION

The inlet housing nose portion (Figs 61 and 62) comprises the central drive, actuating the accessory drive gear box, the centrifugal breather, and the scavenge oil pump. Nose portion housing 1 (See Fig.61) is manufactured from magnesium alloy and is secured to the compressor inlet housing with the aid of 12 studs.

Adapter sleeves 22 are turned into the housing holes through which oil is fed to the oil scavenge pump.

Fitted into the nose portion housing is breather pipe 29, connecting the centrifugal breather to the nose portion upper flange. Fastened to the flange with the aid of two studs is an external breather pipe, bleeding air to the atmosphere. The inner bore of the nose portion housing accommodates press-fitted and dowel-located bearing bush 9 which receives drive 6 of accessory gear box. Accessory gear box drive 6 consists of bevel gear 5, rotating in two ball bearings 4 and 11 between which distance bush 8 and locking ring 10 are installed.

Bevel gear 5 is provided with internal splines serving to transmit the torque to the vertical shaft of the accessory gear box. Fitted into the circular groove is locking ring 7 preventing the shaft from coming out. Axial loads are taken by radial-thrust ball bearings 4, 11, and 24.

The ball bearings of the accessory gear box drive are lubricated by the oil dripping from the accessory gear box. The accessory gear box drive is held in the nose portion housing by locking ring 2.

Two other cavities accommodate oil pump 30, scavenging oil from the centre and rear bearings, as well as from the compressor inlet housing sump, and centrifugal breather 31. Drive

shaft 26, made integral with spur gear 21 and transmitting torque to the oil scavenge pump, rides in roller bearing 19 and in ball bearing 24. The drive shaft shank acts as the inner ring of the roller bearing. The outer ring of roller bearing 19 is fitted into bearing bush 18 and is held in position by locking ring 20. Besides, the drive shaft mounts press-fitted and dowel-located bevel gear 28, transmitting rotary motion to bevel gear 5 of the accessory gear box drive.

Ball bearing 24, mounted on the drive shaft, is retained by locking ring 23. Adjustment of bevel gear clearance is accomplished by the use of adjusting rings 3 and 27. The drive shaft splines mount centrifugal breather drive spur gear 17 and coupling 13 transmitting motion from the compressor to the drive shaft. Spur gear 17 is held against axial displacement on the drive shaft by ring 16; the coupling is held in place by nut 14 and lock 15.

The outer flange of the inlet housing nose portion is fitted with cover 25 made of magnesium alloy МЛ5. Turned into the central part of the cover is an adapter sleeve serving to receive the bolt securing the nose bullet fairing. The nose portion housing mounts oil nozzle 12 held in place by two studs and serving to feed oil to the front bearing of the compressor rotor.

ACCESSORY GEAR BOX

The accessory gear box (Fig.63) is located on the upper part of the compressor inlet housing and is designed to accommodate and to drive the engine and aircraft accessories. The accessory gear box is cast of magnesium alloy МЛ5; it is secured to the compressor inlet housing by four short and two long studs.

The accessory gear box (Fig.64) is provided with eight ports, accommodating the drives of the following gears and units: the driving bevel gear, the driven bevel gear, the two fuel pumps, booster pump ЦН-9 , the oil unit, hydraulic pump 623 and the centrifugal valve. The accessory gear box has a system of ducts providing for lubrication of the bearings and drive gears.

The drive of the driving bevel gear comprises gear 3 (See Fig.63) rotating in roller bearing 5 and in ball bearing 21. The outer ring of the ball bearing is mounted in sleeve 20, which is press-fitted and dowel-located in the accessory gear box. The outer ring of the roller bearing is mounted in bracket 4, secured inside the accessory gear box by two studs.

The shank of driving bevel gear 3 acts as an inner ring of the roller bearing. Driving bevel gear 3 has internal splines serving for connection to the vertical shaft of the inlet housing nose portion; the shaft is held in position by locking ring 22. The drive of the driving bevel gear is retained in the accessory gear box by locking ring 23. Driving bevel gear 3 imparts rotary motion to driven gear 7, whose rim is provided with involute splines for connection to accessory gear box central shaft 2. Driven bevel gear 7 is made integral with the shank having external and internal splines. The gear rotates in two ball bearings 30.

The external splines of driven gear 7 mount central spur gear 9 arranged between the ball bearings. The internal splines of driven gear 7 receive the shank of hydraulic pump drive spur gear 11; ball bearings 30 and central gear 9 are secured on the driven bevel gear with the aid of spur gear 11 and nut 6 with lock 41.

The ball bearings of the driven bevel gear are mounted in sleeves 8 and 10, which are press-fitted and dowel-located in the accessory gear box. Bearing sleeve 8 has a hole which communicates with the oil duct of the accessory gear box housing, thus providing for bearing lubrication.

Driven spur gear 12 of the hydraulic pump drive is internally meshed with spur gear 11 and is driven by the latter.

Driven gear 12 of hydraulic pump 435BM drive imparts rotation to bevel gear 16 through the external splines. Bevel gear 16 rides in two ball bearings 13, whose outer rings are mounted in hydraulic pump drive adapter 15. One of the bearings is held inside the adapter by locking ring 14, the other ball bearing together with bevel gear 16 being secured with the aid of a nut and lock. Bevel gear 16 meshes with bevel gear 17 which also rotates in two ball bearings 18 retained in the adapter by locking ring 19.

The hydraulic pump adapter is manufactured from aluminium alloy АЛ5 and is secured to the accessory gear box by seven studs. To accomplish lubrication of the drive bearings, the hydraulic pump adapter is provided with oil ducts, communicating with the duct of the accessory gear box.

Rotary motion is transmitted to hydraulic pump 435BM through the internal splines of the bevel gear (17) shank.

Hydraulic pump 435BM is held to the accessory gear box by a quick-change ring.

The drive of hydraulic pump 623 which was installed in earlier production engines (Fig.65) differed from the inclined drive by the absence of two bevel gears and two ball bearings. Hydraulic pump 623 was secured by four studs.

Central spur gear 9 (See Fig.63) drives two intermediate gears 31 and 42. Each of the intermediate gears is mounted on two ball bearings, between which a locking ring is fitted. The inner rings of the ball bearings are fitted onto fixed hollow pins 40 and 43, held to the accessory gear box by studs. The pins accommodate plugs 29 and 33. Meshed with intermediate gear 42 is spur gear 25 of the HP-10A fuel pump drive.

The drive of the HP-10A fuel pump consists of fuel pump drive shaft 44, two ball bearings 28, and spur gear 25. Shaft 44 is splined externally and internally; the external splines of the shaft mount spur gear 25 of the HP-10A pump drive, whereas the internal splines receive the shank of the HP-10A fuel pump. Fuel pump drive shaft 44 rotates in two ball bearings 28; the outer ring of one bearing is mounted in bearing bush 45, while the outer ring of the other bearing is fitted into flange 26.

Bush 45 has a hole which serves for lubrication and communicates with the oil duct of the accessory gear box.

The drive of booster pump ЦН-9 is rotated by fuel pump drive gear 25 through intermediate gear 46.

Intermediate gear 46 is similar in construction to intermediate gears 31 and 42.

The drive of booster pump ЦН-9 is arranged inside adapter 47, which is held to the accessory gear box by seven studs. Booster pump drive gear 49 has two tooth rims and rides in two ball bearings 50, between which two distance sleeves 48 and 52 are fitted.

The outer rings of ball bearings 50 are installed into adapter 47 and are held in place by locking ring 51. The internal splines of drive gear 49 receive the shank of booster pump ЦН-9, which is secured to the accessory gear box by seven studs.

Adapter 47 is provided with a system of ducts designed for lubrication of the drives of booster pump ЦН-9.

The smaller tooth rim of pump drive gear 49 meshes with centrifugal valve 24, held to the accessory gear box by a quick-change ring.

Intermediate gear 31 is engaged with HP-11A fuel pump drive gear 34. The drive of the HP-11A fuel pump acts as a drive of the oil unit; it consists of oil pump drive gear 37, riding in two ball bearings 35, and HP-11A fuel pump drive spur gear 34. The outer ring of one of the drive bearings is mounted into bearing bush 36, press-fitted and dowel-located in the accessory gear box housing. Bearing lubrication is accomplished through a hole in bush 36, communicating with the oil duct of the accessory gear box.

The outer ring of the other bearing fits into flange 53, which is secured to the accessory gear box housing by six bolts. Distance sleeve 54 is installed between the ball bearing and the spur gear.

The HP-10A and HP-11A fuel pumps, as well as the centrifugal valve are fastened to the accessory gear box by means of quick-change rings, comprised of two steel half-rings clamped by two bolts.

To prevent entry of oil from the accessory gear box into the HP-10A and HP-11A pumps, flanges 26 and 53 are provided with gland packings 27, held in place by locking rings.

TWO-SPEED DRIVE

The two-speed drive (Fig.66) is designed for transmission of torque from the starter to the engine at starting, and for transmission of rotary motion from the engine to the generator after the engine has been started. Apart from this, the two-speed drive prevents reverse rotation of the idle engine, when the other engine is being started (in case two engines are installed in one compartment).

The two-speed drive consists of housing 12 and cover 7, fabricated from aluminium alloy АЛ5 ; the housing and the cover accommodate two free wheeling clutches and a friction clutch. Housing 12 and cover 7 are coupled by five short and one long studs and are aligned by two centering dowels. Press-fitted and dowel-located in the cover boring on the starter-generator side is bush 4, accommodating two ball bearings 5 and rubber gland 2. The rubber gland is held in position by locking ring 3.

Clutch guide 1 mounted on two ball bearings 5 is engaged with the starter-generator shank through internal splines. At the other side of the clutch guide there is press-fitted and dowel-located bearing bush 29, which accommodates roller bearing 28 without the inner ring. The external splines of clutch guide 1 impart rotation to the steel discs of the friction clutch, whose bronze discs mesh with the internal splines of friction clutch housing 6.

Drive gear 14 is connected to friction clutch housing 6 and to roller clutch holder 19 by means of dowels. It rotates in two ball bearings 13 mounted on the shaft of driven gear 15. Rotation of drive gear 14 is transmitted to ratchet 23. Ratchet 23 rides in two ball bearings 22 and 26, whose outer rings are installed into the bearing sleeves, press-fitted into the housing and the cover of the two-speed drive.

Ball bearing 22 is retained in the bearing sleeve by locking ring 21. The shaft of ratchet 23 mounts the guide, consisting of housing 25 with dogs and gear 20. The housing and the gear are connected by dowels. The guide runs in two roller bearings 24, whose outer rings are secured in the guide with the aid of locking ring 27. The shaft of the ratchet serves as inner rings of the roller bearings. Guide gear 20 transmits rotation to driven gear 15. With the starter-generator operating as starter, driven gear 15 imparts motion to the central shaft of the accessory gear box through the internal splines.

<u>The friction clutch</u> is designed to safeguard the starter against overloads, in case the torque required to spin the engine is increased over the specified value; the friction

clutch also serves to protect the two-speed drive against breakdown in the event the generator is wedged. The clutch consists of housing 6, clutch guide 1, six driven bronze discs 9 and five drive steel discs 8, spring case 11, and spiral springs 10. The bronze discs have 15 2.5-mm diameter holes (in five bands) providing for clutch lubrication. The discs of the friction clutch are packed with graphite lubricant (ТУ027I-44).

The centrifugal clutch (ratchet, free wheeling) is mounted on the shaft of ratchet 23. The clutch consists of housing 25, with dogs fitted on pins 18 and expanded in the housing. The dogs are acted upon by the springs, which engage the former with the ratchet at starting. Under the influence of the centrifugal force the dogs overcome the force of the springs, come up against their stops and disengage from the ratchet.

The roller clutch (Fig.67) is mounted on the splines of the driven gear and comprises cam 3, bronze separator 4, eight rollers 1, and spring 2. Cam 3 is made of steel. The external surface of the cam has eight operating flats arranged at an angle of $8^{o}\pm15'$ to the cam edges. For connection to the driven gear the cam is internally splined. Bearing upon the cam flats are rollers 1, accommodated in the seats of separator 4 and retained by washer 5 which is secured to the separator by rivets 6. Under the force of spring 2, whose one end is secured to the cam and the other to the separator, the separator with the rollers all the time tends to wedge.

When the starter-generator operates as a starter, the torque is transmitted from the starter to the engine. In this case the ratchet clutch is engaged (the dogs are forced by the springs into the respective recesses of the ratchet) whereas the roller clutch is disengaged as the roller clutch holder rotates at a greater speed than the guide with the rollers, making engagement of the clutch impossible. After the engine has been started, the starter-generator begins to operate as a generator, and from this moment on the torque is transmitted in the reverse direction, that is from the engine to the generator. This makes the ratchet clutch come out of engagement, as the centrifugal forces throw the dogs out of mesh with the ratchet. At the same time the roller clutch gets wedged, as the guide with the rollers acquires greater speed than the roller clutch holder to which breaking effort is applied from the starter-generator rotor. Thus, inside the two-speed drive the torque is transmitted directly, past the ratchet. The two-speed drive is secured to the accessory gear box.

Chapter VI

ENGINE LUBRICATION SYSTEM

The РД-9Б engine employs a close-circuit self-sustained oil system, providing for a possibility of inverted flight of the aircraft and designed for lubrication and cooling of the turbine and compressor rotor bearings, as well as of the rotating components of the inlet housing nose portion, accessory gear box, and two-speed drive.

Besides, oil from the oil system is used by the centrifugal governor, controlling compressor air blow-off band operation.

The engine oil system (Fig.68) incorporates oil tank 2, fuel-oil cooler 1, oil unit pressure pump 6, oil scavenge pumps 18, 21, and 22, centrifugal breather 19, oil nozzles 13, 15, and 17 with filters 14, and the respective pipe lines.

The oil tank, fuel-oil cooler, and fuel filter comprise a single unit known as fuel and oil unit 317A.

FUEL AND OIL UNIT 317A

The fuel and oil unit (Fig.69) consists of an oil tank with a filter, fuel-oil cooler, fuel filter, and return valve constituting a single unit.

Oil Tank

The oil tank is fitted with a filter incorporating a deaerator.

Specifications

Oil tank capacity	not less than 12 lit.
Operating pressure	.0.2 - 0.8 kg/sq.cm.
Test pressure	1 kg/sq.cm.
Hydraulic pressure test	1.2 kg/sq.cm.

Oil Tank Construction

The oil tank (Fig.70) is welded from 2-mm thick sheet metal АМцАМ . Welded to the upper part of the oil tank is filler 10. The filler accommodates steel threaded ring 4, held in place by two screws 3. Oil filter 11 is inserted into the filler. The upper part of the oil filter is secured by nut 6, whereas the lower part rests against the taper portion of pipe union 14, serving to feed oil into the oil tank.

The filler is fitted with cap 9, which is locked by crossmember 8 and screw 7.

The circular groove of the cover accommodates rubber packing gasket 5. Oil depth gauge 12 fixed by a dowel on the inner side of the cover is a triangular rod with graduated faces, serving to measure the amount of oil in the tank, depending on the installation of the tank on the engine.

With the fuel-oil unit mounted on the left-hand engine, oil is measured by using the scale marked " Л " ("left"); when the unit is installed on the right-hand engine, measurements are taken by scale " П " ("right"); scale " Г " is used when measuring oil in a horizontally installed unit.

Fastened to oil tank partition 16 by two straps 17 is a rotary oil intake with a breather device, providing for continuous oil feed into the engine at any of the flight attitudes. Where the oil intake with the breather device rotates a port is provided in partition 16.

The oil intake with the breather device is connected by means of pipe 19 to pipe union 18 serving to deliver oil from the tank to the engine.

Pipe union 13 is designed for draining oil from the tank when the fuel and oil unit is installed on the right-hand engine, pipe union 1 serving to drain the tank with the fuel and oil unit mounted on the left-hand engine. Fitted on the left-hand side of the oil tank are steel clamps serving to fasten the fuel-oil cooler. Asbestos gaskets are placed between the clamps and the cooler housing.

The rotary oil intake with breather (Fig.71) consists of breather pipe union 10, welded to the front wall of the tank and connected inside the tank via breather pipe 9 with hollow axle 3. The hollow axle is divided into two parts by a partition. The left-hand part of the axle acts as a duct communicating with breather pipe 1, while the right-hand part serves for connection with oil intake 4.

With the aircraft in flight, oil intake 4 is immersed into the oil, whereas breather pipe 1 is always located in the air space of the oil tank.

To keep the oil intake immersed into the oil, the intake pipe is fitted with pocket 7 filled with 80^{+10} gr of lead (8). Oil is delivered from the tank via oil intake 4, hollow axle 3, pipe 5 and oil outlet pipe union 6.

Oil is vented to the atmosphere through breather pipe 1, hollow axle 3, and pipe 9, connected to breather pipe union 10.

Oil intake 4 is rigidly connected to breather pipe 1 by means of two-chamber bush 2 rotating around axle 3.

The oil filter (Fig.72) comprises cylindrical frame 2, made of 1-mm thick sheet steel. The frame has ports for oil and air outlet. On the outside, the frame is fitted with brass gauze 5 (gauze No.28). Arranged inside the frame are two steel pipes 3 terminating in nozzles 10 in their upper parts. The lower ends of the pipes are soldered to bottom 8 and are interconnected by two plates 4. The lower part of the frame mounts bowl 9. The bowl carries rubber tip 1, which fits against the taper surface of the inlet pipe union when the filter is being mounted into the oil tank.

For ease of installation and removal of the filter, two steel lugs 7 are soldered to the inner wall of the frame.

Oil is directed into the oil filter through a hole in bowl 9, along pipes 3 and further through nozzles 10. The nozzles throw oil against the frame walls, and the air separated by the impact is expelled into the oil tank through the upper ports of the filter frame.

Fuel-Oil Cooler

The fuel-oil cooler is designed for cooling the oil, circulating in the engine oil system. The oil is cooled by the fuel passing through the cooler pipes.

Specifications

Cooler front area	1.26 sq.dm.
Cooling surface	1.53 sq.m.
Number of pipes	not over 480
Oil space capacity	1.5 lit.
Fuel space capacity (fuel filter included)	3.94 lit.
Permissible operating pressure	3/4 kg/sq.cm.
Air pressure test	4/5 kg/sq.cm.
Hydraulic pressure test	6/8 kg/sq.cm.
Destructive pressure	12/16 kg/sq.cm.
Dry weight	13 - 15 kg

Fuel-Oil Cooler Construction

The cooler (Fig.73) consists of a housing, left-hand cover, and cooling element. The fuel filter housing serves as a right-hand cover of the cooler. The cooling element comprises a set of pipes 1, with outer diameter 4 mm and wall thickness 0.2 mm. The pipes are manufactured from alloy ЛТ96 . The ends of the pipes are hexahedral in shape. The pipes are so arrang- ed inside the cooler housing, that their hexagons fit snugly against each other, while their cylindrical portions form clearances for passage of oil. The hexahedral ends of the pipes are soldered to each other and to the cooler housing by sold- er ПОС50 . Hot oil flows between the cylindrical portions of the pipes, while fuel circulates along the pipes.

The cooler housing consists of shell 11, made of 1.5-mm thick sheet brass Л62И , and two steel flanges. The shell is provided with four ports, of which three are designed for oil inlet to and one for oil outlet from the cooler. The shell ports communicate with manifolds 6 and 8 welded to the shell. The right-hand manifold delivers oil to the cooler. The left- hand manifold receives the outgoing oil; the manifolds are con-

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nected by pipe 7, which incorporates a ball valve consisting of a casing with valve seat 14, valve 16, spring 15, and adjusting screw 13. The valve is screwed into pipe 7 and is locked therein by locking ring 17.

If resistance to oil flow at its inlet to the cooler increases in excess of the specified value (due to cooler clogging), the valve opens and by-passes oil from the inlet cavity to the outlet.

The right-hand manifold is fitted with pipe union 10 affording oil inlet into the cooler. The pipe union is brazed with brass. Welded to the left-hand manifold is oil outlet pipe connection 4. Pipe connection 4 communicates with the pipe union serving for oil inlet into the oil tank. Pipe union 12 brazed to the left-hand manifold with brass serves for draining oil from the cooler. Pipe union 12 mounts the pipe union-valve (Fig.74) consisting of pipe union 1, nipple 4, valve rod 3, and spring 2. The valve rod is covered by threaded cap 5. When the valve rod is depressed, oil drains from the cooler.

For better heat dissipation, four partitions 2 (See Fig.73) are fitted inside the cooler housing. The partitions divide the cooler space into five sections. Partitions 2 are manufactured from 1-mm thick sheet brass. Each of the partitions is provided with a port, through which oil successively flows from one section into another, each time changing the direction of flow.

The left-hand flange has cover 5 secured by bolts, whereas the right-hand flange mounts the fuel filter, which at the same time acts as the right-hand cover of the cooler housing.

The joints between the cooler housing flanges and the covers are packed with paronite gaskets. To obtain the required speed of fuel flow, ensuring optimal conditions of heat removal from the cooler, the inner cavities of the covers are divided by partitions 2; the projecting end faces of the partitions fit into the cover grooves.

The fuel-oil cooler is secured to the oil tank by bands placed on straps 9 soldered to the shell. On the outside, the cooler is provided with casing 1 (See Fig.69) secured to the oil tank by screws 2.

To prevent oil seepage from fuel-oil unit 317A into the non-operating engine, the cooler oil inlet pipe union is furnished with return valve 3. The return valve (Fig.75) consists of housing 5, mushroom valve 4, valve guide 2, and spring 3, which forces the valve against the housing seat. The valve guide is clamped inside the housing by pipe union 1. Valve resistance should not exceed 0.03 kg/sq.cm., with oil MK-8 (State Standard 6457-53) delivered at a rate of 14 lit/min., and temperature of 50°C.

Fuel Filter

The fuel filter is designed to clean fuel of mechanical impurities.

Specifications

Number of filtering discs . . . . 40 – 42
Filtering area . . . . .685 sq.cm.
Inlet fuel pressure . . . . 3 kg/sq.cm.

Fuel Filter Construction

The fuel filter (Fig.76) comprises casing 6, filter element 10, and cap 7. The filter casing and the cap are fabricated from alloy АЛ4Т6.

The filter casing carries two flanges with holes for fuel inlet and outlet. The lower part of the filter casing is furnished with two pipe unions 14 for fuel drainage.

When fuel-oil unit 317A is mounted on the right-hand engine, pipe union-valve 4 (See Fig.69) is turned onto the right-hand pipe union (if viewed from the fuel filter side), whereas the other pipe union is furnished with union nut with plug 5. With the fuel-oil unit installed on the left-hand engine, the pipe union-valve and the union nut should be transposed.

The construction of the pipe union-valve is described above. The filter casing incorporates a mushroom valve, separating the fuel inlet chamber from the outlet chamber. The valve consists of mushroom 4 (See Fig.76), valve seat 3, valve disc 1, and spring 2.

When pressure of the fuel pumped through the cooler increases, the valve opens thereby directing fuel from the inlet chamber to the outlet, by-passing the cooler. The valve is so adjusted as to open at a pressure of 0.07 kg/sq.cm. The valve is mounted through the port provided in the casing and closed by a screw plug.

The filter element (Fig.77) comprises a set of 40 - 42 double-sided gauze discs 3, mounted on common core 4.

The gauze disc (Fig.78) consists of two outer fine brass gauzes 1 (gauze No.0045, State Standard 6613-53) and two inner coarse brass gauzes 2 (gauze No.042, State Standard 6613-53). Each pair of gauzes (fine outer and coarse inner) is clamped on the inner diameter by inner rings 4. The coarse gauze acts as a frame for the fine gauze, guarding the latter against damage which may result from pressure difference inside and outside the gauze. Corrugated disc 5 installed between the gauzes renders the gauze disc more rigid. On the outer diameter the gauzes and the corrugated disc are clamped by outer ring 3.

The gauze discs are pressed between bottom 6 and filter cap 1 with the aid of steel rod 5 (See Fig.77) and nuts 7. The filter cap is furnished with handle 15 (See Fig.76) facilitating installation and removal of the filter from the casing; besides, the filter cap is provided with a threaded hole, serving for bleeding air from inside the filter. The threaded hole is stopped by special plug 13; when the plug is backed out 2 to 3 turns, the inner cavity of the filter communicates with the atmosphere through a system of holes, provided in the plug. To prevent leakage of fuel, the plug is fitted with rubber ring 16.

The filter element with the cap is fitted into the filter casing and is secured by clamp 11 and wing nut 12. The cap-to-casing joint is packed by rubber gasket 8. To prevent non-filtered fuel from entering the system at the filter outlet, the cap is sealed with rubber ring 9. The fuel filter is secured to the fuel-oil cooler housing by 28 studs.

Fuel-oil unit 317A is secured by means of two steel clamps to four steel brackets, fastened to the bosses provided on the compressor rear housing. Fitted between the brackets and the unit are four asbestos gaskets serving for thermal insulation of the fuel-oil unit from the hot housing.

OIL UNIT

The oil unit (Figs 79 and 80) consists of oil pressure pump 9 (See Fig.79), reducing valve 44, reducing valve filter 15, oil filter 20, safety valve 32, return valve 34, and air bleeder valve 28.

The oil pressure pump is a gear type, having an output of 25 lit /min. at the normal rating, with counterpressure amounting to 3 - 4 kg/sq.cm. and oil temperature 60 - 65°C. The pump comprises housing 7, operating gears 8 and 49, drive shaft 12, drive gear 1, and two rubber glands 6 and 46. Pump housing 7 is manufactured from aluminium alloy АЛ5; it is held to the housing of oil unit 10 by four studs. Centering of the housing is accomplished by the use of two guide dowels. Oil pump drive gear 1 is coupled to the oil pump drive shaft by means of splines and nut 47 with lock 50. The other end of the drive shaft accommodates press-fitted bush 45 having an internal square, serving to impart rotary motion to the tachometer generator. Drive shaft 12 is mounted on a ball bearing and a friction bearing; it is coupled to drive gear 49 by means of key 48. The drive shaft mounts collared split bush 3 which holds it from axial displacement. Driven gear 8 is made integral with the trunnions and is mounted on two friction bearings. Oil seepage from the pumping unit into the accessory gear box and into the tachometer generator is prevented by rubber glands 6 and 46. The oil trapped by the glands is directed into the suction cavity through special drilled passages.

The oil unit housing accommodates reducing valve 44, return valve 34, oil filter 20, reducing valve filter 15, the pipe union delivering oil to the centrifugal valve, and adapter sleeve 13 serving to direct oil from the tank into the pump.

Reducing valve 44 is a poppet type, serving to maintain pre-determined oil pressure in the engine oil line. The reducing valve consists of housing 42, adjusting screw 43, valve 40, valve seat 39, and a spring. The housing is fabricated from steel 30ХГСА and is screwed into the oil unit housing. Valve 40 is forced by spring 41 against seat 39, which is press-fitted and dowel-located in the oil unit housing. On the opposite side the valve is acted upon by oil pressure.

The reducing valve is adjusted to an oil pressure of 4 to 4.5 kg/sq.cm. Adjustment is carried out by means of adjusting screw 43, turned into the reducing valve housing. If pressure in the oil line increases in excess of the specified value, the valve overcomes the force of spring 41 and by-passes oil to the suction side.

Reducing valve filter 15 consists of an inner and outer frames with filtering gauzes soldered to their faces.

Return valve 34 is a mushroom type; its function is to prevent oil flow from the tank into the oil pipe lines when the engine is inoperative. The valve admits oil into the engine oil system, when oil pressure downstream of the filter reaches 0.2 to 0.3 kg/sq.cm. The return valve consists of housing 33, valve 34, valve guide 36, and spring 35. The valve is spring-loaded and should be capable of free movement along the guide.

Oil filter consists of ten gauze discs 19 (See Fig.79), frame 22, thrust cover 18 with spring 14, and bolt 23. Each of the discs (Fig.81) consists of two outer circular filter gauzes 3 (0.07 mm dia. wire; 4096 meshes in 1 sq.cm.) and two inner frame gauzes 4 (0.22 ± 0.05 mm and 0.24 ± 0.05 mm dia. wire).

Each pair of gauzes (outer filtering and inner frame) is clamped on the inner diameter by holder 6. Corrugated diaphragm 2 is fitted between the gauzes. On the outer diameter, the gauzes and the diaphragm are clamped by holder 1. The filter frame with the bolt is secured in oil filter cap 21 (See Fig.79). The frame mounts ten gauze discs 19 and spring 14 with thrust cover 18, clamped by nut 16.

In case the oil filter gets clogged, oil is directed through the safety ball valve and into the engine oil line, by-passing the filter. The valve starts to function when the difference in oil pressure at the filter inlet and outlet amounts to 0.8 - 1.0 kg/sq.cm. The safety valve consists of housing 30, ball 31, and spring 32. The valve housing is screwed into cap 21 of oil filter 20 so that the valve end face should sink into the cap by 1 - 2 mm. The housing is punched at the slot for a screw-driver.

Air bleeder valve 28 comprises housing 24, incorporating ball 27, spring 26, and bush 25, held in place by locking ring 29.

The valve housing is screwed into the oil filter cap and is locked by wire. The air bleeder valve is designed to eliminate air locks in the pipe line serving to deliver oil to the oil unit, when servicing the engine with a non-filled oil line. To expel air, it is necessary to back out the plug and to depress ball 27 against the force of the spring. The oil unit housing mounts tachometer generator adapter 11 secured by three studs. The oil unit is fastened to the accessory gear box housing with the aid of five studs and one bolt.

The scavenge oil pump (Fig.82) is a gear type comprising three sections: two extreme sections 18 and 20, scavenging oil from the centre and rear bearings, and middle section 19 drawing oil from the compressor inlet housing pan.

Scavenge oil pump output at the normal rating, at a counterpressure of 1.0 kg/sq.cm. and oil temperature of 70 to 75°C, amounts to the following values: the section scavenging oil from the compressor inlet housing - 50 lit/min.; the sections drawing oil from the centre and rear bearings - 22 lit/min. each. The oil pump consists of three housings 4,7 and 10, cover 6, spur gear 11, shaft 1, and axle 3.

The housings and the cover are manufactured from aluminium alloy АЛ5; they are lined up and secured to each other by two steel bolts 17. Pump drive gears 12 and 15 are mounted on the drive shaft, made integral with spur gear 21; the drive gears are secured to the drive shaft by means of keys 2 entering the key ways of the drive shaft and the gears.

Oil pump driven gears 5, 8, and 9 freely rotate on hollow bronze axle 3, which is not fixed axially. The drive and driven gears of the oil pump are identical by their modulus, number of teeth and the outer diameter:

Modulus 2.75

Number of teeth 10

Outer diameter . . . . $34.1^{-0.025}_{-0.005}$ mm

The height of the gears of the extreme sections amounts to 14 mm, whereas the height of the middle section gears is equal to 32 mm.

Oil is fed to the friction surfaces of the pump through radial holes provided in driven gears 5,8, and 9, and in drive shaft 1; the radial holes communicate with the pump cavity. A circular groove is machined in the driven shaft for the same purpose.

The oil pump is driven by spur gear 11, coupled to the drive shaft by means of a spline joint and nut 13 with lock 14. Oil is admitted into all the three sections of the pump through three holes provided in pump housing 4.

To provide a means for oil outlet, middle housing 7 carries a special boss, common to all three sections. Fitted into the boss hole is an oil outlet pipe sealed by rubber ring 16. The pipe runs through the left-hand horizontal strut of the compressor inlet housing (looking from the air intake end) and serves to direct oil into the tank via the fuel-oil cooler.

To improve suction efficiency of the pump at starting, its inlet cavities are primed with oil delivered from the pressure line via drilled passages.

CENTRIFUGAL BREATHER

The centrifugal breather (Fig.83) is designed to separate air from the oil-air mixture drawn from the compressor inlet housing and from the rotor bearing housing, with subsequent discharge of the separated air to the atmosphere. The process of deaeration is based on the principle of mechanical separation of air-oil mixture by the action of centrifugal forces.

The centrifugal breather is held to the compressor nose portion housing by two studs and one bolt. It consists of housing 5, cover 15, rotor 13, thrust cover 1, oil seal bush 2, oil slinger 9, drive gear 12, and two ball bearings 3 and 8.

The housing and covers are manufactured from magnesium alloy МЛ5. The centrifugal breather housing accommodates steel hollow rotor 13 running in ball bearings 3 and 8 mounted in the housing and in the cover. Clearance M between the rotor blades and the housing is adjusted by means of brass shim 14. The rotor has eight radial blades 7. Milled between the rotor blades are eight through holes 6. Rotor thrust disc 4 has sixteen recesses 17 machined on the ball bearing side. The recesses, together with the system of ducts provided in centrifugal breather cover 15, ensure circulation of oil, used for

lubricating and cooling bearing 3. The rotor trunnion mounts oil seal bush 2 preventing oil seepage; thrust cover 1 is fitted with rubber ring 16 serving the same purpose. The centrifugal breather rotor is driven by spur gear 12, coupled to the rotor by means of a spline joint and nut 11 with lock 10. The running rotor draws air-oil mixture through the port and an additional hole into the centrifugal breather housing. Rotor blades 7 impart rotary motion to the mixture and throw the oil, as a more heavy component, against the walls of the housing whence the oil flows into the front bearing housing along the spiral groove and oblique passages machined in the inner surface of the housing. The air enters the rotor through the ports and then is discharged to the atmosphere via a steel pipe.

OIL NOZZLES

Oil for lubrication and cooling of the front, centre, and rear bearings of the compressor and turbine rotors is furnished by the oil nozzles arranged on the inlet housing nose portion, in the centre and rear bearing housings respectively.

The oil nozzle of the centre bearing (Fig.84) consists of body 1, frame 2, and gauze filter 3. The frame with the gauze filter is secured in the body by means of locking ring 4. The nozzle body has a 1.8-mm dia. calibrated central orifice through which oil is fed to the ball bearing. The capacity of the centre bearing oil nozzle at oil pressure 3 kg/sq.cm.and temperature 50 to 60°C amounts to $4^{+0.3}$ lit /min.

The oil nozzle of the rear bearing is similar in construction to the oil nozzle of the centre bearing, the only difference being that the former is provided with an additional 0.6-mm dia. side hole, whereas the diameter of the central calibrated orifice is equal to 1.6 mm. The capacity of the rear bearing fuel nozzle at oil pressure 3 kg/sq.cm. and temperature 50 to 60°C is equal to $4.4^{+0.3}$ lit/min.

The oil nozzles of the centre and rear bearings are each secured by two bolts to the pipe (See Fig.68) for oil delivery to the bearings.

The oil nozzle of the front bearing (Fig.85) consists of flange 1, pipe 2 and jet 3 with 1.8-mm dia. calibrated orifice.

The parts of the front oil nozzle are brazed together by brass Л62 to form an integral unit, secured to the front bearing nose portion by two studs. At an oil pressure of 3 kg/sq.cm., and a temperature of 60 to 75°C, the front bearing oil nozzle delivers oil at a rate of 0.5 - 1 lit/min.

LUBRICATING SYSTEM OPERATION

With the engine running, oil from the oil tank of the fuel-oil unit is supplied to oil unit pressure pump 6, located on the accessory gear box, through the rotary oil intake and pipe line 5 (See Fig.68). The oil pressure pump forces oil through fine oil filter 7 and return valve 8 to the main oil duct of the accessory gear box which constitutes the beginning of the engine oil line. A portion of the oil is directed through 1.7-mm dia. jet and along the ducts, drilled in the cast housings, to the accessory gear box, two-speed drive, compressor inlet housing nose portion (central drive) and to the compressor front bearing, where it is used for lubrication purposes; the remaining part of the oil is supplied through the accessory gear box pipe union to the compressor centre bearing and to the turbine rear bearing.

Lubrication of Accessory Gear Box

All rotating components of the accessory gear box are lubricated with oil supplied via the inner ducts of the accessory gear box. The bevel gears and the bearings of the accessory gear box shafts, except the ball bearing of the drive bevel gear, are force-lubricated by the use of jets. The ball bearing of the drive bevel gear, located in the lower part of the accessory gear box is lubricated by the oil, draining from the accessory gear box into the compressor inlet housing. Lubrication of the spur gears of the accessory gear box is accomplished by splashing.

Oil from the accessory gear box is drained via the upper vertical strut into the compressor inlet housing.

Lubrication of Two-Speed Drive

Oil for lubrication of the ball bearings of the starter-generator drive, driven gear and ratchet gear is supplied along the duct running through the accessory gear box-to-two-speed drive housing joint, and further through the jets. The remaining ball bearings of the two-speed drive, the rollers of the free wheeling clutch, the ratchet clutch and all gears are splash-lubricated.

The friction clutch discs are lubricated with special graphite grease, applied during friction clutch assembly.

The starter-generator drive is fitted with a rubber gland preventing oil seepage from the two-speed drive into the starter-generator.

Oil from the two-speed drive is drained into the accessory gear box.

Lubrication of Inlet Housing Nose Portion

Oil for lubrication of the compressor inlet housing nose portion is supplied as follows. Pressurized oil is delivered from the main oil duct of the accessory gear box to the flange securing the gear box to the compressor inlet housing. Further, via pipe 2 (See Fig.9) running inside the upper vertical strut, oil is fed to the flange of the compressor inlet housing whence it is directed through the inlet housing flange-to-nose portion flange joint into the oil ducts of the nose portion.

The nose portion housing ducts direct oil into the circular grooves machined on the operating surfaces of the bevel gear bearings. From the circular grooves the oil is supplied to the jets serving for lubrication of the bevel gears and radial-thrust bearing 24 (See Fig.61) of the central shaft which is also lubricated by the oil supplied from inside the central shaft. Oil by-pass into the central shaft is accomplished through the use of an oil by-pass bush.

The central shaft roller bearing is lubricated by oil, dripping along the radial clearance between the bearing sleeve and the central shaft.

The bevel gears of the inlet housing nose portion are splash-lubricated. The ball bearings of the driven bevel gear are lubricated by the oil dripping from the accessory gear box. Oil from the inlet housing nose portion is drained into the compressor inlet housing.

Lubrication of Compressor Front Bearing

From the circular groove of the inlet housing nose portion the oil is directed to oil nozzle 12 (See Fig.61) whose jet emits oil for lubrication and cooling of the compressor front roller bearing.

The bearing is fitted with two labyrinth sealings preventing oil seepage from the bearing into the compressor (See Fig.4). The interlabyrinth space is packed with air bled from the compressor eighth stage.

Lubrication of Compressor Centre Bearing and Turbine Rear Bearing

From the accessory gear box pipe union oil is supplied via pipe 10 (See Fig.68) to the tee-piece directing the oil along two pipes terminating in oil nozzles 13 and 15. The nozzles eject oil onto compressor centre ball bearing 12 and turbine rear roller bearing 24 where it is used for lubrication and cooling. The oil nozzle lubricating the rear bearing has an additional orifice feeding oil for cooling the turbine shaft.

To prevent foreign matter from entering the bearings, the oil nozzles of the centre and rear bearings are furnished with gauze filters.

Used oil is accumulated in the sumps of the centre and rear bearing housings, whence it is scavenged via pipes 16 by two sections of the oil scavenge pump, arranged in the compressor inlet housing nose portion. To prevent oil leakage through the centre bearing of the compressor and the rear bearing of the turbine, the bearing housings are furnished with air labyrinths. The air labyrinths make use of air pressure difference between the separated cavities; this pressure difference determines direction of air circulation between the cavities.

The labyrinth sealing of the centre bearing operates on the air pressure difference between the rear relief cavity

and the inner cavity of the bearing housing vented to the atmosphere.

The labyrinth sealing of the turbine rear bearing comprises two stages. The first stage operates on the pressure difference between the cavity supplying air for cooling the turbine, and the rear relief cavity (the interlabyrinth space of the rear bearing housing being connected to the rear relief cavity by six bleeder pipes); the second stage operates on the air pressure difference between the rear relief cavity and the bearing housing cavity.

Scavenging of Oil from Engine

The entire amount of oil, which is drained from the accessory gear box, the inlet housing nose portion and the compressor front bearing is directed into the oil sump of the compressor inlet housing through gauze 5 (See Fig.9) fitted on the lower vertical strut of the inlet housing. From the oil sump the oil is drawn by the middle section of the scavenge oil pump.

Oil from the sumps of the bearing housing is drawn via pipes 16 (See Fig.68) by the first and third sections of the scavenge oil pump.

From all three sections of the oil scavenge oil oil is directed into common pipe line 23, whence it is conveyed into the fuel-oil cooler.

The hot oil enters the interpipe cavity of the cooler first section through the pipe union of the right-hand manifold and through three ports provided in the shell. In flowing through all the three sections and successively changing the direction of flow the oil is cooled by fuel passing along the cooler pipes, and is supplied into the left-hand manifold through the shell port. From the left-hand manifold oil enters oil filter 11 (See Fig.70) where it is cleaned and partially de-aerated; then the cleaned oil and the air are directed to the oil tank.

To ensure normal operation of the engine oil system, to reduce total oil consumption, and to increase operational ceiling of the oil system, provision has been made for venting the oil system to the atmosphere through the centrifugal breather.

To this end, the inner cavities of the compressor inlet housing, the centre and rear bearing housing, and the oil tank are connected to the centrifugal breather; the compressor inlet housing communicates directly with the centrifugal breather through the port and the hole provided in its housing; the centre and rear bearing housing is connected to the centrifugal breather by pipe 11 (See Fig.68) running through the left-hand horizontal strut of the compressor inlet housing; the oil tank is connected by pipe 3 with the accessory gear box, which communicates with the centrifugal breather through the compressor inlet housing.

In the centrifugal breather almost all air is separated from the oil(the principle of operation of the centrifugal breather is described above). The air separated from the oil is discharged to the atmosphere through the pipe running along the upper vertical strut of the inlet housing, through the pocket in the accessory gear box, and further via the aircraft pipe lines.

Oil from the engine oil system is drained through two cocks and a pipe union-valve; one of the cocks is used to drain oil from the compressor inlet housing; the other cock serves to discharge oil from the oil tank; pipe union-valve 4 (See Fig.69) is designed to drain oil from the fuel-oil cooler.

Air locks forming in the engine oil system may interfere with its normal filling.

To expel air from the engine oil system a ball valve is provided in the oil filter cap.

Chapter VII.

ENGINE AIR COOLING SYSTEM (Fig.86)

Cooling of the engine components operating at high temperatures provides for their reliable operation and permits the use of less expensive materials for their manufacture.

The parts of the combustion chambers and the turbine are cooled with the air supplied from the compressor ninth stage, whereas the afterburner components are cooled by the outside air.

The air delivered from the compressor passes through the circular diffuser and enters the combustion chambers through the swirler and the holes provided in the combustion chamber liners. This air may be divided into the primary and secondary air streams.

The primary air supplied for fuel combustion flows into the combustion chambers through the swirler and the holes drilled in the front portion of the liner. The secondary air, considerably exceeding in volume the primary air, enters the combustion chamber through a number of holes in the liner, mixes up with the gas stream and cools it to the required operating temperature. The same air flowing along the combustion chamber walls provided with ribs ensuring better heat dissipation, cools the combustion chambers on the outside, and forms a layer of thermal insulation between the walls of the chambers, rear housing 6 and shield 7.

Air for cooling the turbine (Fig.87) is supplied under the external shoes of first stage nozzle assembly 2 and under shield 6 through holes Б provided in the inner support of the first stage nozzle assembly. Under the external shoes the air is delivered from rear housing 1 through holes A. Having cooled down the outer shroud of the first stage nozzle assembly and the external shoes, the air passes through the clearances between the shoes and the housing and into the cooling ducts provided between the roots of the vanes of second stage nozzle assembly 3 and its shroud, after which it is discharged into the flow section, where it mixes up with the gases.

A portion of the air is passed through the hollow vanes of the first stage nozzle assembly for cooling the internal shoes and the inner support of the nozzle assembly, after which it is directed through the clearances between the vanes and the shoes into the flow section of the engine.

The other stream of the cooling air is supplied from inside the rear housing through holes Б into the circular space limited by shield 6. Further, the air flows through holes B in the shield to cool the turbine first stage disc and the fir-tree roots of the respective blades. Through holes B in the first stage disc the air enters interdisc space Г, whence a portion of the air is directed through milled holes I (by-passing the baffle) and is used for cooling the fir-tree roots of the blades, whereas the remaining portion of the air flowing from space Г through holes И in the second stage disc is directed by baffle Д against the disc, cools the latter and escapes into the afterburner diffuser. The afterburner is cooled by the outside air, flowing between the aircraft inner skin and the engine.

The adjustable jet nozzle shutters and the actuating cylinders are cooled by ejected air (See Fig.86). The air enters the adjustable jet nozzle shroud through 32 30-mm dia. holes, flows between the shroud and the rear pipe shell, cools them and enters the ejector.

Through the holes provided in the shutters the cooling air flows into the shutters. Cooling of the actuating cylinders is accomplished by the use of the free air drawn through the respective pipe unions installed on the aircraft. This air flows between the shields and the actuating cylinders, cools them and also escapes into the ejector. After cooling the above components the air mixes up with the outgoing gases to be discharged to the atmosphere.

No provision has been made for forced cooling of the diffuser and the middle pipe of the afterburner.

The bands have holes providing for ventilation of the space between the shroud and the afterburner shell.

Chapter VIII

ANTI-ICING SYSTEM

At low ambient air temperatures (within +2 to -10°C) and increased humidity the surfaces of the engine nose bullet forming the compressor air intake duct are liable to icing. To eliminate this possibility, provision has been made for a special anti-icing system (Fig.88) whose function is to continuously heat the respective surfaces with hot air, bled from the compressor ninth stage and circulating between the double walls of the components subject to icing.

The rear housing carries pipe connection 8 (where the air is bled from the compressor) connected to pipe 3 along which air is delivered to support pipe connection 4.

From the support pipe connection the air is directed along the lower stamped strut 5 into fairing manifold 1.

A part of the hot air from the fairing manifold is delivered through holes 6, provided in the outer wall, into remaining three stamped struts 2, after which it escapes to the atmosphere through the holes in the inner walls of the struts.

The remaining portion of the air flows from the fairing manifold along pipe 9 into the space limited by partition 10 and the inner wall of the fairing tip, whence it escapes through a circular clearance and passes between the fairing walls. Having heated the fairing walls, the air enters the fairing through the holes provided in the middle portion of the inner wall. From the fairing the hot air is discharged to the atmosphere via the stamped struts.

A portion of the air supplied via pipe 9 flows through the radial grooves of the fairing tip into the compressor in-

take duct, where it is thrown against the outer wall of the fairing, heating the latter.

The required heating temperature is obtained by regulating air expenditure with the aid of jet 7, fitted into the air delivery pipe.

Chapter IX

ENGINE FUEL SYSTEM

The function of the fuel system is to deliver metered amounts of fuel into the engine at any of the operating conditions.

The engine fuel system is comprised of the starting fuel system, main fuel system, afterburner fuel system, and the vent-drain system.

STARTING FUEL SYSTEM

The starting fuel system (Fig.89) is designed to supply fuel into the engine being started on the ground or in flight.

The starting fuel system incorporates starting fuel tank 1, starting fuel pump 3, magnetic valve 4, starting fuel manifold 6, four flame igniters 5, and the connecting pipe lines.

The aircraft is fitted with one starting fuel tank per two engines. The ПНР-IO-9M starting fuel pump is installed on the tank.

The ПНР-IO-9M electric pump is a gear type driven by special electric motor МУ-I02A.

Magnetic Valve

The starting fuel system incorporates a unit installed between the pump and the starting fuel manifold and serving to supply fuel to the starting atomizers when the engine is being started, and to prevent entry of gases from the combustion chambers into the starting fuel system. The unit prevents the starting fuel system from being drained after the engine is started, or when the aircraft is parked.

The unit comprises a magnetic valve and a return valve, mounted in the pipe union of the magnetic valve.

The magnetic valve (Fig.90) consists of housing 1, bush 2, cores 3 and 4, solenoid 5, bonnet 6, plug connector 7, needle 8, needle axle 9, spring 10, bush 11, pipe union 12, lock 18, and filter 14.

Soldered to steel housing 1 is bush 2, accommodating cores 3 and 4. Core 3 is soldered to bush 2, whereas core 4 is capable of shifting inside bush 2 and housing 1.

Bush 2 mounts solenoid 5 with an ohmic resistor R = 9_{-1} ohms. The solenoid coil lead ends are soldered to the contacts of plug connector 7. The plug connector is attached to bonnet 6 by four screws 15. Bonnet 6 is fitted on housing 1 and is held to fixed core 3 by screw 16. Core 4 is provided with a hole receiving axle 9, and another, stepped hole, accommodating needle 8 and spring 10. The spring fitted between cores 3 and 4 forces the needle against bush 11. The bush is made of bronze and is provided with four 2-mm dia. holes, uniformly spaced round the circumference. The holes serve for passage of starting fuel, supplied via filter 14 and the valve seat receiving the cone of needle 8.

The needle is made of steel and is nitrided to a depth of 0.06 to 0.18 mm on the entire circumference. It is ground to bush 11. Steel pipe union 12 is screwed into housing 1. The pipe running from the pipe union connects the magnetic valve to the starting fuel manifold. Placed between pipe union 12 and bush 11 is packing gasket 17. Pipe union 12 is guarded against loosening by lock 13. Filter 14 is of a gauze type. It consists of a casing and a brass gauze No.016 (State Standard 6613-53). The gauze is soldered to the casing. The filter is placed into valve housing 1 and secured by lock 18. The lock is fitted into the groove provided in the filter casing and in the valve housing.

The return valve consists of steel bush 19 press-fitted into bronze bush 11, hemisphere 20, spring 21 and plunger 22. The outside surface of the cylindrical plunger has four perforated flats allowing passage of starting fuel into the plunger. The plunger is divided by a perforated partition contacting hemisphere 20 on one side and spring 21 on the other. The spring presses the plunger with the hemisphere against bush 19, when the magnetic valve needle is closed.

Operating principle of the magnetic valve is described below.

Starting Fuel Manifold with Flame Igniters
(Fig. 91)

The starting fuel manifold is designed for feeding starting fuel to the flame igniter starting atomizers. The manifold comprises four 4x6 mm dia. pipes made of steel IX18H9T. Secured to the pipes (by atomic-hydrogen or argon-arc welding) are pipe unions and nipples serving to connect the pipes to each other and to the flame igniter starting atomizers. Pipe union 3 receives the pipe for fuel supply from the magnetic valve to the manifold.

The starting fuel manifold is coated with yellow enamel A-6.

The function of the flame igniters is to set fire to the fuel-air mixture in the combustion chambers during engine starting.

The flame igniter (Fig.92) consists of housing 3, bush 9, movable bush 7, starting atomizer 2, spark plug 8, discharger 4, and shield 6. Housing 3 is cast of steel X23H18 and carries a flange serving to secure the flame igniter to the compressor rear housing. The taper portion of the housing has two holes through which air is supplied into the flame igniter. Inside, the housing is machined to a spherical shape to form a chamber in which the fuel-air mixture is ignited. The side surface of the housing carries three bosses provided with threaded holes receiving spark plug 8, starting atomizer 2 and discharger 4. The housing has a hole for draining fuel from the flame igniters located in the lower part of the engine. The flame igniters arranged in the upper part of the engine have their drain holes stopped with plug 1. The lower part of the housing carries point-welded bush 9 made of steel IX18H9T. The bush has a sphere accommodating movable bush 7 which is also provided with a sphere. This type of joint permits self-centering of the movable bush in the pipe connection of the combustion chambers

during engine operation, and facilitates installation of the flame igniters on the rear housing. Movable bush 7 is made of alloy ЭИ435 . The lower portion of the bush is provided with eight stamped lugs. Clearances between the lugs and the combustion chamber pipe connection serve for passage of the secondary air cooling the pipe connection and the bush. Shield 6 is manufactured from sheet steel IX18H9T and is secured to the housing by point welding. The shield is designed for directing and swirling the stream of air, thereby providing for intensive mixing of fuel with air and for effective ignition of the resultant mixture. Discharger 4 is fabricated from alloy ЭИ435 .

Spark plug СД-96 is a non-detachable unit. It is radio-shielded and is provided with ceramic insulation. The spark plug is screwed into the flame igniter housing with an effort not exceeding 2.5 - 3 kg-m.

The starting atomizer (Fig.93) is a non-detachable centrifugal type. It consists of pipe union 1 and spray tip 2 rolled into the pipe union. Pipe union 1 is manufactured from steel IX18H9T. It has two diametrically opposed 2-mm dia. holes, connecting spray tip cavity A with fuel supply. Spray tip 2 is a nozzle accommodating the end plate of the swirl chamber. The nozzle is provided with two tangential, diametrically opposed 0.6-mm dia. orifices, a swirl chamber and a central, $0.6^{+0.025}$ mm outlet orifice. The nozzle is made of steel 4X14H14B2M.

The starting atomizers discharge fuel at a rate of 9 ± 0.8 lit /hr, with fuel pressure amounting to 2 kg/sq.cm.; when the fuel pressure is equal to 5 kg/sq.cm., the spray cone amounts to $65^{\circ}\pm5^{\circ}$.

Fuel is supplied to the spray tips through the holes in the starting atomizer pipe unions; after being swirled by the tangential holes of the spray tips, the fuel enters the swirl chambers and is discharged into the chambers of the flame igniters through the central outlet orifices of the nozzles.

The starting fuel system operates as follows (See Fig.89).

Current is supplied simultaneously to the starting fuel pump motor, to the coil of the magnetic valve solenoid, and to the flame igniter spark plugs. This causes core 4 (See Fig.90) with needle 8 to be drawn into the magnetic valve solenoid thereby supplying fuel into bush 19. The fuel delivered by the starting pump through magnetic valve filter 14 enters bush 19 and pressing back hemisphere 20 finds its way into the starting fuel manifold via the connecting pipe. From the starting fuel manifold the fuel flows into the starting atomizers whence it is injected into the chambers of the flame igniters through the central outlet holes of the spray tips. The flame torch, produced in the flame igniters penetrates through the pipe connections into the combustion chambers and ignites the main fuel-air mixture.

As soon as the solenoid coil is de-energized, spring 10 displaces needle 8 thereby cutting off fuel supply to the starting atomizers of the flame igniters. This causes return valve spring 21 to move plunger 22 with hemisphere 20 and to press the hemisphere against the end face of bush 19.

The magnetic valve needle and the return valve provide for adequate sealing, which does not allow the starting fuel to drip through the starting fuel system when the aircraft is parked or during engine operation and also prevents any combustion chamber gases from getting into the starting fuel system.

MAIN FUEL SYSTEM

The main fuel system provides for regulated supply of fuel to the engine at any of the operating conditions. Apart from this the main fuel system is used to control the compressor air blow-off band.

The main fuel system incorporates the following components: a fuel tank with booster pumps, engine booster pump ЦН-9 , fuel and oil unit 317A, regulating fuel pump HP-10A, a drain valve, a fuel manifold with main burners and connecting pipe lines.

The main fuel system may also incorporate pressure gauges measuring fuel pressures forward of booster pump ЦН-9 and main pump HP-10A, and also in the auxiliary fuel manifold. The main fuel system is also equipped with fuel pressure warning mechanism СД-3 .

The fuel tank complete with the booster pumps is installed on the aircraft.

FUEL BOOSTER PUMP ЦН-9

Fuel booster pump ЦН-9 is incorporated in the engine fuel system with the purpose of maintaining constant fuel pressure forward of the HP-10A and HP-11A pumps.

Booster pump ЦН-9 is a centrifugal type fitted with a constant pressure valve operating on the principle of throttling (retarding) the fuel flow at the pump outlet.

Booster pump ЦН-9 is connected into the fuel system in series with the booster pumps of the aircraft fuel tanks.

Specifications of Booster Pump ЦН-9

1. Type . . . . centrifugal, with constant pressure valve
2. Designation ЦН-9
3. Direction of rotation . . . . left-hand (looking from drive shaft end)
4. Maximum speed. . . . . 9000 r.p.m.
5. Absolute fuel pressure at pump inlet for altitudes of up to 20,000 m. . . 0.4 to 2.0 kg/sq.cm.
6. Pump output at 9000 r.p.m., and outlet fuel pressure of 1.6 to 2.4 kg/sq.cm., for altitudes of up to 20,000 m. . . . . 600 - 9500 lit /hr
7. Duty . . . . continuous
8. Pump weight . . . . not over 3200 gr.

7.04 lbs

Construction of Pump ЦН-9

Fuel booster pump ЦН-9 (Fig.94) is comprised of the centrifugal pump assembly and the constant pressure valve assembly. Both assemblies are arranged in a common housing.

The centrifugal pump assembly (Fig.95) consists of housing 1, pump cover 24, sealing cover 27, and impeller 20 with propeller 23, mounted on shaft 4. Housing 1 and covers 24 and 27 are cast of aluminium alloy АЛ5 and when mounted form the working cavity of the pump, which is a widening volute chamber, developing into a pump outlet connection.

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The cover is secured to the housing by five studs screwed into the housing. A packing gasket is fitted between the housing and the cover.

The central borings of the pump housing receive shaft 4 running in ball bearings 6 and 28. The shaft carries four-blade propeller 23 and fifteen-blade impeller 20. Shaft 4 has a shank with involute splines serving to couple it to the internal splines of the drive gear of the engine accessory gear box. The shaft drives the impeller through a key. The propeller face directed towards the impeller has two angular splines engaging the grooves provided in the impeller face and imparting rotary motion to the propeller. The impeller and the propeller are secured to the shaft by screw 21 locked with cotter pin 22. The shaft is held against axial displacement by ball bearing 6, press-fitted onto the shaft and secured by nut 5. The outer ring of the ball bearing is clamped by square cover 3, fastened to the housing by four screws 2. Ball bearing 28 is free-fitted into the housing and is closed by sealing cover 27. The sealing cover together with the pump cover form a diffuser at the fuel outlet from the impeller.

The shaft is furnished with two rubber packing cups 7 and 8 serving to prevent leakage of fuel from the pump into the accessory gear box, and of oil from the accessory gear box into the pump. The intercup space is connected to drainage pipe union 14 which drains off any fuel or oil penetrating through leaky joints.

To relieve ball bearing 28 of the axial stresses and packing cup 8 of fuel pressure, the impeller disc surface directed towards the bearing is provided with blades throwing fuel to the periphery; besides, four holes, drilled in the impeller disc connect the cavity before cup 8 to the fuel inlet cavity.

Ball bearing 6 is lubricated with oil supplied from the engine accessory gear box, while bearing 28 is lubricated with fuel.

The position of the impeller inside the pump working cavity depends on clearances "a" and "б", which are adjusted by selecting proper shims 9 and a proper gasket installed between the pump housing and the sealing cover.

The constant pressure valve assembly consisting of valve 10, membrane 13, spring 15, and cover 16, is mounted

into the boss provided on the side surface of the pump housing, opposite the outlet connection. The boss cavity is divided into four parts by three cross partitions. Two of the partitions have holes serving to receive the valve plates, while the third partition is provided with a hole receiving valve rod guiding bush 11 made of bronze.

The valve is a mushroom type having two plates. It is made hollow and has three ports on the taper surface, connecting the valve body to the rod. The valve rod is rigidly secured to the centre of membrane 13 with the help of washers 12 and a nut, locked with a cotter pin. The membrane edges are clamped between the flanges of the housing and cover 16 fastened to the housing by five studs. The valve is acted upon by spring 15 one end of which rests against tapered plate 19 and the other against nut 18. The nut has a square hole receiving the shank of adjusting screw 17. Rotation of the adjusting screw will cause the nut to shift along the axle thereby changing the tension of the spring and consequently the fuel pressure maintained by the constant pressure valve.

The spring cavity of the constant pressure valve is connected by pipe union 14 to the atmosphere through the engine vent system.

Fuel booster pump ЦН-9 is secured to the flange of the engine accessory gear box by five studs.

Operation of Booster Pump ЦН-9

(Fig.96)

Fuel from the aircraft tank is supplied via the pipe line to the blades of propeller 1. Rotation of shaft 3 causes the propeller to direct the fuel to impeller 2. The output of the propeller exceeds that of the impeller, as a result of which pressure head is created at the fuel inlet to the impeller, improving the operating conditions of the latter.

The propeller supplies fuel to the interblade spaces of the rotating impeller and further into the diffuser.

In the impeller and the diffuser, mechanical energy given out to the fuel, is transformed into potential energy of pressure. As a result, the fuel pressure increases.

From the diffuser the fuel is delivered into the volute and further into cavity A of constant pressure valve 4. The valve maintains a predetermined fuel pressure at the pump outlet.

In case fuel pressure in outlet connection б increases in excess of the value, set with the help of spring 6 adjusted by screw 7, membrane 5 deflects causing valve 4 to shift towards the spring and to partially close outlet connection "б" as a result of which fuel pressure in the connection will be reduced. This, in its turn, will cause the membrane and the valve to move in the reverse direction, which will result in an increase of fuel pressure in the outlet connection.

At high altitudes atmospheric pressure supplied into the spring cavity of the constant pressure valve drops. Membrane 5 sags towards the spring and shifts the valve to decrease fuel pressure in the outlet connection.

To safeguard the pump against excessive pressures which may result from sudden reduction in fuel consumption, the constant pressure valve cavity communicates with fuel return line through duct "a" and jet 8.

HP-10A FUEL PUMP

The HP-10A fuel regulating pump (Figs 97 and 98) is designed to supply metered amounts of fuel into the engine at starting and under any of the operating conditions.

Accordingly, the HP-10A pump incorporates a high pressure, variable displacement plunger pump, a centrifugal variable speed governor with a hydraulic decelerator and an acceleration valve, a throttle cock acting at the same time as a stop-cock, a fuel distributor, an acceleration control unit, and an interlocking contactor located on the hydraulic decelerator.

HP-10A Pump Specifications

1. Type . . . . plunger, variable displacement
2. Designation HP-10A
3. Number of plungers 7
4. Diameter of plungers . . . . 14 mm

5. Direction of rotation of pump rotor . . . . clockwise (looking from pump drive end)
6. Maximum speed of pump rotor . . . . $3565^{\pm}20$ r.p.m.
7. Fuel pressure at pump inlet . . . 1.6 to 2.6 kg/sq.cm.
8. Maximum permissible fuel pressure at pump outlet, in auxiliary pipe line . . . . . 80 kg/sq.cm.
9. Maximum pump output at pump rotor speed of 3500 r.p.m. and outlet fuel pressure of 80 kg/sq.cm. . . . . 4180^{+200} lit /hr
10. Engine speed is regulated automatically from . . . . $2620^{\pm}30$ r.p.m.
11. Weight of HP-10A pump . . . . . . not over 17.5 kg

Construction of HP-10A Pump

The HP-10A pump (Fig.99) is a single unit consisting of three housings: the pump housing with cover, the speed governor housing and the fuel distributor housing. The housings are cast of aluminium alloy.

Pump housing 13 with cover 19 accommodates a high pressure plunger pump, consisting of rotor 15, seven plungers 26, wobble plate 18 with radial-thrust ball bearing 17, steel ported member 14 and pump rotor drive shaft 22.

Steel rotor 15, made integral with the shank, runs in two bearings, one of which is a roller bearing and the other a friction bearing. The roller bearing is press-fitted into the pump housing cover. Friction bearing 29 is fabricated from copper-graphite alloy and is press-fitted into the housing.

Bored in the rotor at some angle to its axis are seven wells uniformly spaced round the circumference. The wells accommodate press-fitted bronze guide bushes 27. The central duct of the rotor is provided with splines serving for connection to rotor drive shaft 22. Press-fitted into the central duct bore is splined bush 24 designed to couple the pump rotor to automatic governor shaft 25. The splined bush is packed with a plug.

The central duct of the rotor communicates with the periphery through seven inclined ducts "a", which serve to supply fuel for lubrication and cooling of the rotor bearings and the wobble plate.

The rotor face rests on the fixed ported member press-fitted into the pump housing. The ported member has two semi-circular ports and a central hole. Corresponding semi-circular cutouts are provided in the pump housing. One of the semi-circular ports and the central hole of the ported member communicate with cavity A at the pump inlet, whereas the other semi-circular port is connected to a high pressure duct at the pump outlet.

To prevent fuel leakage along the rotor shank, the latter is fitted with rubber gland 23 mounted in the pump housing cover.

Steel chrome plated plungers 26 are ground to their respective guide bushes. The plunger faces directed towards the pump housing cover are given a spherical shape. Springs 28 force the plungers against the spherical surface of the cage of the radial-thrust ball bearing fitted into the wobble plate.

Wobble plate 18 has two holes, receiving pins 50, and a lug for connection to rod 30 of wobble plate servo-piston 31. The pins are press-fitted into the pump cover. Depending on the position of the servo-piston, the wobble plate can occupy various angular positions relative to the pump rotor axis. Screws 16 and 20, turned into the housing and the cover, serve to limit the angle of turn of the wobble plate.

As the surface of the wobble plate in the operating position is not perpendicular to the pump rotor axis, the plungers move reciprocally in their guide bushes during pump operation.

The pump rotor is driven by the fuel pump drive shaft mounted in the accessory gear box.

The automatic speed governor, accommodated in the housing, consists of the following main components: centrifugal transmitter 10, transmitter slide valve 8, spring 3, transmitter slide valve sleeve 7, wobble plate servo-piston 31, return servo-piston 32 connected to return slide valve 34, lever 35, and constant pressure valve 81 (IV – IV Section) maintaining constant fuel pressure at the valve outlet irrespective of

the fuel pressure built up by the fuel pump (this allows the components of the automatic speed governor to move at a constant speed, which ensures stable operation of the governor at various ratings).

The constant pressure valve is of the slide type. The slide valve ground to its guide bush is acted upon by a spring whose tension can be changed by fitting washers under the valve cap.

The side surface of the slide valve has some holes communicating with the central duct.

Fuel from the high-pressure duct of the HP-10A pump is supplied to the constant pressure valve through the holes in the slide valve guide bush. As soon as fuel pressure at the valve outlet exceeds the specified value (about 10 kg/sq.cm.), the slide valve will shift against the force of the spring and will partially close the holes in the guide bush thus reducing fuel supply to the valve; the excess fuel will be delivered to the low-pressure cavity via the central duct.

The centrifugal transmitter consists of fork 12 and two weights 11, capable of turning around their axes fastened in the fork. The shorter arms of the weights rest against the face of slide valve 8 through the medium of two needles 9.

When the fork rotates, the resultant centrifugal forces set apart the weights which shift the transmitter slide valve along its axis. The fork with the weights is driven by the pump rotor through governor drive shaft 25, its speed being equal to the speed of the pump rotor.

Transmitter slide valve 8 is ground to sleeve 7, which is ground to bush 6 press-fitted into the governor housing. The external surface of the transmitter slide valve carries two cylindrical bands, regulating fuel circulation in the servo-system.

The force acting on the transmitter slide valve from the centrifugal weight side, is equalized by spring 3 whose tension depends on the position of the engine control lever.

The transmitter slide valve spring tension starts changing only at a certain position of the engine control lever. This position of the lever corresponds to the beginning of automatic operation (the speed governor cuts into operation).

At a speed lower than that at which the governor starts to operate automatically, the tension of the transmitter slide valve spring is maintained constant and is always in excess of the force developed by the centrifugal weights. The speed at which the governor starts to operate automatically may be changed with the help of an adjusting screw. Slide valve sleeve 7 has some holes on the side surface, through which fuel at a constant pressure is supplied into the servo-piston cavities. The slide valve sleeve is connected to the return slide valve through the medium of lever 5. Return slide valve 34 is ground to bush 33, press-fitted into the governor housing, and is capable of axial movement. The surface of the return slide valve is provided with a cylindrical recess through which, at certain positions of the slide valve, fuel may be drained from or supplied into interpiston space Б.

One end of the return slide valve is coupled to the return servo-piston, while the other end is connected to the transmitter slide valve sleeve through lever 35.

Under the action of return lever 35 the transmitter slide valve sleeve can move axially (relative to the transmitter slide valve and the bush).

Effort is transmitted from the engine control lever to the transmitter slide valve spring, whose tension sets the automatic governor at the required speed, through the hydraulic decelerator, with the aid of lever 73 (IV -IV Section).

The hydraulic decelerator consists of rod 74 with piston 75, sliding bush 71, rack 70, and two springs 72 and 76. Rod 74 is provided with a central duct communicating with the periphery through two drilled passages, and with a recess receiving lever 73. The sliding bush is acted upon by spring 72 and is capable of moving along the rod in response to rack 70 connected to the engine control lever. Sliding along the rod the bush cuts off fuel drain through the hydraulic decelerator rod.

To adjust fuel drain cut-off by the angle of turn of the engine control lever, as well as the beginning of automatic operation of the governor, provision has been made for an adjusting device consisting of adjusting screw 67 and retaining bush 68. When the adjusting screw is rotated, threaded

bush 69 moves along the axle and actuates the sliding bush. Rotation of the retaining bush is transmitted through the adjusting screw, the hydraulic decelerator rod, and lever 73 to the transmitter slide valve spring, thereby changing the preset tension of the spring and consequently the speed at which the governor starts to operate automatically.

The adjusting screw is locked inside the retaining bush by two balls 65 acted upon by spring 66.

The hydraulic decelerator piston is acted upon by spring 76 on one side, and by fuel pressure supplied from the duct through the throttling unit on the other. Cavity B under the hydraulic decelerator piston communicates with the return line via the central duct in the rod. At stable engine speeds fuel supply into cavity B is equal to fuel return through the rod.

The position of the rod with piston depends on the angle of turn of the engine control lever, and consequently on the corresponding engine speed.

The engine maximum speed is limited and adjusted with the aid of adjusting screw 79, which restricts the travel of the rod with piston through stop 77. Turning in of the adjusting screw causes a reduction in the engine maximum speed, and vice versa.

The hydraulic decelerator system incorporates a contactor acting as an engine interlocking device. When moving to the right piston 75 shifts lever 78 away from the contactor by means of stop 77, thereby closing the circuit. Adjusting screw 80 serves to regulate the speed at which the contactor operates.

The screws regulating the maximum speed and the speed of contactor operation are locked by nuts and are fitted with caps.

Besides the automatic speed governor, described above, the governor housing accommodates a throttle cock, which is the main metering device, engine speed depending on the position of its needle.

The throttle cock (II - II Section) consists of needle 59 connected to the engine control lever, needle guide bush 60, adjusting knob 62, and low throttle slide valve 63. The throttle cock bronze needle has a specially profiled portion, providing for a required change in fuel supply depending on the angle of turn of the engine control lever (up to the engine speed at which the speed governor starts to operate automatically).

The non-operating portion of the needle is made in the form of a rack engaged with throttle cock shaft gear 64. The shaft, in its turn, is splined to the engine control lever.

The throttle cock needle has two fixed positions depending on the angle of turn of the engine control lever: the extreme left-hand position "Cut-Off" (СТОП) and the extreme right-hand position "Full Throttle" (ПОЛНЫЙ ГАЗ). Besides, the throttle cock needle may be set in an intermediate non-fixed position, corresponding to engine idling speed. Synchronization of engine control is rendered more convenient by specially shaped profiles of the throttle cock needle and the low throttle slide valve. The above feature allows maintaining the cock clear openings, which determine fuel consumption at low throttle, at a constant value, when the engine control lever is shifted within the range of 12 to 22°, from the "Cut-Off" (СТОП) position (the low throttle sector).

When the engine control lever is set in the "Cut-Off" (СТОП) position, the throttle cock acts as a stop-cock, cutting off fuel supply to the engine burners.

When the engine control lever is shifted to the "Low Throttle" (МАЛЫЙ ГАЗ) position, fuel supply is regulated by the low throttle slide valve incorporated in the throttle cock by-pass duct. Idling speed depends on the position of the slide valve. Regulation of idling speed is made possible by the use of a constant pressure drop valve, which provides for the required fuel consumption, with the low throttle duct clear opening remaining constant. The position of the low throttle slide valve which determines the duct clear opening depends on the position of screw 61 of adjusting knob 62. When the screw is turned in the clockwise direction the slide valve goes up thus making for increase of idling speed; rotation of the screw in the counter-clockwise direction will cause idling speed to drop.

Before the speed governor starts to operate automatically regulation of the engine speed is accomplished manually with the aid of the throttle cock.

The control of fuel supply into the engine at ratings below that at which the governor starts to operate automatically is accomplished with the help of the constant pressure drop valve which maintains constant fuel pressure difference upstream

and downstream of the throttle cock (about 10 kg/sq.cm.).

This arrangement provides for uniform fuel flow through the throttle cock depending on the position of the throttle cock needle.

The constant pressure drop valve (V – V Section) consists of slide valve 85 acted upon by spring 84, whose tension can be changed by fitting adjusting washers 82 under cap 83.

On the spring side the slide valve also takes up the pressure of fuel supplied through the central orifice of the throttle cock needle. On the other side, the slide valve is acted upon by fuel pressure upstream of the throttle cock. At stable engine speeds the slide valve is kept in a balanced position by the above forces.

The side surface of the slide valve is provided with cylindrical bands serving to regulate fuel drain from the servo-mechanism interpiston space and fuel supply under the servo-piston of the wobble plate.

The fuel distributor is designed for distributing fuel between the fuel manifolds. The fuel distributor is accommodated in housing 2.

Fuel distributor slide valve 1 is acted upon by spring 37, whose tension is adjusted by adjusting screw 36. As pressure above the distributor slide valve increases (which occurs when the throttle cock is being opened), slide valve 1 moves against the force of spring 37 and uncovers the ducts feeding fuel into the primary manifold, with pressure amounting to 5±1 kg/sq.cm., and then the ducts feeding fuel to the main manifold (at a pressure of 10±1 kg/sq.cm.). This arrangement makes it possible to feed the required amounts of fuel into the manifolds depending on the fuel pressure downstream of the throttle cock.

To ensure proper fuel delivery during engine acceleration, an acceleration valve is provided, which is enclosed in the fuel distributor housing.

The acceleration valve (I – I Section) is composed of the following main parts: slide valve 51, slide valve bush 52, membrane 53, spring 54, and adjusting screw 55. The slide valve provided with cylindrical bands is ground to the bush press-fitted into the fuel distributor housing. The membrane

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is acted upon by the spring which is adjusted with the aid of the adjusting screw; besides, the membrane takes up the pressure of air bled from the compressor eighth stage and corrected by the supply and bleeder jets. On the other side, the membrane cavity communicates with the atmosphere.

Fuel pressure upstream of the distributor slide valve forces the slide valve of the acceleration valve against the membrane.

At stable engine speeds the acceleration valve is cut off.

To ensure proper fuel metering during engine starting the HP-10A pump is fitted with a starter control unit which bypasses excess fuel from the section upstream of the fuel distributor, to the return line. The starter control unit consists of mushroom-type valve 48, valve seat 49, rod 47 with guide 46, membrane 45, spring 44, and adjusting screw 43. The valve is pressed against the seat by the spring, through the medium of the rod and the membrane. The spring tension is regulated by the adjusting screw. Air pressure, supplied from the compressor and corrected by the bleeder jet, acts on the membrane from the spring side. The other side of the membrane communicates with the vent system.

The jet supplies fuel from the pipe line running to the distributor, into the space under the valve. At an engine speed approximating or exceeding the idling speed, the pressure aft of the compressor increases to such a degree, that valve 48 closes and cuts off the starter control unit.

In view of the fact that fuel pressure in the engine fuel system drops at high altitude, the HP-10A fuel pump is furnished with a minimum pressure valve, which prevents a decrease of fuel consumption below the permissible value and thus provides for stable operation of the engine when the control lever is set within the low throttle sector, and also reduces engine acceleration during flight at high altitude (Fig.100).

By reference to Fig.100 it will be seen that at high altitude the idling speed rises first to the value at which the governor starts to operate automatically, and then to the r.p.m. exceeding the maximum speed of the engine. This occurs due to the fact that up to the speed at which the governor starts to operate automatically, the constant pressure drop valve maintains a constant fuel pressure difference at the

throttle cock, while air flow through the compressor decreases; the power required for rotating the compressor decreases too. Excess power delivered by the turbine will be used up to increase the engine speed.

When the governor starts to operate automatically, the engine speed will be maintained constant due to the fact that the governor will reduce gradually the output of the HP-10A pump until the minimum pressure valve starts to operate. From this moment on the engine speed will increase again.

With the minimum pressure valve cut off, engine acceleration would have been greater, for the wobble plate of the HP-10A pump would have come up against the minimum delivery stop causing the fuel pressure to grow.

Slide valve 41 (See Fig.99) of the minimum pressure valve is acted upon by the fuel pressure at the pump inlet and by spring 40 whose tension is regulated by adjusting washers 38 installed under valve cap 39. On the other side the slide valve takes the primary fuel pressure supplied through a special duct. The fuel is fed to the slide valve via the throttling unit which acts as a damper.

The slide valve is ground to bush 42, and has cylindrical bands on its surface serving to cut off fuel drain from under the wobble plate servo-piston.

The tension of spring 40 determines the primary fuel pressure and, consequently, the fuel consumption by the engine.

If fuel pressure in the primary system exceeds the tension of the minimum pressure valve spring, the slide valve cuts off fuel return.

As soon as the pressure in the primary system drops, the slide valve is forced by the spring to connect the cavity under the wobble plate servo-piston to the return line; this will cause the servo-piston to shift the wobble plate towards increased fuel supply.

For expelling the air which may enter the engine fuel system when the latter is being drained, the HP-10A pump is fitted with an air bleeder valve (III - III Section) consisting of ball 57 forced against the seat by spring 56. To expel the air, it is necessary to remove cap 58 and to press the valve ball off the seat, with the aircraft tank booster pump switched on.

The ball is pressed off with the aid of a special device, supplied with the engine.

Operation of HP-10A Fuel Pump

From fuel tank 47 fuel is delivered by booster pump ЦН-9 to the suction line of the HP-10A pump through the fine fuel filter of fuel-oil unit 48.

During rotation of pump rotor 2 (Fig.101) plungers 3 move reciprocally in their guides due to the oblique position of wobble plate 1. When the rotor makes half a turn the plungers draw fuel through the suction port of ported member 4; when the rotor runs through another half a turn the plungers force the fuel through the pressure port and into the high pressure line.

Fuel is fed at high pressure to throttle cock 9 via duct "a" and filter 5. When the throttle cock is open, fuel is directed via duct " б " to the fuel distributor, which distributes fuel between the primary and main burner systems depending on the fuel pressure downstream of the throttle cock.

Regulation of fuel supply into the engine at all ratings, except augmented rating, is accomplished by varying the plunger pump displacement which depends on the angle of inclination of wobble plate 1 (the latter determines the stroke of plungers).

The angle of inclination of the wobble plate is dependent on the position of servo-piston 22, controlled by centrifugal transmitter (governor) 23, slide valve 6 of the constant fuel pressure drop valve, and slide valve 15 of the acceleration valve.

Operation of Centrifugal Governor

At stable engine speeds the centrifugal force developed by the weights is balanced by spring 21 through the medium of slide valve 18. The spring tension depends on the position of the engine control lever. The bands of the transmitter slide valve are so positioned relative to the holes provided in sleeve 20, that fuel supplied into chambers A and Б creates a pressure difference which is necessary to keep servo-pistons 19 and 22 as well as the wobble plate in the balanced position. In this case ducts в, и, д are covered by return

slide valve 46, and interpiston cavity B communicates neither with fuel supply duct г , nor with low pressure fuel return cavity Г through duct " и " (in Fig.101 the system is shown in the initial position).

With the system in the balanced position, the transmitter slide valve occupies practically the same position relative to the sleeve, irrespective of the engine speed.

A change in the predetermined speed of the engine, for example, speed reduction due to different flight conditions, disturbs balance between the tension of transmitter slide valve spring 21 and the centrifugal forces developed by the weights. The transmitter slide valve will be forced by the spring to shift to the left, thereby increasing fuel supply into chamber Б , and its discharge from chamber A (Fig.102). As a result, servo-pistons 19 and 22 (See Fig.101) will move to the left, causing wobble plate 1 to increase its angle of inclination, thereby increasing the output of the plunger pump and fuel supply to the engine. Simultaneously with increase of the engine speed the centrifugal forces developed by the weights will increase, as a result of which the slide valve will start to move to the right; the servo-pistons will continue to shift to the left until the system regains its balance.

Return servo-piston 19 moving to the left aids the system in regaining the balanced position. On its travel to the left the return servo-piston actuates return lever 13, which displaces sleeve 20 to the left thereby reducing fuel circulation in servo-piston chambers A and Б .

If servo-pistons 19 and 22 were rigidly connected (with the volume of interpiston cavity В being constant) the sleeve holes would have been covered by the slide valve bands in a more leftward position and the system would have regained equilibrium at a speed less than the initial one, which would have resulted in unstable regulation. To provide for stable regulation and to maintain the preset engine speed at a constant value at varying flight conditions, servo-pistons 19 and 22 are connected through the medium of cavity B capable of changing its volume.

This arrangement allows wobble plate servo-piston 22 to occupy different positions at stable engine speeds thereby varying fuel supply, with the position of return servo-piston 19 and the tension of transmitter slide valve spring 21 unchanged.

The above movement of the servo-pistons will continue until return slide valve 46 connects interpiston cavity B with fuel delivery duct "e". From this moment interpiston cavity B will be filled with fuel, while the servo-pistons will move in the opposite directions – the wobble plate servo-piston will move to the left, thereby increasing the output of the plunger pump, whereas the return servo-piston will move to the right, towards its initial position, at which interpiston cavity B is disconnected from fuel delivery duct "e". As the return servo-piston is coupled to sleeve 20 through the medium of lever 13, the end of the adjustment cycle (at any position of the wobble plate servo-piston) will always correspond to one and the same position of the sleeve, and, consequently, of the transmitter slide valve. This provides for constant engine speed when the engine control lever is set in a fixed position.

The above is also true for the case of sudden increase of engine speed, the only difference being that the servo-pistons will shift to the right, and return slide valve 46 will connect interpiston cavity B with fuel return line running to low-pressure cavity Г. Fuel delivery to and its discharge from the interpiston cavity is accomplished by the return slide valve through a throttling unit-damper, reducing variations in engine speed during the regulation procedure.

The above case refers to automatic regulation of preset engine speed, with the engine control lever being somewhere between the speed at which the governor starts to operate automatically, and the maximum speed.

At a speed lower than the speed at which the governor starts to operate automatically, the tension of the transmitter slide valve spring always exceeds the forces developed by the centrifugal weights. As a result, the transmitter slide valve is shifted to the left; this might have caused the wobble plate servo-piston to move to the left too and to set the wobble plate in a position, corresponding to maximum fuel supply. To exclude this possibility, control of fuel supply into the engine is accomplished through the use of

constant pressure drop valve 6, whose spring 7 serves to create fuel pressure difference at the cock.

If, due to some reason, the engine speed is increased, with the position of the engine control lever unchanged, the fuel pressure difference at the throttle cock will exceed the specified value, and slide valve 6 will shift to the right. This will cause slide valve 6 to connect interpiston cavity B with fuel return duct "И", and high-pressure fuel will start to flow via duct "k" under the wobble plate servo-piston. As a result of pressure drop in the interpiston cavity and pressure increase under the servo-piston, the latter will shift to the right, thereby setting the wobble plate in a position corresponding to reduced fuel supply. This will cause a decrease of the engine speed. A drop in the output of the plunger pump will reduce the fuel pressure difference at the throttle cock to the specified value, and slide valve 6 will cover partially ducts "И" and "k" to provide for such pressure difference in the cavities of the wobble plate servo-piston, which is required for keeping the wobble plate in the new position.

At an engine speed exceeding the speed at which the governor starts to operate automatically, the fuel pressure difference at the throttle cock is below the value preset by the spring, therefore slide valve 6 is forced by spring 7 to the left, and the valve is cut out.

To by-pass fuel from high-pressure duct "k" into low-pressure cavity Г when the engine is cut off with the pump rotor still running, and the throttle cock closed, the slide valve has some holes for draining fuel when the pressure difference reaches 15 kg/sq.cm. In this case the constant pressure drop valve acts as a reducing valve.

Operation of Acceleration Valve

With the engine control lever quickly (within 1 – 2 sec) shifted towards speed increase, fuel supply into the engine is controlled by the acceleration valve together with the hydraulic decelerator. The function of the acceleration valve consists in limiting delivery of excess fuel during engine acceleration from idling speed to about 9500 r.p.m., while the hydraulic decelerator serves to regulate the speed with

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which the transmitter slide valve spring changes its tension to suit the engine speed set by the engine control lever (Fig.103).

Note: If, with the engine control lever set within the manual control range, engine speed turns to be equal to or in excess of the speed at which the governor starts to operate automatically, which occurs at high altitude, engine acceleration is controlled only by the hydraulic decelerator (the acceleration valve being cut out).

The speed with which the tension of the transmitter slide valve spring is changed, is regulated by throttling unit 12 (See Fig.101). It is so adjusted as to provide for normal shifting of the engine from one rating to another.

When the throttle cock is quickly opened, fuel pressure difference at the throttle cock is sharply reduced, which causes valve 6 to move to the left, thereby covering the respective ducts (See Fig.101). The servo-piston quickly shifts to increase the angle of inclination of the wobble plate; as a result, fuel pressure downstream of the throttle cock sharply rises. As this pressure rise affects slide valve 15 of the acceleration valve, the slide valve shifts to the right thereby uncovering ducts " H " and " X ", connecting cavity B to fuel drain line, and chamber A to high-pressure supply line; the wobble plate servo-piston will move to the right thereby reducing fuel supply into the engine. Acceleration of the engine will be accompanied by a rise in air pressure aft of the compressor; as this pressure affects the acceleration valve membrane, the slide valve will move to the left thereby covering ducts " X " and " X ".

The forces acting on the slide valve of the acceleration valve are so calculated as to provide for the required fuel supply to the engine, when the latter is being accelerated. When the engine control lever is shifted to another position, rack 10 will displace sliding bush 11 to the right and cover the holes in the rod. Fuel drain from under the hydraulic decelerator piston will stop, and the piston together with the rod will slowly move to the right. On its travel, the hydraulic decelerator rod will actuate lever 14 which will smoothly

change the tension of transmitter slide valve spring 21, so that it may suit the respective engine rating (corresponding to the position of the engine control lever).

The speed of this change is adjusted by changing the resistance of the throttling unit.

Operation of Starter Control Unit

The starter control unit provides for required fuel supply to the engine when the latter is being accelerated to idling speed.

The need for a starter control unit is dictated by discrepancy between actual fuel delivery change ensured by the HP-10A pump, and the fuel delivery change required by the engine at starting.

Fig.104 illustrates the nature of changes in actual and required fuel consumption during engine acceleration to idling speed.

By reference to Fig.104 it will be seen that during engine starting, the HP-10A pump, operating at the maximum angle of the wobble plate inclination until a pressure difference of about 10 kg/sq.cm. is created at the throttle cock, and the constant clear opening of the throttle cock, determined by the position of the low throttle slide valve, ensure fuel consumption far in excess of the required amount.

Delivery of great amount of excess fuel may result in overheating of the engine hot section components due to a sharp rise in gas temperature.

The starter control unit regulating fuel delivery at starting operates as follows.

The growing pressure of fuel downstream of the throttle cock increases the force acting on valve 48 (See Fig.99)which is pressed against seat 49 by spring 44. When the force acting on the valve from the fuel duct side overcomes the force of spring 44, valve 48 starts to by-pass some fuel from the high-pressure duct to the suction side of the HP-10A pump. As the engine speed increases, the air pressure supplied into the membrane cavity of the valve grows. This will result in an increase of the force acting on the valve from the membrane cavity side, and the valve will reduce the by-pass of fuel to the suction side of the pump. As soon as the engine reaches idling speed the valve comes up against its seat thereby cutting off fuel by-pass altogether.

FUEL MANIFOLD WITH MAIN BURNERS

Fuel is delivered to the main burners via the fuel manifold.

Specifications for Fuel Manifold with Main Burners

1. Fuel flow through fuel manifold and main burners, at pressure 46 kg/sq.cm. and temperature 25±3°C, with main duct partially throttled . . . . 2800±100 lit /hr
2. Variations in fuel flow through different main burners at pressure 46 kg/sq.cm. and temperature 25±3°C . . . . ±3 per cent
3. Fuel flow through fuel manifold and main burners at pressure 40 kg/sq.cm.and temperature 25±3°C . . . . 3950 – 4100 lit /hr
4. Variations in fuel flow through different main burners at pressure 40 kg/sq.cm. and temperature 25±3°C . . . . ±2 per cent
5. Fuel flow through low throttle (primary) manifold and main burners at pressure 10 kg/sq.cm. and temperature 25±3°C . . . . 250 – 265 lit /hr
6. Variations in fuel flow through different main burners at pressure 10 kg/sq.cm. and temperature 25±3°C . . . . ±6 per cent

The nature of changes in fuel flow through the fuel manifold and the main burners depending on the fuel pressure is illustrated in Fig.105.

Fuel Manifold Construction

The fuel manifold (Fig.106) comprises primary manifold 3 and main manifold 1. Primary manifold 3 consists of ten 4x6 mm dia. pipes, connecting the pipe unions of the burner primary fuel ducts and forming a closed ring. The lower pipe of the primary manifold is provided with a pipe union receiving the pipe, which connects the primary manifold to the drain valve; the upper pipe of the primary manifold carries a pipe union serving for fuel delivery to the manifold.

Main manifold 1 consists of an 8x10 mm dia.closed circular pipe, made up of two halves, and ten 4x6 mm dia. pipes, which connect the pipe unions of the burner main ducts to the circular pipe. The upper part of the main manifold circular pipe is furnished with a pipe union for fuel delivery into the manifold, whereas the lower part has a pipe union receiving the pipe which connects the main manifold to the drain valve.

The pipes are connected to the burners and to each other by means of threaded joints interlaid with rubber rings.

The fuel manifold pipes are fabricated from steel IX18H9T coated on the outside with yellow enamel A-6. The fuel manifold with the main burners is checked for tightness by kerosene at a pressure of 150 kg/sq.cm.

Main Burners

The main burners are designed to spray fuel supplied by the HP-10A fuel pump, into the engine combustion chambers.

Fuel is injected into the combustion chambers by ten main burners.

Specifications for Main Burner

1. Type . . . . open, centrifugal, duplex
2. Fuel flow through primary duct of burner at pressure 30 kg/sq.cm. and temperature 25±3°C . . . . 44±1 lit /hr
   Fuel flow through both ducts at pressure 40 kg/sq.cm. . 420±5.7 lit/hr
3. Spray cone of fuel delivered through primary duct at pressure 30 kg/sq.cm

and temperature $25\pm3^{\circ}C$ . . . . . . $110\pm5^{\circ}$
Spray cone of fuel delivered through both ducts at pressure 40 kg/sq.cm. . . . . $83\pm5^{\circ}$

4. Back pressure in main duct with fuel supplied through primary duct only, at fuel pressure 30 kg/sq.cm. and temperature $25\pm3^{\circ}C$ . . . . . . $0.45^{+0.05}$ kg/sq.cm.
5. Uniformity of spray (at distance 70 mm from nozzle) with fuel delivered through primary duct at pressure 30 kg/sq.cm. and temperature 15 - $35^{\circ}C$ . . . . not over ±15 per cent
   Uniformity of spray, with fuel delivered through both ducts at pressure 40 kg/sq.cm. . . not over ±15 per cent
6. Dry weight of main burner . . . . .266 gr

The nature of changes in fuel flow through the main burner ducts depending on fuel pressure before the burner is illustrated in Fig.107.

Main Burner Construction

The main burner (Fig.108) consists of the following parts: body 1, separating bush 2, swirler 7, filters 8, spray tip 4, nut 6, packing ring 5, and lock 3.

Steel body 1 has a flange for fastening the burner to the rear compressor housing, two pipe unions and two ducts for fuel delivery to the burner spray tip.

The spray tip (Fig.109) consists of primary nozzle 1, main nozzle 2 and plug 3.

The primary nozzle is made of steel XB5 and has two 0.35 mm dia. tangential holes, a swirl chamber, and a $2.2^{+0.02}$ mm dia. central outlet hole.

The main nozzle is manufactured from steel XB5 and has six 1-mm dia. tangential holes, uniformly spaced around the circumference, a swirl chamber, and a $2.2^{+0.02}$ mm dia. central outlet hole. The main nozzle is press-fitted into the primary

nozzle. Steel nut 6 (See Fig.108) has six 3-mm dia. holes, uniformly spaced round the circumference and serving to supply air to swirler 7. Besides, it has two $3.5^{+0.08}$ mm dia. holes for a special wrench serving to screw the nut onto the body. The nut is nitrated round the entire circumference to a depth of 0.06 to 0.18 mm.

Filter 8 is a gauze type. It consists of a steel casing and brass gauze No.016 (State Standard 6613-53). The side surface of the casing has three recesses uniformly spaced round the circumference and covered with gauze.

To obtain adequate fuel spray within a wide range of fuel consumption, the main burner is provided with two systems. The first system comprises the primary duct and the primary nozzle through which fuel is injected into the combustion chamber. Through the first system fuel flows at a pressure of 6 to 8 kg/sq.cm. which corresponds to the pressure built up at starting. The second system consists of the main duct and the main nozzle projecting into the swirl chamber of the primary nozzle. When fuel pressure in the primary manifold reaches 6 to 8 kg/sq.cm., the second system starts functioning.

The two swirl chambers allow the fuel supplied from the second system to be additionally swirled by the fuel delivered through the first system. This arrangement contributes to adequate atomization of fuel at the moment the second system starts to function. With the fuel distributor of the HP-10A pump fully open, the first and second systems operate in parallel.

The ducts of the first and second systems are divided by separating bush 2 (See Fig.108). Spray tip 4 is sealed in the body by copper tapered packing ring 5. The ring is tightened with the help of nut 6, which is secured by lock 3. Carbon formation on the primary nozzle and on the nut face is prevented by swirler 7 installed between the packing ring and the inner face of the nut. The swirler has eight tangential slots for passage of air which is delivered to the outlet surface of the nozzle. Air is supplied to the swirler through six holes provided in nut 6. The body pipe unions incorporate filters 8 safeguarding the burner spray tip against clogging. The filters may be removed from the burner for inspection without dismantling the burner from the engine. The finally assembled main burners

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are tested for fuel flow, spray cone, uniformity of spray, and for tightness.

The main burners are fully interchangeable and may be arranged on the fuel manifold without impairing its operation.

Afterburner Fuel Supply

The system of fuel supply into the engine at augmented rating provides for delivery of automatically metered amounts of fuel into the engine afterburner depending on the speed and altitude of flight.

The afterburner fuel system includes the HP-11A fuel pump, front and rear manifolds with fuel nozzles, and fuel pressure warning mechanism ДСД-2 providing for opening and closing of the jet nozzle shutters, when the afterburner is turned on and off respectively.

HP-11A FUEL PUMP

The HP-11A fuel pump is designed for delivery of automatically metered amounts of fuel into the engine operating at augmented rating.

Specifications for HP-11A Pump

1. Type . . . . variable displacement plunger type
2. Designation HP-11A
3. Number of plungers 9
4. Diameter of plunger . . . . .15 mm
5. Direction of rotation of pump rotor . . . . right-hand (if viewed from drive end)
6. Maximum speed of pump rotor . . . . 3565±20 r.p.m.
7. Fuel pressure at pump inlet . . . . 1.6 – 2.6 kg/sq.cm.
8. Maximum permissible fuel pressure at pump outlet . . . . 90 kg/sq.cm.

9. Maximum output at pump rotor speed 3565 r.p.m. . . . . . 3620 – 3740 lit./hr
10. Pump output at all ratings except augmented . . . . .300-600 lit./hr
11. D.C. voltage energizing solenoid . . . . .20– 26 V
12. Pump weight . . . . not over 14 kg

Construction of HP-11A Fuel Pump

The HP-11A fuel pump (Figs 110 and 111) is a variable displacement plunger type. It ensures automatic metering of fuel, delivered into the engine, depending on the altitude and speed of flight.

The cast aluminium housing and cover accommodate a high-pressure plunger pump, an afterburner cock, a fuel valve with a cut-off valve, a constant fuel pressure valve, a fuel by-pass valve, a solenoid valve controlling operation of the afterburner cock, and an interlocking device contactor.

Fuel delivery into the engine depending on the altitude and speed of flight is regulated by the barostat mounted on the pump housing flange.

The pumping unit of the HP-11A pump (Fig.112) is similar in design to that of the HP-10A pump, the only difference being that the HP-11A pump has nine plungers, 15 mm in diameter. Besides, the pump rotor is furnished with roller bearing 6 and wobble plate thrust ball bearing 10.

The angle of inclination of wobble plate 57, and, consequently, the pump output are changed by servo-piston 20 which is coupled to wobble plate 57 through the medium of rod 21. On one side the servo-piston is acted upon by springs 18 and 19, as well as by fuel pressure supplied from the high-pressure duct through jet 17 and the damper. On the other side the servo-piston is acted upon by the pressure of fuel delivered from the high-pressure duct. Fuel consumption depending on the altitude and speed of flight is controlled by the barostat (See the Graph presented in Fig.113). The barostat (III – III Section, Fig.112) consists of two housings 29 and 56, divided by flexible partition 32 carrying the support of lever 31. Spring 39 presses the lever against mushroom valve 38, preventing fuel drain from cavity A behind the wobble plate servo-piston. The force of spring 39 is opposed by aneroid 28, the fuel pressure supplied from cavity A, and the fuel pressure supplied from the high-pressure duct to the barostat through membrane 34 and piston 33, resting on lever 31 below. The piston is accommodated in eccentric bush 35. The place where the fuel pressure is applied to the lever may be changed by turning the eccentric bush.

A damper installed forward of the membrane safeguards the barostat against deleterious action of fuel pulsation which is likely to occur.

As the spring tension remains unchanged at various conditions of flight, fuel pressure in the high-pressure duct will be determined by the aneroid resilience which depends on the full pressure of the air admitted into the engine. Thus, the barostat utilizes the principle of direct dependence between the fuel pressure downstream of the pump and the altitude and speed of flight.

Barostat adjustment is carried out in compliance with the specifications, by using adjusting screw 40 of mushroom valve spring 39, and also by manipulating aneroid screw 41.

With the afterburner turned on, fuel supply into the engine is accomplished by opening the afterburner cock. The afterburner cock (II – II Section) comprises bronze needle 43. The needle has a specially shaped portion to provide for the required changes in fuel delivery when the cock is being opened, and cylindrical groove "a". With the afterburner cock closed, the cylindrical groove serves for draining fuel from cavity A, as a result of which the wobble plate is set in a position, corresponding to minimum fuel delivery (limited by screw 26).

The afterburner cock needle is connected with piston 44 and moves along steel guide bush 42.

The piston of the afterburner cock needle is acted upon by spring 45; on the other side it is affected by the fuel pressure supplied to the space below the piston from the high-pressure duct.

To ensure that the afterburner cock be open at a constant speed irrespective of the fuel pressure in the pump high-pressure duct, provision has been made for constant pressure valve 3, the tension of valve spring 2 determining the value of constant pressure aft of the valve.

The speed of afterburner cock opening is dependent on the capacity of throttling unit 25.

The afterburner cock is opened and closed by solenoid valve 1, controlling fuel delivery to the space below the piston of the afterburner cock needle.

The afterburner cock system incorporates a contactor serving the interlocking devices. When the afterburner cock piston reaches the extreme position (See II – II Section), which indicates that the afterburner cock is fully open, rod 47 cuts in contactor 46 thereby closing the electric circuit. The contactor is set to operate within 0.9 to 1.0 of the augmented rating.

Fuel valve 50 located at the pump outlet, regulates fuel supply into the engine at augmented rating depending on the fuel pressure set by the barostat. The valve has a specially shaped portion fitting into the metering port of valve bush 60. Clear openings of the valve depend on the position of the valve shaped portion relative to the metering port of the bush.

Valve travel for opening, and consequently fuel feed into the engine depend on the fuel pressure before the valve and on the force of spring 49, whose tension may be changed by manipulating adjusting screw 48.

To reduce the fuel pressure which tends to rise sharply in the high-pressure duct due to closing of the afterburner cock, the HP-11A pump is furnished with a by-pass valve, connecting the ducts arranged upstream and downstream of the afterburner cock with the return line.

The by-pass valve consists of slide valve 23 loaded with spring 24, whose tension determines the beginning of fuel by-pass. The slide valve is acted upon by the fuel pressure upstream of the afterburner cock and by the fuel pressure downstream of the afterburner cock from the spring side. With the afterburner cock open, the difference between the fuel pressures upstream and downstream of the afterburner cock is too small, therefore spring 24 forces the slide valve to cut off fuel by-pass. When the afterburner cock is being closed, the fuel pressure shifts the slide valve against the spring thereby by-passing fuel into the low-pressure cavity.

To eliminate fuel leakage through the afterburner fuel nozzles (when the engine is at a standstill) cut-off poppet valve 52 is installed upstream of the fuel cock. The valve is loaded with spring 59 resting on plug 58. The valve is prevented from cocking by guiding dowel 53 press-fitted into the plug and guiding the valve motion. The working surface of the valve rests on seat 51 thereby preventing fuel leakage.

Any air getting into the pump when oil is drained from the aircraft tanks, or when the pipe lines are detached, is discharged through pipe union B furnished with a ball valve. Ball 55 is acted upon by spring 54, which presses it against the seat thereby preventing fuel flow from the pump. To evacuate the air, it is necessary to switch on the fuel tank booster pump and to depress the ball with a special device supplied with the engine.

The HP-11A fuel pump is installed on the accessory gear box flange(at the left-hand side of the engine) with the help of a quick-change joint.

Operation of HP-11A Fuel Pump

The HP-11A fuel pump is connected to the fuel system of the engine in parallel with the HP-10A pump (See Fig.101).

The pumping unit of the HP-11A pump operates on the same principle as the HP-10A pump.

Fuel from the high-pressure duct is delivered to afterburner cock 36, into cavity Б of servo-piston 26, to membrane (aneroid) 32, barostat mushroom valve 28, and to constant pressure valve 27.

With the afterburner cock closed, cavity Ж aft of the wobble plate servo-piston is connected to the low-pressure cavity through duct "p", jet "c",and cylindrical groove "m", provided in the afterburner cock. Due to this the wobble plate is set in a position corresponding to minimum fuel delivery and located by screw 24.

When the afterburner is turned on, the electric circuit of the solenoid valve closes, causing valve 38 to cut off fuel drain via duct Φ . Fuel pressurized to a value, set by constant pressure valve 27, will be supplied below afterburner cock piston 37 thereby shifting it to the right. The speed of the afterburner cock travel depends on the capacity of throttling unit 35. When the afterburner cock is open to capacity it cuts in contactor 41 of the interlooking device disconnecting the ignition system in the afterburner.

While travelling to the right, the afterburner cock will cut off fuel drain from cavity Ж aft of the wobble plate piston, and the latter will move to the left to increase fuel delivery. The speed of the wobble plate motion depends on the capacity of jet "c" and damper "ж". Simultaneously, the afterburner cock will direct fuel through cut-off valve 44 to fuel valve 43.

The fuel pressure will cause the fuel valve to shift to the right thereby supplying fuel into afterburner manifolds 45.

The servo-piston travel will continue until the plunger pump output is sufficient to meet the required fuel consumption as set by the barostat.

Changes in the conditions of flight, for instance, increase of altitude, or reduction of speed, will cause air pressure in barostat aneroid chamber K to drop; aneroid 34, tending to expand, will act on lever 31 with a greater force thereby relieving spring 29 of valve 28, and increasing fuel by-pass from cavity Ж aft of the wobble plate piston. The wobble plate servo-piston will move to the right. The output of the plunger pump will decrease, causing a reduction of fuel pressure in high-pressure duct "n", and consequently of fuel delivery to the afterburner manifold. The fuel feed will be reduced until a state of balance sets up in the barostat again.

When the afterburner is turned off, the solenoid valve circuit will open, valve 38 will open the fuel drain line from cavities Ж and M of the afterburner cock piston, and the afterburner cock will be closed by spring 40. The cylindrical groove, provided in the afterburner cock, will connect cavity Ж to fuel drain line, and the servo-piston with the wobble plate will shift in a position, corresponding to minimum fuel delivery.

With the afterburner cock being closed, the difference between fuel pressures upstream and downstream of the afterburner cock will increase, causing out-off valve 44 to open and to by-pass fuel from the high-pressure duct, thus safeguarding the high-pressure ducts against excessive stresses.

Cooling of the pumping unit of the plunger pump and lubrication of the bearings during pump operation are accomplished by the fuel circulating through the pump. When the pump rotor spins, fuel flows via central drilling O in the ported member to cavity Д of the rotor whence it is delivered by centrifugal forces via oblique ducts H of rotor 25 into the interrotor cavity. From this cavity the fuel is directed to the suction side of the pump through jet M.

FRONT AFTERBURNER MANIFOLD

The front afterburner manifold is designed for fuel delivery to the afterburner fuel nozzles.

The front afterburner manifold (Fig.114) is a non-detachable structure comprising a closed circular pipe, 8x10 mm in diameter, with ten welded uniformly spaced pipes carrying the fuel nozzle bodies, and a fuel supply pipe.

The fuel supply pipe has a sleeve at the end which serves to connect the pipe line delivering fuel from the HP-1M pump to the manifold. The components of the front afterburner manifold are manufactured from steel IX18H9T.

Rolled into the fuel nozzle bodies are fuel nozzles which atomize and inject fuel into the afterburner, at an angle of 45^{o} to the gas stream. The fuel nozzles are of the centrifugal, single duct type. The fuel nozzle (Fig.115) consists of atomizer 1, plug 2 and retainer 3.

Atomizer 1 is made of steel X10C2M and has three 0.7-mm diameter tangential holes evenly spaced round the circumference, a swirl chamber and a $2.2^{+0.01}$ mm diameter centrifugal outlet orifice. Press-fitted into atomizer 1 are plug 2 and retainer 3, preventing the plug from movement.

Fuel from the front manifold is fed to the fuel nozzles and, after being swirled in passing through the tangential holes and the swirl chambers, is injected into the afterburner through the central orifices.

The amount of fuel delivered through the fuel nozzles of the front manifold at a pressure of 40 kg/sq.cm., and a temperature of 25$\pm$10^{o}C is within 1500 to 1570 lit /hr, while discrepancy in fuel flow does not exceed $\pm$3 per cent.

REAR AFTERBURNER MANIFOLD

The rear manifold serves to feed fuel to the starting and main fuel nozzles of the afterburner.

The rear afterburner manifold (Fig.116) being similar in design to the front manifold, differs from the latter in that it has only five main fuel nozzles. Besides, it is furnished with starting fuel nozzles supplying fuel to the centre of the afterburner where spark plug СП-02 is located.

The amount of fuel delivered through the rear manifold fuel nozzles at a pressure of 40 kg/sq.cm., and a temperature of 25$\pm$10^{o}C is within 1050 to 1100 lit /hr, whereas discrepancy in fuel flow does not exceed $\pm$3 per cent.

ENGINE VENT AND DRAIN SYSTEMS

The vent system serves to prevent the drainage oavities from being overfilled with fuel leaking through the packed joints of the accessory drives, as well as to remove excess fuel and oil from inside the engine.

The drain system is designed for discharging fuel from the fuel manifold (the main manifold and the primary manifold). Fuel is drained with the purpose of preventing combustion outside the combustion chambers at starting or after the engine is shut off, as it may cause overheating of individual engine parts and result in abnormal operation of the engine.

The vent and drain systems are comprised of the following main parts and units: a drain valve, a tee-piece, drain cocks, a drainage tank, fuel sumps and pipe lines.

The drain valve is designed for automatic drainage of fuel from the fuel manifold after the engine is shut off.

The drain valve (Fig.117) consists of the following parts: housing 2, cover 1, cup 3, valve 6, spring 4, valve stop 5, filters 7, and bush 8.

Housing 2 is manufactured from duraluminum. It accommodates the parts of the drain valve. On the outside the housing carries three pipe unions serving for connection of pipe lines. Pipe union "a" is connected to the primary manifold; pipe union "б" communioates with the main manifold; pipe union "B" is connected to the drainage tank through the drain tee-piece.

Cover 1 is fabricated from steel and is furnished with a pipe union and a stop. Fuel from the cavity forward of the HP-10A pump distributing valve is delivered to pipe union "a" via the pipe line. The stop limits the travel of the valve and cup to the left.

Press-fitted into the pipe unions of housing 2 and cover 1 are filters 7, safeguarding the valve against clogging.

Filter 7 consists of a bush and a gauze. The gauze is soldered to the bush face. Valve 6 is comprised of a seat and a hemisphere hinged to the valve seat with the help of a dowel. The hemisphere is capable of swinging around the dowel which permits it to occupy a proper position relative to the valve stop during drain valve operation. Valve stop 5 consists of two steel bushes press-fitted into housing 2. Inner duct "г" of the stop inner bush serves to drain fuel from the primary manifold, while fuel from the main manifold is discharged via outer circular groove "g" running between the housing and the outer bush of the valve stop. The face of the valve stop as well as the sealing surface of the valve proper are ground to each other. With the engine running, rubber cup 3 and valve 6 are forced against spring 4 to the extreme right-hand position by the fuel pressure supplied from the cavity forward of the HP-10A pump distributing valve; in this position the rubber cup and the valve cut off fuel drain from the fuel manifold.

After the engine stoppage, fuel pressure on the valve cup is relieved and the spring forces the valve to the extreme left-hand position, thereby connecting the fuel manifold to the drain line.

To ensure free travel of valve 6 and cup 3 tending to connect the fuel manifolds with the drain line(to avoid hydraulic lock), when the stop-cock is being closed, bush 8 and housing 2 are provided with ducts affording communication between the cavity under the cup and the drain cavity for the primary manifold. These ducts serve to drain fuel expelled by the moving parts of the drain valve when the engine is stopped.

For limiting fuel supply into the primary manifold from the cavity located forward of the HP-10A pump distributing valve, when the engine is running, the duct in bush 8 is made in the form of a 0.5-mm diameter jet.

The drain valve is secured by two bolts to a steel bracket mounted on the lower portion of the compressor rear housing flange.

The tee-piece (Fig.118) consists of steel adapter 1, union nuts 2, and locking rings 3.

The side surfaces of adapter 1 carry one pipe union and three nipples. The lower part of the adapter is fitted with a flange. When the engine is installed on the aircraft a pipe is secured to the adapter flange, through which fuel is discharged to the atmosphere.

The adapter nipples mount union nuts 2 held in place by locking rings 3. The locking rings are press-fitted into the circular grooves formed by the semi-circular grooves in the adapter nipples and in the union nuts. The adapter is provided with three ducts.

Duct "д" connects pipe union "a" with nipple "б". Pipe union "a" is connected to the drainage tank through a pipe. Nipple "б" is connected to the drain valve with the help of a union nut. Nipples "в" and "г" mount drain cocks secured by means of union nuts.

The drainage tank (Fig.119) receives fuel flowing from the vent and drain systems, and discharges it beyond the jet nozzle.

The drainage tank is a welded structure made up of upper half 9 and lower half 10 fabricated from 1.8-mm thick aluminium alloy AMцМ . Welded to the upper and lower halves are two bearers 11 and six pipe unions made of aluminium alloy AMгМ . The drainage tank is secured to the brackets through the holes provided in the bearers. Pipe unions 3 and 6 serve for delivering fuel into and out of the drainage tank. Depending on whether the drainage tank is installed on the right-hand or left-hand engine, one of these pipe unions is used for draining fuel into the drainage tank, whereas the other serves to discharge fuel from the drainage tank via the pipe line and beyond the afterburner adjustable jet nozzle. Reserve pipe union 4 is stopped with a plug.

To ensure complete drainage of fuel from the drainage tank, pipe unions 3, 4 and 6 are provided with pipes 12, which are arranged in such a manner that fuel can drain from the lowest point of the tank. Compressed air is supplied into the drainage tank from the compressor rear housing through pipe unions 1 and 8. Depending on whether the drainage tank is arranged on the right-hand or left-hand engine, one of these pipe unions is used for compressed air supply, the other being stopped with a plug. Air delivery is via a pipe furnished with a 1-mm diameter jet. The drainage tank communicates with the atmosphere through pipe union 7. To provide for proper venting of the drainage tank irrespective of its installation on the right-hand or left-hand engine, pipe union 7 is fitted with 4x6 mm diameter pipe 5, having an additional 4-mm diameter hole located near the pipe union.

The pipe is secured by clamp 2, welded to the upper half of the drainage tank. The outer pipe connects pipe union 7 to the pipe serving to discharge fuel from the drainage tank. The drainage tank is checked for tightness by air pressure of 0.5 kg/sq.cm. maintained for 5 min. The tank is coated with black enamel A-12. It is mounted in the lower part of the compressor housing, on four brackets secured by the bolts of the lower joint.

The drain cock (Fig.120) comprises aluminium alloy body 2 with three pipe unions and two lugs. Accommodated inside the body is steel rod 3. The rod is grooved at one end to receive rubber packing ring 1, the other end carrying thrust bush 4 secured by dowel 6. The bush takes the thrust of spring 11 tending to shift the rod to the right.

Packing ring 1 rests against the cock body thereby sealing the outlet hole of pipe union "a". The other end of the spring bears against washer 7. Fitted between the washer and the cock body is rubber packing ring 8 preventing seepage of fuel and oil from the cock pipe union cavity into the spring cavity, and consequently into the aircraft engine compartment. The cock body lugs mount cam 5 fastened by dowel 10. Placed between the cam and the body lugs are plate springs 9, holding the cam in a definite position. Pipe unions "a" connect the drain cocks via the pipe lines with the compressor inlet housing pan and with the oil tank of fuel-oil unit 317A. Pipe unions "б" and "в" afford communication between the drain cocks on the one hand, and the drainage pipes and the tee-piece on the other. The drain cocks serve to discharge oil from the pan of the compressor inlet housing and from the oil tank of fuel-oil unit 317A.

At the same time, the side holes of the drain cock pipe unions serve to drain fuel from all units irrespective of the position of the drain cock rod.

The drain cocks are opened by turning the cam through 90°, which causes the rod to overcome the force of the spring and to move to the left thereby directing oil from pipe union "a" through the drain cock and into the tee-piece,whence it is drained through the hole in the tee-piece flange and is further discharged under the aircraft fuselage via a pipe.

Construction of the fuel sumps is described in Chapter IV "Afterburner".

Drainage of Fuel and Oil

The fuel leaking through the glands of the drive shafts of the HP-10A, HP-11A and ЦН-9 pumps (See Fig.101), through the clearances of the drive rods of the HP-10A and HP-11A pump limit switches, through the cup of the air blow-off control mechanism rod, the fuel forced out of the air blow-off control mechanism cylinder when the air blow-off band is being closed, as well as the oil seeping from the accessory gear box through the glands of the HP-10A, HP-11A and ЦН-9 pump drives, are directed into the common drainage pipe to be discharged to the atmosphere through the drain cocks and the tee-piece.

The fuel leaking along the rod of the HP-10A pump acceleration control unit valve is discharged directly to the atmosphere.

The fuel drained from the fuel sump at the nozzle assembly-to-diffuser joint, from the nozzle assemblies of the first and second stages, as well as from the aft part of the compressor rear housing, is directed to the pipe unions receiving the aircraft pipe lines. The flame igniters and the front part of the compressor rear housing are drained through a pipe and a flange.

Drainage of fuel from the fuel sump arranged at the afterburner shell-to-diffuser joint, from the afterburner pipe with diffuser, from the afterburner and the ejector, is effected through the pipe unions receiving the aircraft pipe lines.

When the engine is stopped, fuel from the main fuel manifold and from the primary manifold is drained into the drainage tank via the drain cock and the drilled passage in the tee-piece.

During the next engine starting the fuel is forced out of the drainage tank and into the atmosphere by compressed air (P_2) supplied from the compressor into the drainage tank.

PIPE LINES OF ENGINE FUEL, OIL, AND AIR SYSTEMS

The pipe lines of the engine fuel, oil, and air systems are fabricated from steel 20A, except for the pipe lines of the high-pressure fuel system, which are manufactured from steel IX18H9T.

The diameters of the pipe lines vary from 4x6 mm to 32x34 mm.

The pipe lines of the fuel system are coated with yellow enamel A-6, the pipe lines of the oil system with brown enamel A-8, and the pipe lines of the air system with black enamel A-12.

The pipes subjected to high temperatures are not painted.

To provide for rigid attachment of the pipe lines and to prevent vibration, the pipes are secured to the engine by means of yokes (Fig.121) installed on the engine; besides, the pipes are secured to each other by aluminium clamps (Fig.122).

The following types of joints are employed on the engine pipe lines:

(1) a standard spherical joint installed in places subject to high temperatures;

(2) a nipple joint with type AM rubber packing (Fig.123) used primarily in locations with normal temperatures;

(3) a nipple joint sealed with aluminium or copper rings (Fig.124) used in places subject to high temperatures;

(4) flanged joints packed with rubber gaskets (Fig.125);

(5) a telescopic joint (Fig.126);

(6) a nipple joint of "Parker" type (Fig.127);

(7) a durite joint (Fig.128);

(8) a nipple joint (Fig.129).

Chapter X

ENGINE ELECTRIC EQUIPMENT

The function of the engine electric equipment is to provide for engine starting, to energize the units installed on the aircraft and on the engine, to cut in the maximum and the augmented ratings, and to provide the means of checking engine operation. Besides, the engine electric equipment includes the system of interlocking devices safeguarding the engine and its units against operation at abnormal conditions.

Depending on their function individual equipments of the electric system are divided into power sources, starting units, units cutting in maximum and augmented ratings, interlocking devices and measuring instruments.

This Chapter deals with the description of engine electric equipment operating on 24 - 48 V.

Particulars relating to electric equipment operating on 24 V only are referred to at the end of this Chapter.

POWER SOURCES

Starter-generator ГСР-СТ-6000А rated at 6000 W and 30 V constitutes the main power source.

Starter-generator ГСР-СТ-6000А is a protected six-pole D.C. machine with enclosed bearings and three commutating poles. The unit is driven through a reduction gear with a ratio of 1.25; direction of rotation - counter-clockwise(if observed from the drive end). The machine is force-cooled by ram air.

When operating as a generator, the machine is shunt-excited and functions in combination with voltage regulator P-25A, differential-minimum relay ДМР-400, stabilizing transformer ТГ, and ballast resistor БС-6000.

When the starter-generator is employed as a power source for starting the other engine, it operates as a generator with differential excitation, delivering current from terminal CT.

The units operating together with the starter-generator, serve:

(a) to stabilize voltage supplied to the aircraft mains, when the starter-generator speed varies;

(b) to safeguard the storage battery against discharge current at low speed or at parking;

(c) to ensure uniform loading of the two generators operating in parallel.

Specifications for Starter-Generator ГСР-СТ-6000А

Weight . . . . 22 kg

A. Generator Duty

Power (at 30 V) 6000W
Rated voltage . . . . .28.5 V
Rated loading current . . . . .200 A
Operating speed range . . . . .4000 to 9000 r.p.m.
Maximum current maintained during 1 min (with generator speed amounting to 5000 – 8000 r.p.m.) . . . . .300 A
Maximum current maintained during 10 sec.(with generator speed amounting to 6000 – 8000 r.p.m.). . . . . 400 A
Maximum permissible loading current, with generator being not cooled for 30 min. . . . . . . 60 A
Amount of air required for cooling . . . . .not less than 75 cu.dm /sec.

B. Starter Duty

(a) With voltage across terminals amounting to 21 V, compound excitation, and braking torque of 1.8 kg-m, starter should develop speed of not less than . . . . 1400 r.p.m.
Consumed current . . . . not over 200 A

(b) With voltage across terminals amounting to 21 V, series excitation and braking torque of 1.1 kg-m, starter should develop speed of not less than . . . . .2400 r.p.m.
Consumed current . . . . not over 200 A

The starter-generator is connected in parallel with the aircraft storage batteries, providing for autonomous starting of the engine.

ENGINE STARTING EQUIPMENT

The engine starting equipment comprises the following units:

(1) The starter-generator with starting equipment.

(2) Booster coil unit КП-21БІМ with four spark plugs СД-96.

(3) Electric motor МУ-102А driving starting gasoline pump ППР-10-9Д.

(4) A magnetic valve of the starting fuel system.

(5) A magnetic valve closing the air blow-off band.

Starter-Generator with Starting Equipment

When the engine is being started, the starter-generator (Fig.130) operates as an electric motor serving to accelerate the engine compressor till the engine starts to run independently.

When the starter-generator operates as a starter, two excitation windings are employed: parallel (shunt) and series.

At the beginning of the engine starting period the starter-generator runs on compound excitation. As the speed of rotation

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increases, the shunt winging is disconnected, only series winding being employed to the very end of the starting period.

The starting equipment includes:

(1) Starting box ПКС-6000И.

(2) Storage battery change-over box КПА-2.

(3) Storage battery change-over relay РПА-200И.

(4) Timer АВ-5А.

(5) Two relays РП-2, three relays РП-3 and one relay РЛ-20Г.

The equipment listed above is installed on the aircraft and serves the purpose of starting both engines.

Starting Box

Starting box ПКС-6000И receives the electric signals produced by the timer, and, by employing a system of relays and contactors, controls the starting units of both engines.

The starting box accommodates the following equipment: seven relays РЛ-20Г (changing over the starter shunt winding, changing over the generator shunt winding, switching on the ignition system, disconnecting the starter shunt winding); five relays РП-3 (starting the engine in air, changing over the storage batteries); two relays РП-6 (changing over the electric system to be energized from the starter-generator of the running engine); two contactors КМ-50Д (switching on the starter); three contactors КМ-200Д (shunting the starting resistor, disconnecting the starter circuits from the storage batteries when starting is accomplished by the use of the starter-generator of the running engine). The box also incorporates a starting resistor rated at 0.28 ohm.

On the outside, the box is furnished with bolt terminals serving to connect the wires running from the starter-generator, and with a plug connector receiving the control circuits.

Timer

Timer АВ-5А (Fig.131) provides for automatic functioning of the engine starting equipment.

By employing the starting box, the timer switches on and off the starting units in strict succession and at definite intervals.

The timer employs electric motor Д5-ТР whose speed is maintained at a constant value by a centrifugal governor. The electric motor is fitted with a magnetic braking clutch, which prevents rotation of the engine rotor after the power supply is cut off, thereby providing for a definite initial position of the rotor.

The motor torque is transmitted to the reduction gear, whose axle carries five profiled cams controlling limit switches КВ-6 connected to the control circuit of starting box ПКС-6000И.

The limit switches are set to operate at the following intervals after button "Starting" (ЗАПУСК) is pressed:

1st limit switch . . . . 0.4±0.2 sec.

2nd limit switch . . . . 0.9±0.1 sec.

3rd limit switch . . . . 2.5±0.2 sec.

4th limit switch . . . . 16.5±0.3 sec.

5th limit switch . . . . 8.5±0.3 sec.

The complete cycle of operation of timer АВ-5А is 31.5±0.5 sec.(at supply voltage 24V and ambient air temperature 20±5°C).

Voltage is supplied to the limit switches via two relays РП-3 accommodated in the timer housing.

Booster Coil Unit with Spark Plugs

Specifications

(1) Kind of current . . . . D.C.

(2) Supply voltage across unit terminals:

(a) when starting on ground . . . . 12 to 28.6 V

(b) when starting during flight . . . . . 20 to 28.6 V

(3) Current in coil primary winding (as indicated by ammeter of ПМ-70 type) at supply voltage of 24^{+1}V . . . . $2^{+0.25}_{-0.4}$ A

Note: The booster coil unit should deliver current to a three-electrode needle discharger with a spark gap of 6 mm and a shunt resistor rated at 1 megohm

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increases, the shunt winging is disconnected, only series winding being employed to the very end of the starting period.

The starting equipment includes:

(1) Starting box ПКС-6000И.

(2) Storage battery change-over box КПА-2.

(3) Storage battery change-over relay РПА-200М.

(4) Timer АВ-5А.

(5) Two relays РП-2, three relays РП-3 and one relay РЛ-20Г.

The equipment listed above is installed on the aircraft and serves the purpose of starting both engines.

Starting Box

Starting box ПКС-6000И receives the electric signals produced by the timer, and, by employing a system of relays and contactors, controls the starting units of both engines.

The starting box accommodates the following equipment: seven relays РЛ-20Г (changing over the starter shunt winding, changing over the generator shunt winding, switching on the ignition system, disconnecting the starter shunt winding); five relays РП-3 (starting the engine in air, changing over the storage batteries); two relays РП-6 (changing over the electric system to be energized from the starter-generator of the running engine); two contactors КМ-50Д (switching on the starter); three contactors КМ-200Д (shunting the starting resistor, disconnecting the starter circuits from the storage batteries when starting is accomplished by the use of the starter-generator of the running engine). The box also incorporates a starting resistor rated at 0.28 ohm.

On the outside, the box is furnished with bolt terminals serving to connect the wires running from the starter-generator, and with a plug connector receiving the control circuits.

Timer

Timer АВ-5А (Fig.131) provides for automatic functioning of the engine starting equipment.

By employing the starting box, the timer switches on and off the starting units in strict succession and at definite intervals.

The timer employs electric motor Д5-ТР whose speed is maintained at a constant value by a centrifugal governor. The electric motor is fitted with a magnetic braking clutch, which prevents rotation of the engine rotor after the power supply is cut off, thereby providing for a definite initial position of the rotor.

The motor torque is transmitted to the reduction gear, whose axle carries five profiled cams controlling limit switches КВ-6 connected to the control circuit of starting box ПКС-6000И.

The limit switches are set to operate at the following intervals after button "Starting" (ЗАПУСК) is pressed:

1st limit switch	0.4 ± 0.2 sec.
2nd limit switch	0.9 ± 0.1 sec.
3rd limit switch	2.5 ± 0.2 sec.
4th limit switch	16.5 ± 0.3 sec.
5th limit switch	8.5 ± 0.3 sec.

The complete cycle of operation of timer АВ-5А is 31.5 ± 0.5 sec.(at supply voltage 24V and ambient air temperature $20 \pm 5^{\circ}C$).

Voltage is supplied to the limit switches via two relays РП-3 accommodated in the timer housing.

Booster Coil Unit with Spark Plugs

Specifications

(1) Kind of current . . . . D.C.

(2) Supply voltage across unit terminals:

(a) when starting on ground . . . . 12 to 28.6 V

(b) when starting during flight . . . . . 20 to 28.6 V

(3) Current in coil primary winding (as indicated by ammeter of ПМ-70 type) at supply voltage of 24^{+1}V . . . . $2^{+0.25}_{-0.4}$ A

Note: The booster coil unit should deliver current to a three-electrode needle discharger with a spark gap of 6 mm and a shunt resistor rated at 1 megohm and connected in parallel with the discharger electrodes.

High voltage for energizing the spark plugs is supplied by booster coil unit КП-21БІМ (Fig.132) which operates the spark plugs of four flame igniters.

Structurally booster coil unit КП-21-БІМ is composed of two independent booster coils, accommodated in a common aluminium housing. Each of the booster coils (vibrators) comprises a transformer converting direct current into high voltage pulsating current, an interrupter and a mica capacitor connected in parallel with the interrupter. The interrupter vibrating at a frequency of about 400 to 800 c.p.s. and connected in series with the primary winding, induces high alternating voltage in the secondary winding, which creates a spark between the electrodes of the spark plugs.

The secondary winding of the coil has two high voltage leads and a centre point connected to the frame (wiring diagram of booster coil unit КП-21БІМ is illustrated in Fig.133).

The booster coil unit has four high-voltage leads and one low-voltage plug connector. Booster coil unit КП-21БІМ is secured to the compressor middle housing on a common panel with booster coil КПМ-ІА.

Starting Pump Motor, Magnetic Valve and Magnetic Cock

Electric motor МУ-І02А is designed for driving starting gasoline pump ПНР-І0-9М.

Electric motor МУ-І02А is a D.C. machine rated at 60 W, 5 A; it develops a speed of 3000 r.p.m.

The motor operates in conjunction with booster coils КП-21БІМ and the magnetic valve.

Power is supplied to the motor through small-size plug connector ВШ-2. Electric motor МУ-І02А is secured to starting fuel pump ПНР-І0-9М which is installed on the aircraft and serves the needs of both engines.

The starting fuel line incorporates the magnetic valve with return valve installed between starting pump ПНР-І0-9М and the starting fuel manifold. The magnetic valve consumes 24 V, 3A current.

Closing of the air blow-off band on the running engine when the other engine is being started, is ensured by a magnetic cock, which operates automatically when the starter of the other engine is switched on.

The cock electromagnet is rated at 1.5 A, 24 V.

ELECTRIC EQUIPMENT CONTROLLING ENGINE MAXIMUM AND AUGMENTED RATINGS

Engine operation at the maximum and augmented ratings is controlled by the following electric equipment.

(1) Control panel ПУ-3.
(2) Two-position slide valves ГА-2І.
(3) Booster coil КПМ-ІА with spark plug СП-02.
(4) Electromagnet of the НР-11А fuel pump
(5) Afterburner control unit КАФ-2А.
(6) Limit switch of НР-11А pump

Control Panel ПУ-3

(Figs 134 and 135)

Control panel ПУ-3 serves:

(1) To switch on and off the augmented rating.
(2) To switch on and off the maximum rating.
(3) To shift the shutters of the jet nozzle to the augmented position at a speed below 4500 - 6500 r.p.m., to facilitate engine starting.
(4) To carry out cold spinning of the engine.
(5) To change over the stages of minimum oil pressure warning mechanism 2СДУ5-І.3-3.
(6) To prevent switching on of the maximum or augmented ratings at speeds lower than those at which air blow-off band is closed on the accelerating engine.
(7) To prevent the shutters from shifting to the augmented position, with the engine throttled down at altitudes, where the idling speed exceeds the speed at which operation of the air blow-off band control mechanism takes place.

The control panel consists of aluminium housing 1 (See Fig.135) accommodating shaft 2 fitted with six profiled cams 3. The shaft is mounted on a ball bearing and a needle bearing.

The profiled cams are furnished with a split micrometric sleeve having micrometric screw 4 and coupling screw 5, which provides for changing the angular position of the cam relative to the shaft.

The splined end of the shaft mounts two-arm lever 6, coupling control panel ПУ-3 to the lever of the HP-10A pump (through the free moving link) and to the engine control link.

The angle of turn of the control panel shaft is indicated on dial 7 mounted on the other end of the shaft; the value of divisions is 2^{o}.

Running through the housing of control panel ПУ-3 are two fixed axles 8 and 9. Axle 8 mounts six guides with springs, whereas axle 9 carries six limit switches 10 - 15.

As the control panel shaft is linked with the engine control lever, shifting of the latter will cause the shaft to turn. As a result, the profiled cams and the guides will operate the respective limit switches at certain angles of turn of the shaft.

The limit switches of the control panel are set to operate at the following angles of turn of the shaft:

(a) limit switch XП (11) cutting off ignition and delivery of starting fuel when the engine is subjected to cold spinning is set to operate at an angle of 4^{0}_{-1}°;

(b) limit switch З (10) designed to shift the jet nozzle shutters to the augmented position to facilitate engine starting, is set to operate at an angle of $23^{o}\pm1^{o}$.

The augmented position of the shutters covers the range of angles from 0 to $23^{o}\pm1^{o}$; the normal position of the shutters is characterized by the range of angles from $23^{o}\pm1^{o}$ to 75^{0}_{-1}° (for shifting of the shutters at altitude, see Section "Operation of Electric Equipment");

(c) limit switch M (12) serving to turn on and off the maximum rating is set to operate at an angle of 75^{0}_{-1}°;

(d) limit switch Ф (13) serving to turn on and off the augmented rating is set to operate at an angle of 85^{0}_{-1}°.

Limit switch Б and the reserve switch are not employed.

Adjusting screws 16 serve for adjustment of the travel of the limit switch rod.

The control panel also incorporates switch 2ПП-45 BK and limit switch Л(17).

The function of switch BK is to switch over the electric equipment so as to provide for delivering fuel to the fuel system without switching on ignition, when carrying out corrosion preventive treatment of the engine inner surfaces, or when removing corrosion-preventive compound from the engine.

Normally, switch BK is set in the "Operating position" (Рабочее положение). Prior to subjecting the inner surfaces of the engine to corrosion-preventive treatment or removing the corrosion-preventive compound from the engine, the switch is set manually in the "corrosion-preventive treatment" (Кон - сервация) position, thereby opening the primary winding of booster coil unit КП-2IБIМ and simultaneously energizing the solenoid of the HP-11A fuel pump.

Limit switch Л serves:

(a) to switch over two-stage oil pressure warning mechanism 2СДУ5-I.3-3 by closing or opening the circuit of the second-stage contactor;

(b) to connect the interlocking relay to the supply circuits of two-position slide valve ГА-2I with the purpose of preventing the jet nozzle shutters from shifting to the augmented position, when the engine control lever is shifted to the idling stop at an altitude where the idling speed exceeds the value at which the air blow-off band control mechanism operates;

(c) to prevent the engine from being set to run at the maximum or augmented ratings during acceleration (to exclude the possibility of setting the augmented or maximum ratings when the engine speed is lower than the speed of operation of the air blow-off band, i.e. 9700_{-100} r.p.m.).

Limit switch Л is operated automatically in response to operation of the air blow-off band control mechanism through a special drive, which is mounted on the air blow-off band control mechanism bracket.

The control panel housing also mounts wires, main plug connector ШР55П35НШЗ and sleeves for wires connecting the control panel to other units.

The control panel is secured by three bolts to the brackets arranged on the compressor middle housing.

Booster Coil КПМ-IА

(Fig.136)

Booster coil КПМ-IА is a power source supplying high voltage to the afterburner spark plug.

The booster coil operates on the same principle as booster coil unit КП-2IБIМ, the only difference being that the secondary winding of booster coil КПМ-IА has only one high-voltage lead, its second end being connected to the frame (the wiring diagram of the booster coil is illustrated in Fig.137).

Current is supplied to the primary winding of the coil through low-voltage plug connector ШРI6П2ЭШ5.

Booster coil КПМ-IА is mounted on a common panel with booster coil unit КП-2IБIМ; the panel is secured to the compressor middle housing.

Afterburner spark plug СП-02is a non-detachable unit with ceramic insulation. The spak plug is fitted with a special adapter which is inserted into the central flame arrester socket through the upper strut of the afterburner diffuser. The other end of the plug is secured with the aid of a sphere to the shell of the afterburner diffuser.

Two-Position Slide Valve ГА-2I

(Fig.138)

For remote control of the jet nozzle shutters use is made of magnetically controlled two-position slide valves ГА-2I. The slide valves by-pass hydraulic fluid into the cylinders controlling operation of the jet nozzle shutters.

The electromagnetic system of the unit is comprised of a coil with two windings, and a limit switch closing the supply circuit of one winding while opening the supply circuit of the other. Pulse current, 24 V, consumed by one winding does not exceed 10 A.

The position of the limit switch depends on that of the slide valve. When the slide valve shifts to either of the extreme positions(Fig.139) it operates the limit switch which, in its turn, opens the supply circuit of the winding which has caused the slide valve to change its position, and prepares

the supply circuit of the other winding. The slide valve can remain in either of the two extreme positions for any period of time, with the coil being de-energized.

Slide valve ГА-2I has three-pin plug connector ШР20П3ЭГ7. When current is supplied to pins 1 - 3, the electromagnet becomes energized and actuates the slide valve, after which it is cut off by the limit switch. Circuit 1 - 3 remains open, while circuit 2 - 3 is being prepared. With the slide valve in this position, pipe union "from pump" (от насоса) communicates with pipe union "extension" (выпуск), while pipe union "return" (слив) communicates with pipe union "retraction" (уборка).

When current is supplied to pins 2 - 3, the electromagnet system functions in a similar way, but the slide valve shifted to a new position will connect pipe union "from pump" (от насоса) to pipe union "retraction" (уборка), whereas pipe union "return (слив) will communicate with pipe union "extension" (выпуск).

In order to set the jet nozzle shutters in three positions two slide valves are required; pipe union "extension" (выпуск) of one of the slide valves is plugged.

Solenoid of НР-11А Pump

The solenoid of the НР-11А fuel pump switches on fuel supply by the НР-11А pump into the afterburner manifold.

The electromagnet is energized from D.C. power supply, rated at 24 V, 0.35 A.

The electromagnet winding is connected to the supply through plug connector ШРI6У2ЭШ5 .

Limit Switch of НР-11А Fuel Pump

The limit switch of the НР-11А fuel pump is designed to cut off booster coil КПМ-IА when the afterburner cock is fully open.

The booster coil should be cut off as it is rated for a continuous operation up to 32 sec. only.

By the end of this period the combustion of fuel in the afterburner becomes stable, which makes it possible to cut off ignition when the afterburner fuel pressure reaches the rated value.

Afterburner Control Unit КАФ-2А

Afterburner control unit КАФ-2А serves to set the maximum and augmented ratings, and also to prevent the setting of these ratings under unfavourable conditions. The aircraft is provided with one afterburner control unit per two engines. Afterburner control unit КАФ-2А comprises a stamped box-type housing, accommodating two timing relays РВВ-1 and thirteen relays РП-3 (two of them being reserve relays). The afterburner control unit incorporates the following interlocking elements:

(a) relay РП-3 (See ref.No. 57 in Fig.146) controls the maximum and augmented ratings depending on the fuel pressure downstream of the booster pump (as indicated by minimum fuel pressure warning mechanism СД-3);

(b) timing relay РВБ-1 (See ref.Nos 54 and 54a in Fig.146) in conjunction with hydraulic switch УГ-34 blocks afterburner operation depending on the pressure of hydraulic fluid in the pipe line controlling the shutters in the augmented position.

The construction of the afterburner control unit provides for disconnecting of some of the afterburner blocking devices when checking the system for proper functioning. For this purpose the unit is fitted with two terminal blocks, having three contact screws each. When in the operating position, the slots on the contact screw heads are arranged vertically. When the slots are set in the horizontal position, the following blocks are eliminated:

(a) the screw marked "shutter opening" (открытие створок) eliminates blocking of the shutters opening depending on the minimum pressure of fuel in the afterburner manifold (as indicated by fuel pressure warning mechanism ДСД-2);

(b) the screw marked "hydraulic fluid" (гидросмесь) eliminates blocking of the augmented rating depending on the hydraulic fluid pressure (hydraulic switch УГ-34/I is disconnected);

(c) the screw marked "shutter closing" (закрытие створок) eliminates blocking of the jet nozzle shutters closing depending on minimum pressure of fuel in the afterburner manifold (as indicated by fuel pressure warning mechanism ДСД-2).

MAXIMUM AND AUGMENTED RATING BLOCKING DEVICES

The limit switch of the НР-10А pump hydraulic decelerator excludes the possibility of cutting in the maximum or augmented ratings at an engine speed below 10,400 r.p.m., with the engine control lever being smoothly shifted over. The limit switch operates as follows: when the throttle control is set at the "maximum" (максимал) or "afterburner" (форсаж) stop, the hydraulic decelerator limit switch will keep open the circuit of limit switches M or Ф of control panel ПУ-3 until the engine, in response to a smooth motion of the control lever, gains a speed of not less than 10,400 r.p.m.

The limit switch is connected to the circuit through low-voltage plug connector ВШ-4.

In case this blocking arrangement is to be eliminated(when checking the shutters and the afterburner ignition for proper operation, with the engine at a standstill), use is made of plug connector 754П-7 , which is mounted on the wire bundle detached from the plug connector of the hydraulic decelerator limit switch (plug connector 754П-7 is supplied with the single set of spare parts).

Fuel pressure warning mechanism СД-3 is installed on the aircraft, its function being to block the maximum and augmented ratings of both the engines depending on fuel pressure in the aircraft booster pump line. It prevents the above ratings from being switched on if the fuel pressure in the booster pump line is below 0.3 kg/sq.cm. (which is evidenced by the pilot lamp lighting up).

If the booster pump does not build up adequate fuel pressure, fuel pressure warning unit СД-3 closes the supply circuit of the winding of blocking relay РП-3 , arranged in afterburner control unit КАФ-2А ; relay ПУ-3 , in its turn, will open the circuit of control panel limit switches M and Ф .

Fuel pressure warning mechanism ДСД-2 (Fig.140) mounted on the engine is actuated by the difference between the fuel pressure in the afterburner manifold and the total gas pressure in the afterburner diffuser. The mechanism is set to operate at an excess fuel pressure of 0.2 ± 0.05 kg/sq.cm.

The fuel pressure warning mechanism provides for:

(a) opening of the jet nozzle shutters when the afterburner is cut in and excess fuel pressure reaches 0.2±0.05 kg/sq.cm.;

(b) closing of the jet nozzle shutters when the afterburner is cut off and excess fuel pressure drops to 0.2±0.05 kg/sq.cm.

Besides this, switching on of fuel pressure warning mechanism ДСД-2 causes the afterburner ignition to be turned on and the coil of relay PBB-1 to be de-energized. Thus, cutting-in of the afterburner becomes dependent on the pressure of hydraulic fluid in the pipe line controlling the shutters in the augmented position.

The housing of the fuel pressure warning mechanism is divided by a membrane into two chambers. One chamber takes the fuel pressure in the afterburner manifold, whereas the other is acted upon by the gas pressure in the afterburner diffuser. The contact system of the fuel pressure warning mechanism is accommodated in the chamber which takes the gas pressure. With the excess fuel pressure equal to or more than 0.2 kg/sq.cm., the contacts are closed; when the excess pressure is less than the above value, the contacts are opened. The contacts of fuel pressure warning mechanism ДСД-2 are connected to the supply circuit of the interlocking relay incorporated in afterburner control unit КАФ-2А . Both the chambers of the fuel pressure warning mechanism are hermetically sealed, the gas chamber being capable of withstanding a pressure of up to 3 kg/sq.cm., and the fuel chamber – up to 100 kg/sq.cm.

The fuel pressure warning mechanism is connected to the electric circuit through a low-voltage plug connector.

Should it become necessary to eliminate interdependence between afterburner operation and minimum fuel pressure in the respective manifold (when checking spark formation on the afterburner spark plug), use is made of three-pin connector 834П7 , which is mounted onto the wire bundle detached from the plug connector of fuel pressure warning mechanism ДСД-2 (three-pin plug connector ДСД-2 is available in the single set of spare parts).

Hydraulic switch УГ-34/I (Fig.141) is mounted on the aircraft and serves (in conjunction with relay PBB-1) to cut off fuel supply to the afterburner manifold by switching off the solenoid of the HP-11A pump when there is no pressure in the hydraulic pipe line controlling the shutters of the

jet nozzle in the augmented position. This [illegible] prevents combustion of fuel in the afterburner with the jet nozzle shutters closed, ruling out the possibility of engine overheating.

Limit switch Л of control panel ПУ-3 establishes interdependence between cutting in of the maximum and augmented ratings and engine acceleration. The need of an additional interlocking device (besides the hydraulic decelerator switch) has been dictated by the fact that during engine acceleration the hydraulic decelerator switch may be closed at a speed less than that at which the air blow-off band is closed.

Interlocking is accomplished as follows. Limit switch Л with the help of relay РП-3 (See ref. Nos 32, 32a in Fig.146) opens the circuit of control panel limit switches M and Ф , in case engine speed is less than that at which the air blow-off band is set to operate (9700_{-100} r.p.m.), thereby preventing the maximum or augmented ratings from being cut in at the above engine speed.

MEASURING INSTRUMENTS

The engine is fitted with the following measuring instruments: tachometer generator ДТ-3 , minimum oil pressure warning mechanism 2СДУ5-I.3-3 , and thermometer ТВГ-II serving to measure gas temperature aft of the turbine.

Tachometer generator

Tachometer generator ДТ-3 (Fig.142) designed for recording engine speed operates in conjunction with indicator ТЭ-15 or with double-dial indicator 2ТЭ-I5-I.

The tachometer generator is a three-phase, A.C. machine, with a two-pole permanent magnet acting as a rotor.

A.C. voltage produced by the generator is fed to the synchronous motor of the indicator.

Recording of the engine speed is based on the fact that the engine rotor speed (and consequently the generator rotor speed) is proportional to the frequency of the three-phase alternating current produced by the generator.

The generator rotor is manufactured from alloy [illegible], characterized by high inductance and coercivity. Vibration does not cause any noticeable variations in the magnetic properties of the alloy.

The startor winding is of the two-pole, three-phase type. Each of the phases is provided with four coils; the phasea are star-connected.

Two-Stage Oil Pressure Warning Mechanism 2СДУ5-I.3-3

Oil pressure warning mechanism 2СДУ5-I.3-3 (Fig.143) serves to indicate (by switching on the respective pilot lamp) insufficient oil pressure at the engine inlet. The mechanism relieves the pilot of the necessity to keep the oil pressure indications under constant observation.

The oil pressure warning mechanism has two stages, the respective minimum pressures amounting to $1.3^{+0.3}$ kg/sq.cm. and $3_{-0.2}$ kg/sq.cm.

The stages are changed over by control panel(ПУ-3) limit switch Л when the air blow-off band control mechanism operates at a speed of 9700_{-100} r.p.m.

Thus, oil pressure warning mechanism 2СДУ5-I.3-3 switches on the pilot lamp in case oil pressure drops below 1.3 kg/sq.cm. when the engine is accelerated from idling speed to 9700_{-100} r.p.m., and below 2.8 kg/sq.cm. when engine speed is brought from 9700_{-100} r.p.m. to the maximum value.

Oil pressure warning mechanism 2СДУ5-I.3-3 is a membrane type.

At an oil pressure of $1.3^{+0.3}$ kg/sq.cm. the membrane deflects and opens the pair of contacts of the first stage; a pressure of $3_{-0.2}$ kg/sq.cm. causes the membrane to open the contact pair of the second stage.

The key diagram of the oil pressure warning mechanism is illustrated in Fig.144. The mechanism should be capable of reliable operation throughout the entire service life of the engine, with the ambient air temperature within -60 to +120°C.

<u>Note</u>: When the other engine is being started, the air blow-off band of the engine already running at idling speed, automatically closes the air blow-off ports thereby cutting in the second stage of the oil pressure warning mechanism at a wrong speed (idling speed).

In this case, indications of the respective pilot lamp before termination of the starting cycle should be disregarded.

Thermometer ТВГ-II

Thermometer ТВГ-II (Fig.145) comprises a set of four thermo-couples connected in series, and a magnetic millivoltmeter.

The thermometer is designed to measure gas temperature aft of the turbine.

Thermometer ТВГ-II operates on the thermo-electric principle.

When the temperature in the exhaust cone exceeds 300°, a thermo-electromotive force is induced in the circuit of the thermo-couples, made up of two different fused conductors. The thermo-electromotive force is proportional to the temperature difference between the working (hot) end and the free (cold) ends.

The thermo-electromotive force is registered by the indicator (millivoltmeter) whose scale is graduated in °C.

The thermo-couples are connected in series thereby making up a thermopile whose total thermo-electromotive force corresponds to mean gas temperature at four points of the exhaust cone.

The thermo-couple electrodes are fabricated from materials developing thermo-electromotive force when the temperature of the hot end amounts to 300°C or over, therefore the temperatures of the thermo-couple free ends varying within -60° to +50°C practically do not affect the thermoelectromotive force (and consequently the accuracy of readings).

Variations in the ambient air temperature tell on the resistance of the indicator coil. To eliminate measuring error, the indicator is furnished with a silit resistor having a negative temperature factor.

ELECTRIC EQUIPMENT OPERATION

The electric equipment provides for:

(1) Automatic starting of the engine;

(a) autonomous starting of the engine from the aircraft storage batteries (24 - 48 V system);
(b) autonomous starting of the engine from the starter-generator of the running engine (with the storage batteries disconnected);
(c) starting from the ground power supply (24 V system).

(2) Starting of the engine, with manual control of fuel supply for all three cases (See Points a, b, and c).

(3) Starting of the engine in air.

(4) Spinning of the engine without supplying starting fuel or switching on ignition.

(5) Cutting in of the maximum and augmented ratings.

(6) Supplying current to the aircraft and engine consumers and boost-charging of the aircraft storage batteries (with the engine running).

Fig.146 illustrates the diagram of the electric equipment of the two engines.

To ensure normal operation of the electric system the following units should be turned on:

(1) Master switch 72, connecting storage batteries 71 and 73 into the aircraft mains.

(2) Generator switch 69 (69a).

(3) Circuit breaker АЗС-25 24 "Starting units" (Агрегаты запуска), delivering voltage from the aircraft mains to the servo-circuits of the starting system.

(4) Circuit breaker АЗС-10 23 "Timer АВ-5А" (Автомат времени АВ-5А) feeding voltage from the aircraft mains to the starting system control circuits.

(5) Circuit breaker АЗС-10 25 "Engine shutters" (Створки двигателя), directing voltage from the aircraft mains to the circuits controlling two-position slide valves ГА-2I.

(6) Circuit breakers АЗС-5 (22 and 22a) "Afterburner emergency cut-out" (Аварийное выключение форсажа) supplying voltage to the circuits controlling the maximum and augmented ratings.

(7) Circuit breaker АЗС-5 (21) supplying voltage to fuel pressure warning mechanism СД-3.

When circuit breaker АЗС-10 (25) is turned on, voltage

from the aircraft mains is delivered via terminal 10 of afterburner control unit КАФ-2А (59), contacts 5 and 4 of relay 55 (55a), contacts 5 and 4 of relay 58 (58a), and terminal 15 of afterburner control unit КАФ-2А to terminal 31 of plug connector 15 and further on to the contacts of limit switch 3 of control panel 5 (5a); depending on the position of switch "З" voltage is further supplied either via terminal 25 of plug connector 15 to contacts 2, 3 of relay 32 (32a) and to terminal 1 of the plug connector of two-position slide valve ГА-2I 33 (33a), or via terminal 14 of plug connector 15 directly to terminal 2 of the plug connector of the same two-position slide valve. This will cause the jet nozzle shutters to shift to the augmented or normal position respectively.

Limit switch "З" of control panel 5 (5a) operates when the engine control lever is shifted through 23±1° from the "Cut-Off" (Стоп) stop (as indicated on the control panel dial). Within this range of travel of the engine control lever the shutters remain in the augmented position. With the engine control lever moved further (from the position where operation of limit switch "З" has taken plate) to the Maximum (Максимал) stop, the shutters will shift to the normal position.

With the engine control lever moved in the opposite direction, the shutters will operate in the reverse sequence.

At altitudes, where the idling speed exceeds the speed at which operation of the air blow-off band takes place, closing of the throttle does not cause the shutters to shift to the augmented position (which precludes the possibility of engine acceleration in excess of the maximum speed). This is accomplished through the use of limit switch Л of control panel 5 (5a) and relay 32 (32a).

Should the engine speed exceed the speed at which operation of the air blow-off band takes place (with the band closed), limit switch Л of control panel 5 (5a) opens the supply circuit of relay 32 (32a), whose contacts 2 and 3 open the supply circuit of terminal 1 of the plug connector of the two-position slide valve ГА-2I 33 (33a) (the winding of relay 32 is energized through circuit breaker АЗС-20, terminal 24 of plug connector 15 via switch A and terminal 6 of plug connector 15).

In this case, closing of the throttle will not cause limit switch"3"5(5a) to energize terminal 1 of the two-position slide valve ГА-2I and the jet nozzle shutters will remain in the normal position.

Automatic Autonomous Starting of Engine from Aircraft Storage Batteries

Automatic autonomous starting of the first engine is accomplished from two storage batteries 12САМ-12. When the engine is being started, the storage batteries are switched over from parallel to series connection (24 - 48 V system).

The storage batteries are connected into the aircraft mains by master switch 72. Cutting in of master switch 72 is accompanied by turning on of contactors 75 and 78.

The winding of contactor 75 is permanently connected to the plus of storage battery 71, the minus of the same battery being connected to the winding via terminal 2 of storage battery switch box КПА-2 (74), contacts 1, 2 of relay 70, and master switch 72.

The winding of contactor 78 is permanently connected to the plus of storage battery 73, while connection to the frame (the minus of storage battery 73 being connected to the frame) is accomplished through contacts 4 and 5 of relay 76, terminal 1 of storage battery switch box КПА-2 , and master switch 72.

Terminal "+" of storage battery 71 is permanently connected to terminal "+" of starting box ПКС-6000И (38) and via contactor 77 to the aircraft mains. Terminal "-" is connected to the frame through contactor 75.

Terminal "-" of storage battery 73 is permanently connected to the frame while terminal "+" is connected to the aircraft mains through contactor 78.

Thus, the storage batteries are connected in parallel supplying 24 V into the aircraft mains.

To start the engine proceed as follows:

(1) shift the engine control lever to the "Low throttle" (Малый газ) stop;

(2) press button "Starting" (Запуск) 31 (31a) and keep it pressed for 1 - 2 sec.

The starting system provides for:

(1) blocking of starting button 31 (31a) (0.4 sec. after the button has been pressed, current starts to flow to the starting equipment by-passing the starting button);

(2) switching on (0.9 sec. after the starting button has been pressed) of booster coil unit 10, and of starting fuel pump motor 28, as well as of starting fuel valve electromagnet 12 (12a) and of ignition pilot lamp 17 (17a);

(3) power supply to the starter through the starting resistor;

(4) connection of the starter shunt winding to the aircraft mains;

(5) disconnection (2.5 sec. after the starting button has been pressed) of the starting resistor from the starter supply circuit;

(6) switching over (within 8.5 sec) of the storage batteries to a series connection into the starter supply circuit, with simultaneous disconnection of supply from the windings of voltage regulator 61 (61a) and of differential minimum relay 62 (62a);

(7) cutting off (within 16.5 sec) of the starter shunt winding;

(8) stopping (within 31.5 sec) of the starting equipment operation and connecting of the shunt winding of the starter-generator (changing over to the generator duty) to the voltage regulator.

Upon completion of the operating cycle of the starting equipment further acceleration of the engine to the idling speed is ensured by the fuel system only.

Within not more than 60 sec. after button "Starting" (Запуск) has been pressed, the engine should gain a speed 100 r.p.m. lower than the idling speed.

The electric equipment operates as follows (See Fig.146).

When button "Starting" 31 (31a) (Запуск) is pressed, current is supplied to motor M of timer 26 via circuit breaker 23, terminal 3 of timer plug connector, the closed contacts of the switch of cam 2, terminal 7 of the timer plug connector, button 31 (31a), contacts 5 and 4 of relay 29 (29a), terminal 2 (10) of the timer plug connector, and terminal "У" of relay A (as the other end of the winding of relay A is connected to the frame through relay terminal П and terminal 6 of the timer plug connector, relay A will operate connecting contacts 2 with contacts 3; contacts 5 with 6; contacts 8 with 9), contacts 9 and 8 of relay A (Б), contacts 4 and 5 of relay Б(A); the other end of motor M circuit through terminal 6 of the timer plug connector is connected to the frame.

Cams 1, 2, 3, 4, and 5 start to turn.

Through contacts 5 and 6 of relay A (Б) current is supplied to the switches of cams 2, 3, 4, and 5, while through terminal 11 of the timer plug connector, terminal 19 of the starting box, contacts 2 and 1 of relay 41a, and contacts 1 and 2 of relay 41 current flows to the winding of relay 50.

Relay 50 operates, connecting the starting circuit of starting box ПКС-6000И to terminal "+" supplied with 24 V current.

Operation of the first cam switch occurs 0.4 sec. later, and current starts flowing from circuit breaker 23 to motor M through terminal 3 of the timer plug connector, and through the contacts of the first cam. Relay A (Б) picks up when button 31 (31a) is pressed and is kept energized, its winding being supplied from the closed contacts of the first cam through contacts 5 and 4 of relay Б (A) and contacts 8 and 9 of relay A (Б). Through closed contacts 5 and 6 of relay A current is also delivered to contacts 2, 3, 4, and 5, and through terminal 11 of the timer plug connector, to the winding of relay 50.

At this moment the "Starting" (Запуск) button may be released, as it is shunted by the contacts of the first cam switch.

In 0.9 sec. the switch of the second cam operates opening the circuit of button "Starting" (Запуск) 31(31a) and supplying current from circuit breaker 23 via terminal 3 of the timer, the closed contacts of cam 1, contacts 5 and 6 of relay A, the closed contacts of cam 2, through contacts 3 and 2 of relay A (Б), terminal 4 (9) of the plug connector of timer 26, and terminal 16 of starting box 38 to the windings of relays 39 (39a) and 42(42a) and of contactor 47 (47a); through contacts 4 and 5 of relay 40 (40a), terminal 7 (6) of the plug connector of starting box 38, terminal 21 of plug connector 15 (15a), limit switch X.П. (cold spinning) of control panel 5 (5a), terminal 9 (8) of the plug connector of

starting box 38 current is supplied to the winding of relay 44 (44a).

As a result the following units are switched on:

(a) booster coil unit 10 (10a), starting fuel magnetic valve 12 (12a), and ignition pilot lamp, energized through circuit breaker 24, terminal 1 of the plug connector of starting box 38, contacts 8 and 2 of relay 44 (44a), and terminal 13 (27) of the plug connector of starting box 38; the supply current of the booster coil unit runs through the closed contacts of switch BK of control panel 5 (5a);

(b) starting fuel pump motor 28, energized through circuit breaker 24, terminal 1 of the plug connector of starting box 38, contacts 7 and 3 of relay 44 (44a), and terminal 21 of the starting box plug connector;

(c) starter-generator 14 (14a), energized from the storage batteries via closed contactor 50, starting resistor 49, and contactor 47 (47a);

(d) the shunt winding of starter-generator 14 (14a) supplied with current through circuit breaker 24, terminal 1 of the plug connector of starting box 38, contacts 5, 8, 7 and 6 of relay 45, contacts 3 and 7 of relay 42 (42a) and terminal 28 (2) of the starting box plug connector /up to this moment the starting box has been connected to voltage regulator 61 (61a) by contacts 7 and 6 of relays 42 (42a) and 43 (43a)/;

(e) magnetic valve 13a (13) controlling the air blow-off band of the other engine through circuit breaker 24, terminal 1 of the plug connector of starting box 38, contacts 8 and 2 of relay 42 (42a), terminal 11 (10) of the plug connector of starting box 38 and terminal 20 of plug connector 15a (15) (however, this will not cause the band control mechanism to operate, as, the other engine being at standstill, there is no pressure in its oil and fuel systems).

Thus, operation of the second cam switch results in starting of fuel supply and ignition; the starter-generator, energized through the starting resistor, smoothly takes up backlashes in the drive system and proceeds to spinning the engine.

In 2.5 sec., the switch of the third cam of timer 26 picks up cutting in contactor 48 (48a), which is energized via terminal 5 of the timer, terminal 15 of the starting box and through contacts 3 and 2 of relay 39 (39a).

Resistor 49 is shunted, starter-generator 14 (14a) is supplied with 24 V and starts to spin the engine with ever increasing speed.

The switch of the fifth cam picks up 8.5 sec. later. The fifth cam delivers current through terminal 8 of the timer and terminal 26 of the plug connector. Relay 46 (switching over the storage batteries) picks up delivering current to terminal 4 of the plug connector of storage battery switch box 74 via contacts 3 and 2 and terminal 18 of the starting box plug connector.

From terminal 4 of the storage battery switch box plug connector current flows via contacts 7 and 8 of relay 76 to relay 70 which opens the supply circuit of the winding of contactor 75 with its contacts 1 and 2, and the supply circuit of the winding of relay ДМР-400 62 (62a) with its contacts 4 and 5 (7 and 8).

Simultaneously, current from terminal 4 of the plug connector of storage battery switch box 74 flows via contacts 11 and 10 of relay 76 to switching contactor 77 and relay 68, which causes contacts 6 and 7 (5 and 8) to open the supply circuit of the winding of voltage regulator 61 (61a).

As a result of the operation of contactors 75 and 77 the storage batteries are connected in series to terminal "+" of starting box ПКС-6000И (38).

The battery circuit is connected as follows: "-" of battery 73, "+" of battery 73, contactor 78, contactor 77 (in the lower position), contactor 75 (in the upper position), minus of battery 71, whose plus terminal is permanently connected to the pole of starting box ПКС-6000И (38).

Terminal "+" of the starting box, and consequently terminal CT of starter-generator 14 (14a) are supplied with 48 V and the starter-generator continues to spin intensively the engine; the aircraft mains is supplied with 24 V current from one storage battery 73.

The switch of the fourth cam of timer 26 operates in 16.5 sec. cutting in relay 45 through terminal 1 of the timer plug connector and terminal 14 of the starting box plug connector; contacts 8, 5, 7, and 6 of relay 45 open the supply circuit of the shunt winding of starter-generator 14 (14a).

The starter-generator starts to operate with series excitation thus accelerating engine speed.

In 31.5 sec. the switch of the first cam returns to the initial position thereby de-energizing the entire starting system. The starting circuit of starter-generator 14 (14a) and the ignition are cut off; supply of starting fuel is cut off too; ignition pilot lamp 17 (17a) goes out.

The starter-generator rotated by the engine automatically passes over to the generator duty; its shunt winding is connected to the voltage regulator through contacts 7 and 6 of relays 42 (42a) and 43 (43a).

<u>Automatic Autonomous Starting of Engine from Starter-Generator of Running Engine</u>

Starting of the other engine is accomplished from the starter-generator of the first engine, running at idling speed.

In this case, the starting system components function in a different way so far as their operating sequence is concerned. This difference is due to the fact that relay 41a (41) takes part in the starting cycle; operation of the relay is ensured by the presence of voltage on terminal Γ of the first engine starter-generator which has passed over to the generator duty.

The starting system provides for:

(1) blocking of starting button 31a (31);

(2) disconnection of the starting circuit from the starter control unit;

(3) cutting in of ignition, starting fuel pump motor 28, starting fuel system magnetic valve 12a (12), ignition pilot lamp 17a (17)of the magnetic cock of the running engine;

(4) current supply from the starter-generator of the running engine to the starter-generator of the engine to be started, via the starting resistor;

(5) connection of the shunt winding of the running engine starter-generator to the aircraft mains;

(6) connection of the running engine starter-generator shunt winding to the series-connected storage batteries, with simultaneous disconnection of the voltage regulator winding

and the winding of the differential minimum relay of the running engine from the aircraft mains;

(7) disconnection of the starter-generator shunt winding after the engine starting;

(8) de-energizing (within 31.5 sec.) of the starting equipment.

The electric equipment operates as follows.

When button "Starting" (Запуск) 31a (31) is pressed, current flows via circuit breaker 23, terminal 3 of the timer plug connector, the contacts of the second cam switch, terminal 7 of the timer, button 31a (31), contacts 5 and 4 of relay 29a (29), terminal 10 of the timer to the winding of relay Б , which closes contacts 8 and 9; 6 and 5; 3 and 2. Further, current passes to the winding of motor M via contacts 9 and 8 of relay Б (A) and contacts 4 and 5A (Б).

Contacts 5 and 6 of relay Б (A) supply current to the switches of cams 2, 3, 4, and 5, to terminal 11 of the timer plug connector, to terminal 19 of starting box 38, and further to the winding of contactor 50 via contacts 2 and 1 of relays 41a and 41.

Motor M starts turning cams 1, 2, 3, 4, and 5.

After the first cam switch has operated (within 0.4 sec.) current will flow to motor M through its contacts.

0.9 sec. later the switch of the timer second cam will operate and will cut in the following units:

(a) relays 39a (39), 42a (42) and contactor 47a (47), energized via contacts 2 and 3 of relay Б (A) of timer 26, terminal 9 of the starter control unit, and terminal 17 of starting box 38;

(b) relay 44a (44) supplied with current through contacts 4 and 5 of relay 40a (40), terminal 6 of starting box 38 and limit switch X.П. of control panel 5a (5);

(c) relay 41a (41) energized via terminal Г of differential minimum relay 62, terminal 7 of storage battery switch box 74, contacts 14 and 13 of storage battery switch box relay 76, terminal 11 of switch box 74, terminal 4 of starting box 38, and contacts 5 and 6 of relay 39a (39);

(d) contactor 48 (48a) to which current is fed via contacts 8 and 9 of relay 41a (41).

The supply circuit of relay 50 winding is opened by contacts 1 and 2 of relay 41a (41), as a result of which the starting circuit is disconnected from the storage batteries.

When relay 44a (44) picks up, current starts flowing from circuit breaker 24 via terminal 1 of starting box 38, closed contacts 7 and 3 of relay 44a (44), terminal 21 of starting box 38 to the winding of starting fuel pump motor 28.

Simultaneously, current will flow via closed contacts 8 and 2 of relay 44a (44) and terminal 27 of starting box 38 to pilot lamp 17a (17), to booster coil unit 10a (10) and to starting fuel valve electromagnet 12a.

The shunt of starter-generator 14a (14) is connected to the 24 V mains through circuit breaker 24, terminal 1 of starting box 38, contacts 5, 8, 7, and 6 of relay 45, and contacts 3 and 7 of relay 42a (42).

Starter-generator 14a (14) of the engine being started is supplied with current from terminal C[illegible] of the starter-generator of the running engine via terminal CT1 of starting box 38, contactor 48 (48a), starting resistor 49 and contactor 47a (47).

The switch of the third cam of timer [illegible]6 operates 2.5 sec. later, cutting in contactor 48a (48) supplied with current through contacts 3 and 2 of relay 39a (39), and relay 43 (43a) energized via contacts 3 and 2 of relay 39a (39) and contacts 11 and 12 of relay 41a (41).

Contactor 48a (48) shunts the starting resistor and contactor 47a (47). Relay 43 (43a) disconnects the shunt [illegible] starter-generator 14 (14a) from voltage regulator 61 (61a) and connects it to terminal "+" of starting box [illegible] 38 via contacts 7 and 6 of relay 42 (42a) and contacts 7, 3, 2, and 8 of relay 43 (43a).

The upper branch supplies current to terminal 4 of storage battery switch box 74 from the third c[illegible] via terminal 5 of the timer, terminal 15 of starting box 38, contacts 5 and 6 of relay 41a, terminal 12 of the starting box, terminal 12 of the [illegible] and terminal 14 of the timer, the terminal of the fourth cam, [illegible] timer.

From terminal 4 of switch box 74 current flows via contacts 11 and 10 of relay 76 to contactor 77 and relay [illegible] the latter opens contacts 6 and 7 (5 and 8) thereby disconnecting the windings of voltage regulator 61 (61a) from the aircraft mains. Simultaneously, current delivered from terminal 4 of switch box 74 flows via contacts 7 and 8 of relay 76 to relay 70, which opens its contacts 1 and 2 thereby cutting off contactor 75, while its contacts 4 and 5 (7 and 8) disconnect the winding of differential minimum relay 62 (62a) from the aircraft mains.

Connection of contactor 77 and disconnection of contactor 75 will cause the series-connected storage batteries to be connected to terminal "+" of starting box 38; the shunt winding of starter-generator 14 (14a) connected to the same terminal will be supplied with 48 V. Voltage across the terminals of running engine starter-generator 14 (14a) energizing starter-generator 14a (14) of the engine being started will be increased causing the starter-generator to spin the engine with high speed.

The aircraft mains, and consequently the control circuits and the shunt winding of starter-generator 14a (14) will be energized with 24 V supplied from one storage battery 73.

Differential minimum relay ДМР-400 62 (62a), whose supply circuit is opened by the contacts of relay 70, will disconnect the aircraft mains from the high voltage delivered by starter-generator 14 (14a).

When the switch of the fifth cam of timer 26 operates (in 8.5 sec.), energy will be fed to the winding of relay 46 via terminal 8 of the timer and terminal 26 of starting box 38; relay 46 will pick up and deliver current from circuit breaker 23 to the winding of relay 45 via contacts 5 and 6 of relay 46 and contacts 14 and 15 of relay 41a (41). Relay 45 will de-energize the shunt winding of starter-generator 14a (14) of the engine being started. Starter-generator 14a (14) starts operating as a series motor causing the engine to pick up speed.

Operation of the fourth cam switch will not affect the functioning of the electric equipment. The fourth cam will supply energy via terminal 1 of the timer and terminal 14 of the starting box to the winding of relay 45 which has already been energized.

At the end of the starting cycle the fifth cam returns to the initial position and opens the supply circuit of terminal 4 of storage battery switch box 74, as a result of which contactors 75 and 77 switch the storage batteries over to parallel operation.

Relay 45 remains energized to the very end of the cycle, the fourth cam being the last but one to return to the initial position.

The entire system is unblocked by the first cam, which is the last to return to the initial position.

Starter-generator 14a (14) begins to operate as a generator, its shunt winding being connected to voltage regulator 61a (61) via closed contacts 7 and 6 of relay 42a (42) and contacts 7 and 6 of relay 43a (43).

Starting of Engine from Ground Power Supply

Starting of the engine from an external power source is accomplished in the same manner as when carrying out autonomous starting of the first engine, the only difference being that the storage batteries are not switched over to 48 V. This difference is accounted for by the fact that when current is fed to ground supply receptacle 66, relay 76 of storage battery switch box 74 picks up cutting off the storage batteries from the aircraft mains and terminal "+" of starting box 38.

Pressing of "Starting" (Запуск) button 31 (31a) and subsequent operation of switches 1, 2 and 3 of the timer cams cause the electric equipment to function in the same manner, as when accomplishing autonomous starting of the first engine. The switch of the fifth cam de-energizes the shunt winding of starter-generator 14 (14a), the contactors of storage battery switch box 74 being kept in the same position by energized relay 76.

Operation of the fourth cam switch, similarly to autonomous starting (from the generator) of the other engine, does not cause any changes in the functioning of the starting equipment.

After expiration of 31.5 sec. the starting system returns to the initial position.

The starting system equipment operates as follows (See Fig.146).

Current from receptacle 66 flows to the winding of switchover relay contactor K and via terminal 3 of storage battery switch box 74 to the winding of relay 76; the other end of the relay winding runs to terminal "-" of receptacle 66 via terminal 12 of switch box 74. When energized, relay 76 feeds current to relay 70 through contacts 9 and 8, and terminal 5 of switch box 74.

The minus end of contactor K winding is connected to the frame via the closed contacts of relay ПР of switch-over relay 67, contacts 5 and 6 of relay 76, and master switch 72.

In case of wrong voltage polarity across receptacle 66, relay ПР picks up and opens the winding of contactor K (with the receptacle connected properly, relay ПР cannot pick up because of a solid rectifier placed into its circuit).

Contactor K of switch-over relay 67, and relays 76 and 70 are energized. The circuits of contactors 75 and 78 are opened by contacts 1 and 2 of relay 70, and 4 and 5 of relay 76, respectively.

The storage batteries are cut off from the aircraft mains, while the external supply is connected to the mains via contacts K and 77. Simultaneously, contacts 4 and 5 (7 and 8) of relay 70 cut off the winding of relay ДМР-400 62 (62a).

Pressing of "Starting" (Запуск) button 31 (31a) and subsequent operation of the switches of cams 1, 2 and 3, cause the electric equipment to be switched on in exactly the same manner as in the case of autonomous starting of the first engine.

The fifth cam switch delivers energy to the winding of relay 45 via contacts 3 and 2 of relay 46.

Relay 76 of storage battery switch box 74 being energized, the current fed by the fifth cam to terminal 4 of switch box 74 instead of flowing via contacts 11, 10 and 7,8 will flow via contacts 11, 12 and further via terminal 10 of switch box 74 and to terminal 14 of starting box 38, whence it is supplied to the winding of relay 45, which opens the supply circuit of the starter shunt winding.

Starting of the other engine from the external power source does not differ in any way from the starting procedure described for the first engine, the generator operation being prevented by relay 76, which opens the supply circuit of relay 41 (41a) (the relay switches over the starting equipment for operation from the starter-generator of the running engine).

The starter-generator of the running engine is cut off from the aircraft mains by differential minimum relay ДМР-400, whose supply circuit is opened by the contacts of relay 70.

Engine Starting with Manual Control of Fuel Supply (Non-Automatic Starting)

During non-automatic starting of the engine fuel supply is regulated manually with the help of the engine control lever.

Starting is accomplished as follows:

(1) Press "Starting" (Запуск) button 31 (31a) and keep it pressed for 1 to 2 sec.

The starting equipment operates in the same way as in the case of the automatic starting.

(2) Slowly and smoothly shift the engine control lever to the Low throttle" (Малый газ) stop, thereby regulating gas temperature aft of the tubrine.

Engine Starting in Air

Starting of the engine in the air is carried out without employing the starter, as the rotor is spun by ram air.

The engine is started as follows:

(1) fuel is supplied into the engine in the same way as in the case of the automatic starting;

(2) press button "Starting in air" (Запуск в воздухе) 30 (30a) and keep it pressed for 1 to 2 sec.

With button 30 (30a) pressed, current flows to the winding of relay 40 (40a) via circuit breaker 23, terminal 23 of starting box 38, button 30 (30a) and contacts 2 and 1 of relay 40a(40). Further, current is supplied to motor M of timer 26 through contacts 8 and 9 of relay 40 (40a), terminal 20 of starting box 38, terminal 13 of the timer plug connector, contacts 7 and 8 of relay Б , and contacts 4 and 5 of relay A. After operation of the first cam switch, motor M and relay 40 (40a) are energized through the contacts of relay 40 (40a) in parallel with button 30 (30a).

The switches of cams 2, 3, 4 and 5 are de-energized, as relays A and Б are cut off.

Relay 44 (44a) is energized through circuit breaker 23, terminal 25 of starting box 38, contacts 6 and 5 of relay 40 (40a), terminal 7 of starting box 38, and limit switch Х.П. of control panel 5 (5a); the contacts of relay 44 (44a) feed current to booster coil unit 10 (10a), to the solenoid of starting fuel valve 12 (12a), and to starting fuel pump motor 28. Pilot lamp "Ignition" (Зажигание) 17 (17a) lights up.

As the circuit of button 30 (30a) runs across the normally closed contacts of relay 40a (40), starting of both the engines simultaneously is impossible.

31.5 sec. later, the timer switches off the ignition system and pilot lamp 17 (17a) goes out.

Cranking of Engine

Engine cranking is accomplished by switching on the starting cycle without cutting in the ignition.

The ignition is cut off by control panel 5(5a)limit switch Х.П which opens the ignition and starting fuel circuits, when the engine control lever is set in the "Cut-Off" (Стоп) position.

To start cranking, it is sufficient to press button "Starting" (Запуск) 31 (31a) for 1 or 2 seconds.

With the button pressed, the starting procedure is controlled by the timer in the same way as when starting is accomplished automatically. The starter-generator will operate through the entire starting cycle, thereby cranking the engine to a speed of 800-1100 r.p.m.

If cranking is not to be carried out to the very end of the starting cycle, the latter should be discontinued by operating circuit breaker 23. Then circuit breaker 23 should be turned on again for 30 to 40 sec. to enable the timer to complete the cycle.

The electric equipment of the starting system is provided with a special blocking arrangement, excluding the possibility of resuming or cutting in the starting cycle, when the system is in the intermediate position. This arrangement does not allow the engine and its accessories to operate under abnormal conditions. The blocking is ensured by the following elements of the starting system.

The switches of cams 2, 3, 4 and 5, cutting in the starting units, are supplied with energy through the contacts of timer relay А or Б , which can be energized only via starting buttons 30 or 31. The starting button circuit, in its turn, can be closed only when the timer second cam switch is in the initial position.Therefore, with the starting circuit(or the aircraft mains) de-energized, supply of current into the starting circuit via the circuit breaker or into the aircraft mains will result only in cutting-in of motor M, which will complete the cycle and set the cams in the initial position. At the same time, pressing of the starting button will not lead to any changes in the electric circuit, the button circuit being opened by the second cam switch.

Setting Engine to Maximum and Augmented Ratings

Cutting in of the maximum and augmented ratings is accomplished by setting the engine control lever in the "Maximum" (Максимал) and "Afterburner" (Форсаж) positions, respectively.

To provide for stable operation of the engine (without surging), the maximum and augmented ratings should be out in only when the engine reaches the specified speed. For this purpose provision has been made in the electric system for blocking the maximum and augmented ratings when the engine speed is not sufficient. This function is performed by the HP-10A pump hydraulic decelerator contactor which opens the circuit of the automatic devices controlling the maximum and augmented ratings at an engine speed below 10,400±200 r.p.m. (with the engine control lever shifted smoothly).

However, contactor operation may occur at various engine speeds, depending on the rate of engine control lever shifting. Thus, during engine acceleration the contactor may operate at a speed of 8000 r.p.m.

This necessitated introduction of an auxiliary blocking arrangement setting up interdependence between cutting-in of the maximum and augmented ratings and the engine during acceleration; blocking is provided by switch " Д " of control panel ПУ-3.

Thus, when the engine control lever is set at the "Maximum" (Максимал) or "Afterburner" (Форсаж) stops, the above ratings will be cut in only when the engine speed reaches 10,400±200 r.p.m. (with smooth increase of fuel supply), or 9700_{-100} r.p.m. (during engine acceleration).

Cutting in of the maximum or augmented ratings results in a sharp increase of fuel consumption, which leads to a reduction of fuel pressure in the aircraft booster system.

To raise fuel pressure at the engine inlet, with the engine running at the maximum or augmented ratings(in order to avoid damage to the fuel pumps), provision has been made for an interlocking arrangement which sets up an interdependence between cutting-in of the above ratings and the minimum pressure of fuel in the aircraft booster system. This interlocking is ensured by minimum fuel pressure warning mechanism СД-3 which does not allow cutting-in of, or engine operation at, the maximum and augmented ratings, if fuel pressure in the aircraft booster system is less than 0.3 kg/sq.cm.

Switching Maximum Rating On and Off

The engine is set to the maximum rating by reducing the diameter of the jet nozzle clear opening. This results in a reduced gas pressure difference across the turbine, which tends to decrease the engine speed.

The centrifugal speed governor, striving to maintain engine speed at a constant level, will increase fuel supply, which in its turn will cause a rise in gas temperature forward of the turbine.

Thus, thrust augmentation at the maximum rating is achieved due to an increase in the temperature of jet gases, and, consequently, an increase of their velocity.

Shifting of the engine control lever to the "Maximum" (Максимал) stop causes limit switch M of control panel ПУ-3 to operate.

Relay 51 (51a) picks up and delivers current to the electromagnet of two-position slide valve ГА-2I 35 (35a).

The slide valve changes its position thereby changing delivery of hydraulic fluid to the cylinders controlling the jet nozzle shutters. As a result, the jet nozzle shutters will be partially closed.

To switch off the maximum rating, it is necessary to shift the engine control lever from the "Maximum" (Максимал) stop towards speed reduction. In this case, limit switch M of control panel ПУ-3 will open, de-energizing relay 51 (51a). The jet nozzle shutters, depending on the position of the engine control lever (the position of the cam of switch "3") are set either to the normal or augmented position.

The individual components of the system operate as follows (See Fig.146).

The moment the engine control lever is shifted to the "Maximum" (Максимал) stop, limit switch "M" of control panel 5 (5a) will operate.

Relay 51 (51a) is supplied with current via circuit breaker 22 (22a), terminal 19 (17) of afterburner control unit КАФ-2А 59, contacts 8 and 7 (5 and 4) of relay 57, terminal 22 (29) of the afterburner control unit plug connector, terminal 23 of plug connector 15, limit switch 3 (3a) of the HP-10A pump hydraulic decelerator, limit switch M of control panel 5 (5a), terminal 10 of plug connector 15, and terminal 3 (36) of the afterburner control unit plug connector. The other end of the winding of relay 51 is connected to the frame through terminal 16 of afterburner control unit 59. Current flows through circuit breaker 25, terminal 10 of afterburner control unit 59, and contacts 2 and 3 of energized relay 51 (51a) to terminal 1 of the plug connector of slide valve ГА-2I 35 (35a).

The jet nozzle shutters shift to the "Maximum" (Максимал) position.

As soon as the maximum rating is switched off, limit switch M of control panel 5 (5a) opens the supply circuit of relay 51 (51a). Energy is delivered via circuit breaker 25 and contacts 2 and 1 of relay 51 (51a) to terminal 2 of the plug connector of slide valve ГА-2I 35 (35a). Depending on the position of limit switch "3" of control panel 5 (5a), current will also be fed either to terminal 2 or 1 of the plug connector of slide valve ГА-2I 33 (33a).

Current is fed to slide valve ГА-2I 33 as follows: from circuit breaker 25 via terminal 10 of the afterburner control unit, contacts 5 and 4 of relay 55, contacts 5 and 4 of relay 58, terminal 15 of the afterburner control unit, to terminal 31 of plug connector 15. Further, current flows either to terminal 25 or terminal 14 of plug connector 15, depending on the position of switch "3". From terminal 25 energy is delivered to contact 2 of relay 32, and further via contact 3 to terminal 1 of slide valve ГА-2I 33, provided relay 32 is energized.

Relay 32 is fed through blow-off band switch "Л" which receives current from circuit breaker A3C 20.

From terminal 14 of plug connector 15 current is fed to terminal 2 of slide valve ГА-2I 33.

With the shutters in the augmented position, current is supplied to terminals 2 or 1 of slide valve ГА-2I 35 and to terminal 1 of slide valve ГА-2I 33; when the shutters are in the maximum (Максимал) position current is fed to terminal 1 of slide valve ГА-2I 35 and to the terminal of slide valve ГА-2I 33.

Switching Augmented Rating On and Off

Operation of the engine at the augmented rating is ensured by burning an additional amount of fuel in the afterburner. With the exhaust area of the jet nozzle remaining unchanged, this would have resulted in an increase of gas pressure aft of the turbine. To safeguard the engine against surging and to prevent excessive rize of gas temperature forward of the turbine, the diameter of the jet nozzle exhaust area is increased.

When the augmented rating is switched on or off, there should be a definite synchronization between supply of afterburner fuel and the time period within which the jet nozzle exhaust area is changed. This is achieved by adjusting the rate of jet nozzle shutter shifting and the speed at which afterburner fuel pressure increases and drops. The same purpose is served by a blocking arrangement incorporated in the afterburner control system.

Provision has also been made in the electric system for blocking the operation of the jet nozzle shutters depending on afterburner fuel pressure and for cutting off afterburner fuel supply when there is no hydraulic pressure in the pipe line controlling the shutters in the augmented position.

The blocking arrangement is devised:

(1) to prevent the shutters from opening before fuel is delivered into the afterburner, and thus to avoid a drop of gas temperature in the afterburner; this would have made ignition of afterburner fuel impossible and caused abrupt reduction of the engine thrust;

(2) to prevent burning of afterburner fuel with the shutters closed, and thus to preclude engine surge and overheating when the augmented rating is switched on;

(3) to prevent the jet nozzle shutters from closing when there is fuel pressure in the afterburner manifold, and thus to preclude engine surge and overheating when the augmented rating is cut off.

To cut in the augmented rating, the engine control lever is shifted to the "Afterburner" (Форсаж) stop. This turns on limit switch Ф accommodated in control panel 5 (5a), and coupled to the engine control lever.

As a result, current is fed to HP-11A fuel pump electromagnet 9 (9a). Fuel is admitted into the afterburner manifold and the afterburner pilot lamp lights up.

When fuel pressure in the afterburner manifold exceeds the total gas pressure aft of the turbine by 0.2 kg/sq.cm., afterburner minimum fuel pressure warning mechanism ДСМ-2 6(6a) energizes relay 58 (58a), which provides for:

(1) setting the electromagnet of two-position slide valve ГА-2I 33 (33a) in a position at which the hydraulic fluid is supplied into the interpiston spaces of the shutter control cylinders(as a result the shutters shift to the augmented position);

(2) cutting in afterburner booster coil 8 (8a);

(3) de-energizing timing relay РВВ-1 54 (54a).

When fuel pressure in the afterburner manifold reaches the highest permissible value, that is, when the piston of the HP-11A pump afterburner cock almost comes up against the stop, limit switch 4 (4a) of the HP-11A pump energizes relay 52 (52a), which switches off booster coil 8 (8a).

De-energizing of the afterburner ignition system is necessary because continuous operation of booster coil [illegible] 8 (8a) must not exceed 32 sec.

The augmented rating is switched off by removing the engine control lever from the "Afterburner" (Форсаж) stop. This causes switch Ф of control panel 5 (5a) to open, as a result of which electromagnet 9 (9a) of the HP-11A pump is de-energized. Fuel supply into the afterburner manifold is cut off. The afterburner pilot lamp goes out.

When excess fuel pressure in the afterburner manifold (i.e. the pressure exceeding the total gas pressure aft of the turbine drops below 0.2 kg/sq.cm., fuel pressure warning mechanism ДСД-2 6 (6a) will open its contacts thereby de-energizing relay 58 (58a).

Depending on the position of the engine control lever, the jet nozzle shutters will shift to the maximum, normal, or augmented position (at idling rating).

If the shutters do not open after switching on augmented rating (due to absence of pressure in the pipeline controlling the shutters in the augmented position), afterburner fuel supply and ignition are cut off. This blocking is accomplished as follows.

The winding of the timing relay being energized when circuit breaker 22 is cut in, is de-energized only when the afterburner is turned on after the operation of fuel pressure warning mechanism ДСД-2 and relay 58 (58a).

When the winding of relay РВВ-I is de-energized, the contact system of the latter closes 0.3 to 0.5 sec. after the operation of fuel pressure warning mechanism ДСД-2 takes place.

Incorporated in the pipeline feeding hydraulic fluid to the cylinders controlling the shutters in the augmented position, is hydraulic switch УГ34/I 34 (34a), whose normally closed contacts are opened under the pressure of hydraulic fluid 0.1 sec. after the operation of fuel pressure warning mechanism ДСД-2 takes place.

The contact systems of hydraulic switch УГ34/I 34 (34a) and of timing relay РВВ-I 54 (54a) are connected into the circuit of the winding of relay 53 (53a) (the contacts of hydraulic switch УГ34/I are connected to the circuit plus, the contacts of relay РВВ-I to the circuit minus).

If there is no pressure in the pipeline feeding hydraulic fluid to the shutter control cylinder by the time the contacts of timing relay РВВ-I are closed, the contacts of timing relay РВВ-I and of hydraulic switch УГ34/I will close at the same time thereby energizing relay 53 (53a). Relay 53 (53a) will cut off electromagnet 9 (9a) of the HP-11A pump, discontinuing fuel delivery into the afterburner manifold. Relay 53 (53a) will remain closed until the engine control lever is moved from the "Afterburner" (Форсаж) stop.

With the shutter hydraulic system operating normally, hydraulic switch УГ34/I opens its contacts before the contacts of relay РВВ-I are closed, therefore relay 53 (53a) will not pick up and fuel will continue to flow into the afterburner manifold.

The equipment operates as follows.

When the engine control lever is shifted to the "Afterburner" (Форсаж) stop, electromagnet 9 (9a) and relay 55 (55a) become energized through circuit breaker 22 (22a), terminal 19 of afterburner control unit 59, contacts 8 and 7 (5 and 4) of relay 57, via terminal 22 of afterburner control unit 59 and terminal 23 of plug connector 15, the contacts of limit switch 3 (3a) of the HP-10A pump hydraulic decelerator, limit switch Ф of control panel 5 (5a), terminal 29 of plug connector 15 and terminal 12 of afterburner control unit 59, contacts 5 and 4 of relay 53 (53a), terminal 4 of afterburner control unit 59, terminal 12 of plug connector 15, and via cut-in switch ВК. Electromagnet 9 (9a) controls fuel supply into the afterburner manifold.

Relay 55 (55a), energized via contacts 5 and 4 of relay 53, provides for energizing the supply circuit of slide valve ГА-21 33 (33a), and of booster coil КПМ-IА 8 (8a). Afterburner pilot lamp 36 (36a) lights up being supplied via circuit breaker 25 and contacts 5 and 6 of relay 55 (55a).

When afterburner fuel pressure warning mechanism ДСД-2 6 (6a) operates, relay 58 (58a) is energized via circuit breaker 22, terminal 17 of plug connector 15 and the contacts of fuel pressure warning mechanism 6(6a), terminal 18 of plug connector 15 and terminal 34 of afterburner control unit 59.

Current is fed to terminal 1 of slide valve ГА-21 plug connector via circuit breaker 25, terminal 10 of afterburner control unit 59, contacts 5 and 6 of relay 55 (55a), contacts 8 and 9 of relay 58 (58a) and terminal 14 of afterburner control unit 59. The jet nozzle shutters shift to the augmented position.

Simultaneously, when relay 58 (58a) picks up, current is fed to booster coil 8 (8a) via circuit breaker 22, terminal 19 of afterburner control unit 59, contacts 2 and 3 of relay 58 (58a), contacts 9 and 8 of relay 55 (55a), contacts 4 and 5 of relay 52 (52a), terminal 6 of afterburner control unit 59, and terminal 2 of plug connector 15.

drops below 0.2 kg/sq.cm., fuel pressure warning mechanism ДСД-2 6 (6a) will open its contacts thereby de-energizing relay 58 (58a).

Depending on the position of the engine control lever, the jet nozzle shutters will shift to the maximum, normal, or augmented position (at idling rating).

If the shutters do not open after switching on augmented rating (due to absence of pressure in the pipeline controlling the shutters in the augmented position), afterburner fuel supply and ignition are cut off. This blocking is accomplished as follows.

The winding of the timing relay being energized when circuit breaker 22 is cut in, is de-energized only when the afterburner is turned on after the operation of fuel pressure warning mechanism ДСД-2 and relay 58 (58a).

When the winding of relay PBB-I is de-energized, the contact system of the latter closes 0.3 to 0.5 sec. after the operation of fuel pressure warning mechanism ДСД-2 takes place.

Incorporated in the pipeline feeding hydraulic fluid to the cylinders controlling the shutters in the augmented position, is hydraulic switch УГ34/I 34 (34a), whose normally closed contacts are opened under the pressure of hydraulic fluid 0.1 sec. after the operation of fuel pressure warning mechanism ДСД-2 takes place.

The contact systems of hydraulic switch УГ34/I 34 (34a) and of timing relay PBB-I 54 (54a) are connected into the circuit of the winding of relay 53 (53a) (the contacts of hydraulic switch УГ34/I are connected to the circuit plus, the contacts of relay PBB-I to the circuit minus).

If there is no pressure in the pipeline feeding hydraulic fluid to the shutter control cylinder by the time the contacts of timing relay PBB-I are closed, the contacts of timing relay PBB-I and of hydraulic switch УГ34/I will close at the same time thereby energizing relay 53 (53a). Relay 53 (53a) will cut off electromagnet 9 (9a) of the HP-11A pump, discontinuing fuel delivery into the afterburner manifold. Relay 53 (53a) will remain closed until the engine control lever is moved from the "Afterburner" (Форсаж) stop.

With the shutter hydraulic system operating normally, hydraulic switch УГ34/I opens its contacts before the contacts of relay PBB-I are closed, therefore relay 53 (53a) will not pick up and fuel will continue to flow into the afterburner manifold.

The equipment operates as follows.

When the engine control lever is shifted to the "Afterburner" (Форсаж) stop, electromagnet 9 (9a) and relay 55 (55a) become energized through circuit breaker 22 (22a), terminal 19 of afterburner control unit 59, contacts 8 and 7 (5 and 4) of relay 57, via terminal 22 of afterburner control unit 59 and terminal 23 of plug connector 15, the contacts of limit switch 3 (3a) of the HP-10A pump hydraulic decelerator, limit switch Ф of control panel 5 (5a), terminal 29 of plug connector 15 and terminal 12 of afterburner control unit 59, contacts 5 and 4 of relay 53 (53a), terminal 4 of afterburner control unit 59, terminal 12 of plug connector 15, and via cut-in switch BK. Electromagnet 9 (9a) controls fuel supply into the afterburner manifold.

Relay 55 (55a), energized via contacts 5 and 4 of relay [illegible], provides for energizing the supply circuit of slide valve [illegible] 33 (33a), and of booster coil КПМ-IA 8 (8a). Afterburner pilot lamp 36 (36a) lights up being supplied via circuit breaker 25 and contacts 5 and 6 of relay 55 (55a).

When afterburner fuel pressure warning mechanism [illegible] 6 (6a) operates, relay 58 (58a) is energized via circuit breaker 22, terminal 17 of plug connector 15 and the contacts of fuel pressure warning mechanism 6(6a), terminal 18 of plug connector 15 and terminal 34 of afterburner control unit 59.

Current is fed to terminal 1 of slide valve [illegible] [illegible] connector via circuit breaker 25, terminal 10 of afterburner control unit 59, contacts 5 and 6 of relay 55 (55a), contacts 8 and 9 of relay 58 (58a) and terminal 14 of afterburner control unit 59. The jet nozzle shutters shift to the augmented position.

Simultaneously, when relay 58 (58a) picks up, current is fed to booster coil 8 (8a) via circuit breaker 22, terminal [illegible] of afterburner control unit 59, contacts 2 and 3 of relay [illegible] (58a), contacts 9 and 8 of relay 55 (55a), contacts 4 and [illegible] of relay 52 (52a), terminal 6 of afterburner control unit 59, and terminal 2 of plug connector 15.

When the pressure of afterburner fuel reaches its maximum value, the piston of the HP-11A pump afterburner cock will cut in limit switch 4 (4a), which will supply current to the winding of relay 52 (52a) via circuit breaker 22 (22a), terminal 19 of afterburner control unit 59, contacts 8 and 7 (4 and 5) of relay 57 and terminal 22 of afterburner control unit 59, terminal 23 of plug connector 15, limit switch 3 (3a) of the HP-10A pump hydraulic decelerator, limit switch Ф of control panel 5 (5a), terminal 29 of plug connector 15, terminal 4 of the same plug connector and limit switch 4 (4a) of the HP-11A pump, terminal 30 of plug connector 15 and terminal 11 of afterburner control unit 59.

Contacts 4 and 5 of relay 52 (52a) open the supply circuit of booster coil 8 (8a). By this time, stable burning of fuel should take place in the afterburner.

When the afterburner is turned off, limit switch Ф of control panel 5 (5a) de-energizes electromagnet 9 (9a) of the HP-11A pump and relay 55 (55a). The latter breaks the supply circuit of booster coil 8 (8a), terminal 1 of the plug connector of slide valve 33 (33a) and of pilot lamp 36 (36a). No more fuel is supplied into the afterburner manifold; the afterburner pilot lamp goes out.

When excess fuel pressure in the afterburner manifold drops below 0.2 kg/sq.cm., fuel pressure warning mechanism ДСД-2 6 (6a) will de-energize relay 58 (58a) whose normally closed contacts 4 and 5 will complete the supply circuit of control panel 5 (5a) limit switch "З".

Depending on the position of the engine control lever, the jet nozzle shutters will shift to the maximum, normal, or augmented position (at idle rating).

In case there is no hydrulic pressure in the pipeline controlling the shutters in the augmented position, when the afterburner is turned on, current is delivered to relay 53 (53a) from limit switch Ф of control panel 5 (5a) via terminal 29 of plug connector 15, through contacts 1 and 2 of hydraulic switch УГ34/I 34 (34a) and terminal 5 of afterburner control unit 59. The other end of the winding of relay 53 is connected via contacts 1, 2, 3 of relay PBB-I 54 (54a) to terminal 16 of afterburner control unit 59, connected to the frame. Relay PBB-I 54 (54a) is energized via circuit breaker 22 (22a) and

contacts 2 and 1 of relay 58 (58a); it is de-energized when relay 58 (58a) picks up, that is, when fuel pressure warning mechanism 6 (6a) operates. When de-energized, the contacts of relay PBB-1 are closed. Contacts 4 and 5 of energized relay 53 (53a) open the supply circuit of the HP-11A pump electromagnet 9 (9a) and of relay 55 (55a); relay 53 (53a) remains energized until the engine control lever is moved from the "Afterburner" (Форсаж) stop; it is supplied with current via limit switch Ф of control panel 5 (5a), terminal 29 of plug connector 15; terminal 12 of afterburner control unit 59 and its contacts 5 and 6; the other end of the winding of relay 53 is connected to terminal 16 of the afterburner control unit via its contacts 2 and 3.

SUPPLY OF AIRCRAFT AND ENGINE POWER CONSUMERS AND BOOST-CHARGING OF AIRCRAFT STORAGE BATTERIES

(Starter-Generator ГСР-СТ-6000А Operates as Generator)

After the starting cycle is completed, starter-generator 14 (14a), driven by the engine, passes over to the generator duty.

The shunt winding of the starter-generator is connected in parallel with the armature to terminal Г of minimum-differential relay ДМР-400 62 (62a) via terminal 28 of starting box 38, contacts 7 and 6 of relays 42 (42a) and 43 (43a), terminal 29 of starting box 38, terminals A and Б of voltage regulator 61 (61a), terminals 6 and 7 (5 and 8) of relay 68.

Under the influence of self-excitation the generator starts to deliver increasing voltage. When voltage reaches 18 V, relay 29 (29a) picks up, thereby opening the circuit of button "Starting" (Запуск) 31 (31a) and preventing the starter-generator from passing over to the starting duty with the engine running (the relay is de-energized when voltage drops to 5 V).

When switch 69 (69a) is closed, minimum-differential relay 62 (62a) connects the generator into the aircraft mains in parallel with storage batteries 71 and 73.

This connection is accomplished as follows.

Current from terminal Г of minimum-differential relay 62 is fed to the plus terminal of relay 62 (62a) via contacts 5 and 4 (7 and 8) of relay 70 and switch 69 (69a); further it is delivered to the winding of relay П. The contact system of relay П closes, as a result of which the winding of relay P, polarized by a permanent magnet, appears to be kept at P.D. of the generator and the aircraft mains (terminals Г and Б).

When voltage delivered by the generator happens to be lower than that of the aircraft mains, the contacts of relay P are open. As soon as voltage supplied by the generator exceeds the voltage of the aircraft mains, the contacts of relay P close and current is fed to the winding of contactor K which connects the generator into the aircraft mains.

Simultaneously with energizing contactor K, current is supplied from terminal A of relay 62 (62a) to the winding of relay РП-2 64 (64a), whose contacts 1 and 2 open the circuit of the pilot lamp of generator 65 (65a), thereby switching off the lamp.

A burning lamp indicates that the generator is disconnected from the mains, which, with the engine running normally, is an evidence of some trouble in the electric system.

During autonomous starting (when switching the storage batteries over to 48 V) or when an external power supply is connected, the contacts of relay 70 open the supply circuit of winding П of minimum-differential relay ДМР-400 , thereby preventing the relay from being energized at high voltage and when starting the engine from a powerful external source.

Voltage across the generator terminals (28±1.5 V) is maintained at a constant level by voltage regulator 61 (61a).

The main component of the regulator is a carbon rheostat, connected into the circuit of the shunt excitation winding.

With an increase in the engine speed, voltage across the generator terminals begins to grow. This results in an increase of the electromagnetic force of the operating winding, acting on the main spring of carbon pile voltage regulator 61 (61a). This causes the resistance of the carbon pile to increase, thereby reducing the current in the generator shunt winding, which leads to a decrease in the voltage across the generator terminals.

With the engine speed reduced, the above process will be reversed.

When both starter-generators operate as generators, equal distribution of load between them is ensured by corresponding connection of the windings affecting the resistance of the carbon

rheostats of the voltage regulators (terminals Г and Д) and of ballast resistors 16 (16a).

Uneven load distribution disturbs the balance of voltages taken off the ballast resistors.

Direct equalizing current will flow along the windings of the voltage regulators (terminals Г and Д).

The resistance of the carbon rheostats will be changed so that equality of voltages, and consequently of the generator loads will be restored.

The voltage regulator operates in conjunction with stabilizing transformer ТП 63 (63a).

ELECTRIC EQUIPMENT OPERATING ON 24 V

The main characteristic feature of the 24 V system is that the storage batteries are not changed over to series connection when starting the engine from any power source. This feature accounts for some differences in the electric equipment and for absence of some units as compared to the 24 – 48 V system.

Power Sources

Similarly to the 24 – 48 V system, the main power source in the 24 V system is starter-generator ГСР-СТ-6000А described above.

Engine Starting Units

(1) The starter-generator with starting equipment.

(2) Booster coil unit КП-21БІИ with spark plugs СД-96.

(3) Electric motor МУ-102А for starting fuel pump ПНР-10-9И , the starting fuel magnetic valve, and the magnetic valve controlling the air blow-off band.

The starting system units enumerated above are the same for the 24 V and 24 – 48 V systems, with the exception of the starting equipment.

The starting equipment is comprised of starting box ПКС-6000Е and two relays РП-2 .

The starting box (Fig.147) incorporates: timer АВП-1БЕ , three small size contactors КМ-200Д, five magnetic relays РЛ-20Г, two magnetic relays РП-3 , and a starting resistor rated at 0.28 ohm.

Timer АВП-1БЕ consists of electric motor of the Д5-ТР type with a centrifugal speed governor and an electromagnetic retarding clutch, a reduction gear with four profiled cams, four limit switches of the KB-6 type and relay РП-9Т .

Switches KB-6 are set to operate within the following periods/from the moment button "Starting" (Запуск) is pressed/:

1st switch . . . . 0.5 ± 0.2 sec.
2nd switch . . . . 1.3 ± 0.2 sec.
3rd switch . . . . 3.8 ± 0.2 sec.
4th switch . . . . 8.5 ± 0.3 sec.
Complete cycle . . . . 44.3 ± 0.5 sec.

The starting box has terminal bolts receiving the supply conductors running from the starter-generator, and a plug connector for connection of the control circuits.

Two relays РП-2 , included in the starting equipment, serve to prevent the starting cycle from being switched on when the engine is running.

The starting equipment is mounted on the aircraft and serves for starting both engines.

Electric Equipment Controlling Engine Maximum and Augmented Ratings

Engine operation at maximum and augmented ratings is controlled by the following electric equipment:

(1) Control panel ПУ-3.
(2) Booster coil КПМ-IA with spark plug СП-02 .
(3) Two-position slide valves ГА-2I.
(4) The electromagnet of the HP-11A fuel pump.
(5) Afterburner control unit КАФ-2.
(6) The limit switch of the HP-11A pump.

The above units have been described elsewhere in this book.

Afterburner control unit КАФ-2 (Fig.148) differs from afterburner control unit КАФ-2А (used in the 24 - 48 V system) in that it does not incorporate two stand-by relays РП-3 . However, this does not tell in any way on the operation of afterburner control units КАФ-2 and КАФ-2А .

Maximum and Augmented Rating Blocking Devices

Blocking of maximum and augmented ratings is ensured by the following devices:

(a) the limit switch of the HP-10A pump hydraulic decelerator;

(b) limit switch Л of control panel ПУ-3;
(c) minimum fuel pressure warning unit СД-3;
(d) minimum afterburner fuel pressure warning unit ДСД-2;
(e) hydraulic switch УГ34/I.

The above devices have been described in the preceding Sections.

OPERATION OF ELECTRIC EQUIPMENT IN 24 V SYSTEM

The electric equipment serves for:

(1) Automatic starting of the engine:
(a) autonomous starting of the engine from aircraft storage battery 12САМ-28;
(b) autonomous starting of the engine from the starter-generator of the running engine;
(c) starting of the engine from ground supply sources.
(2) Starting of the engine with manual control of fuel supply.
(3) Starting of the engine in air.
(4) Cranking of the engine.
(5) Setting the engine to maximum and augmented ratings.
(6) Feeding of the aircraft and engine current consumers, as well as boost-charging of the aircraft storage batteries (with the engine running).

Presented in Fig.149 is the diagram of electric equipment for two engines.

To ensure normal functioning of the system the following devices should be switched on:

(1) Generator switch 56 (56a).
(2) Circuit breaker 21 feeding current to starting box ПКС-6000Е.
(3) Circuit breaker 25 supplying energy to the timer and fuel pressure warning mechanism СД-3 .
(4) Circuit breaker 59 energizing afterburner control unit КАФ-2.
(5) Circuit breaker 22 (22a) supplying current to control panel ПУ-3.
(6) Circuit breaker 17 (17a) feeding current to the pilot lamp of the oil pressure warning mechanism and to relay РП-2

preventing the jet nozzle shutters from shifting to the augmented position at altitude, with the engine running at idling speed.

Current is fed to terminal 2 of the plug connector of two-position slide valve ГА-2I 31 (31a) via circuit breaker 59 and contacts 2 and 1 of relay 35 (35a).

Simultaneously, limit switch "3" of control panel 5 (5a) is energized via circuit breaker 59, contacts 5, 4 of relays 39 (39a) and 38 (38a).

Further, depending on the position of switch "3" (that is on the position of the engine control lever) current is fed either via contacts 2, 3 of relay 58 (58a) to terminal 1 of the plug connector of two-position slide valve ГА-2I 30 (30a) (with the jet nozzle shutters in the augmented position), or directly to terminal 2 of the same plug connector (the shutters shift to the normal position).

Limit switch "3" of control panel 5 (5a) operates when the engine control lever is moved by 23° from the Cut-Off (Стоп) stop (as indicated on the control panel dial), which corresponds to an engine speed of 4500 - 6500 r.p.m.

Within the range between the idling rating and the above value the jet nozzle shutters are kept in the augmented position. Starting from the speed exceeding the above limit up to the maximum rating the shutters occupy the normal position.

The shutters are prevented from shifting to the augmented position when the engine is brought to idling speed at altitude, in exactly the same manner as when the 24 - 48 V system is employed.

Automatic Starting of Engine

When the engine is started automatically with the use of the 24 V system, the respective electric equipment functions in the same way, no matter which of the power sources is employed for the purpose (the aircraft storage batteries, external supply, or starter-generator of the running engine).

Starting is accomplished as follows:

(1) shift the engine control lever to the "Low Throttle" (Малый газ) stop;

(2) press button "Starting" 29 (29a) and keep it pressed for 1 to 2 sec. (See Figs 149 and 150).

The components of the electric system operate as follows:

When button "Starting" (Запуск) is pressed, energy is fed to the coil of relay 48 via circuit breaker 25, terminal 16 of starting box 50, terminal 3 of timer 49, the closed contacts of cam II and timer terminal 7, terminal 15 of starting box 50, starting button 29, contacts 2 and 1 of relay 28, terminal 5 of starting box 50, and contacts 1 and 2 of relay 48a. The other end of relay 48 coil runs to the minus of the aircraft mains via the minus terminal of starting box 50 and terminal 16 of afterburner control unit 34.

Contacts 8 and 9 of energized relay 48 (48a) feed current to timer terminal 2 and further to the winding of the timer motor (the other end of the motor winding is connected to the minus of the aircraft mains via timer terminal 6). Simultaneously, current is fed to timer blocking relay РЛ-9Х through the contacts of switch 1, set in the initial position. The motor starts running thereby turning switch cams I, II, III, and IV.

Timer switch I operates 0.5 sec. later.

The timer motor is energized directly via circuit breaker 25, starting box terminal 16, timer terminal 3, and the contacts of switch 1, by-passing the starting button. Button "Starting" (Запуск) 29 (29a) now may be released.

Relay РЛ-9Х, being still energized, feeds current to cams II, III, and IV.

Relay 48 (48a) also remains energized being supplied with power through the contacts of switch I, timer terminal 2 and via its contacts 9 and 8.

As the circuit of the "Starting" button runs across the normally closed contacts of relay 48a (48), the possibility of simultaneous starting of both engines is eliminated.

Relay 28 (28a), placed into the circuit of button 29 (29a), prevents starter-generator 14 (14a) from functioning as a starter when the engine is running (with the generator circuit being energized).

Timer switch II operates 1.3 sec. later. The starting cycle comes to its final stage.

Current flows across the closed contacts of cam I, the closed contacts of relay РЛ-9Х, across the contacts of switch II and via timer terminal 4, contacts 6 and 5 of relay 48 (48a) to the coil of relay 46 (46a), and to contactor 42 (42a), while via starting box terminal 13, terminal 21 of plug connector 15, limit switch XП of control panel 5 (5a) and terminal 5 of plug connector 15 energy is supplied to magnetic valve 3a(3) and to relay 45 (45a) via ignition switch 27 (27a) .

As a result, the following equipment is energized:

(a) booster coil unit КП-2IБIМ 10 (10a), starting fuel magnetic valve 13 (13a), ignition pilot lamp 19 (19a) - via circuit breaker 21, starting box terminal 7, contacts 8 and 2 of relay 45 (45a), starting box terminal 10, terminals 32 and 34 of plug connector 15; in this case the booster coil unit is supplied via switch BK of control panel 5 (5a);

(b) electric motor МУ-I02А 26 - via circuit breaker 21, starting box terminal 7, contacts 7 and 3 of relay 45 (45a), and terminal 12 of starting box 50;

(c) the shunt winding of starter-generator 14 (14a) - via circuit breaker 21, starting box terminal 7, contacts 8, 5, 6, 7 of relay 47 (47a), contacts 2 and 8 of energized relay 46 (46a), and starting box terminal 1 (up to this moment the shunt winding has been connected to voltage regulator 52 through contacts 8 and 5 of relay 46);

(d) starter-generator 14 (14a) - from the aircraft mains via starting box terminal 4, starting resistor 43 and contactor 42.

Starting fuel is supplied to the engine and is ignited.

Starter-generator 14 (14a) energized via the starting resistor, gradually takes up clearances in the drive system and starts to smoothly spin the engine rotor. This causes the air blow-off band of the other engine to close the compressor ports (if the engine is running).

In 3.8 sec.switch III of timer 49 operates thereby cutting in contactor 44 and shunting starting resistor 43.

Starter-generator 14 (14a) gains full power and starts cranking the engine more intensively.

In 8.5 sec. switch IV of timer 49 operates and begins to supply current to the coil of relay 47 (47a). Contacts 8, 5, 6 and 7 of energized relay 47 (47a) open the circuit of the shunt winding of starter-generator 14 (14a). The latter starts to operate as a series motor thereby accelerating the engine additionally.

In 44.3 sec. the cam of switch I returns to the initial position and breaks the supply circuit of the relays.

The booster coil unit and the starting fuel pump become inoperative.

Starter-generator 14 (14a) automatically begins to operate as a generator. Its shunt winding is connected to voltage regulator 52 (52a) via contacts 5 and 8 of relay 46 (46a).

Further acceleration of the engine up to idling speed is ensured by the fuel control equipment, with the electric system taking no part in the process.

Within not more than 80 sec. after button "Starting" (Запуск)has been pressed, the engine should be brought to a speed of 100 r.p.m. below the idling rating.

Starting of Engine in Air

With the electric equipment operating on 24 V, engine starting in air differs from the starting procedure used in the case of 24 - 48 V in that no timer is employed.

Starting should be performed as follows:

(1) shift the engine control lever to the "Low Throttle" (Малий газ) stop;

(2) set ignition switch 27 (27a) in the "Starting in air" (Запуск в воздухе) position.

Current flows directly from the aircraft mains to relay 45 (45a) via ignition switch 27 (27a), circuit breaker 21, and terminal 8 of starting box 50; as a result, energy from the aircraft mains is fed to the booster coil unit, starting system magnetic valve, and to the starting fuel pump motor via circuit breaker 21, terminal 7 of starting box 50, and contacts 7, 3, 8, and 2. The following units start to operate: booster coil unit 10 (10a), electric motor МУ-I02А of starting pump 26, and magnetic valve 13 (13a); pilot lamp "Ignition" (Зажигание) lights up.

The starting cycle completed, turn off the ignition switch; this should cause pilot lamp "Ignition" (Зажигание) to go out.

Engine Starting with Manual Control of Fuel Supply

This method of engine starting differs from automatic starting in that fuel supply into the engine is controlled manually by manipulating the engine control lever.

The engine starting should be accomplished as follows:

(1) press button "Starting" (Запуск), and keep it pressed for 1 to 2 sec; the starter-generator will crank the engine just as in the case of the automatic starting;

(2) move the engine control lever in a smooth, slow manner to feed main fuel into the engine; accelerate the engine to idling speed.

Switching on of ignition occurs simultaneously with fuel supply into the engine (when operation of control panel switch XП takes place).

Cold Cranking of Engine

During cold cranking the engine is spinned by the starter-generator, with fuel supply and ignition cut off (the engine control lever is set in the "Stop" position).

To perform cold cranking, button "Starting" (Запуск) 29(29a) should be kept pressed for 1 to 2 sec.

The starter-generator will operate through the entire starting cycle thereby spinning the engine to 800 - 1100 r.p.m.

In case the engine is to be cranked to a lower speed, the starting cycle is interrupted by turning off circuit breaker 25. To prepare the timer for subsequent starting (or cold cranking) after the rotor is stopped, it is necessary to turn on circuit breaker 25 for 30 to 40 sec. to enable the timer to complete the interrupted cycle.

Turning Maximum Rating On and Off

Maximum rating is turned on by setting the engine control lever at the "Maximum" (Максимал) stop, which causes operation of control panel 5 (5a) switch M (See Figs 149 and 151).

As a result, current will flow to relay 35 (35a) via circuit breaker 22 (22a), terminal 19 (17) of the plug connector of afterburner control unit 34, contacts 8 and 7 (5 and 4) of relay 41 (which blocks maximum and augmented ratings depending on minimum fuel pressure in the aircraft booster system), terminal 22 (23) of the afterburner control unit plug connector, contacts 4 and 5 of relay 58 (58a), terminal 23 of plug connector 15 (15a), the contacts of switch 4 (4a), the contacts of

control panel switch M, terminal 10 of plug connector 15 (15a), and terminal 3 (36) of afterburner control unit plug connector.

Relay 35 (35a) closes contacts 2 and 3 thereby switching over supply from terminal 2 of slide valve 31 (31a) to terminal 1. Slide valve 31 (31a) changes over hydraulic fluid supply into the cylinders controlling the jet nozzle shutters. The jet nozzle exhaust area decreases.

To switch-off maximum rating, the engine control lever is shifted from the "Maximum" (Максимал) to the "Normal" (Номинал) stop. Limit switch M of control panel 5 (5a) opens the supply circuit of relay 35 (35a), as a result of which supply will be switched over from terminal 1 of slide valve 31 (31a) to terminal 2. The slide valve returns to the initial position thereby causing the shutters to shift to the "Normal" (Номинал) position.

Turning Augmented Rating On and Off

To turn on augmented rating, the engine control lever is set at the "Afterburner" (Форсаж) stop.

The energized switch Ф of the control panel will direct current to afterburner pump solenoid 9 (9a) (See Figs 149, 151) via circuit breaker 22 (22a), terminal 19 (17) of the plug connector of afterburner control unit 34, contacts 8 and 7 (5 and 4) of relay 41, terminal 22 (23) of the afterburner control unit plug connector, contacts 4 and 5 of relay 58 (58a), terminal 23 of plug connector 15 (15a), the contacts of switch 4 (4a) of the HP-10A pump, the contacts of control panel switch Ф, terminal 29 of plug connector 15 (15a), terminal 12 (26) of the afterburner control unit plug connector, contacts 5 and 4 of relay 36 (36a), terminal 4 (30) of the afterburner control unit plug connector, terminal 12 of plug connector 15 (15a), and switch BK of control panel 5 (5a).

The HP-11A pump starts delivering fuel into the afterburner manifold.

At the same time, contacts 2 and 3 of energized intermediate relay 39 (39a) switch on afterburner pilot lamp 23 (23a) and prepare the supply circuit of two-position slide valve ГА-21 30 (30a) and the booster coil [illegible]-1A 8 (8a).

Synchronization of jet nozzle shutter opening and fuel pressure rise in the afterburner manifold is provided for by fuel pressure warning mechanism ДСД-2 . When fuel pressure in the afterburner manifold comes to exceed the full pressure of gases aft of the turbine by 0.2 kg/sq.cm., the contacts of fuel pressure warning mechanism ДСД-2 12 (12a) will close thereby supplying energy to the coil of relay 38 (38a) via circuit breaker 22 (22a), terminal 17 of plug connector 15 (15a), the contacts of the warning mechanism, terminal 18 of plug connector 15 (15a), and terminal 34 (35) of the plug connector of afterburner control unit 34.

Relay 38 (38a) picks up thereby directing current to terminal 1 of two-position slide valve 30 (30a) via circuit breaker 59, terminal 10 of the afterburner control unit plug connector, contacts 5 and 6 of relay 39 (39a), contacts 8 and 9 of relay 38 (38a), and terminal 14 (28) of plug connector 34. The jet nozzle shutters shift to the augmented position.

At the same time, relay 38 (38a) energizes booster coil КПМ-IA 8 (8a) via circuit breaker 22 (22a), terminal 19 (17) of the plug connector of afterburner control unit КАФ-2 34, contacts 2 and 3 of relay 38 (38a), contacts 9 and 8 of relay 39 (39a), contacts 4 and 5 of relay 40 (40a), terminal 6 (27) of the plug connector of afterburner control unit 34, and terminal 2 of plug connector 15 (15a). Spark plug СП-2 7 (7a) starts to function thereby igniting afterburner fuel.

When afterburner fuel pressure reaches its full value, that is when the HP-11A pump afterburner cock piston comes up against the cock maximum opening stop, limit switch 6 (6a) of the HP-11A pump operates and begins to supply energy to relay 40 (40a) from switch Ф of control panel 5 (5a) via terminals 29 and 4 of plug connector 15 (15a), contacts of switch 6 (6a), terminal 30 of plug connector 15 (15a), and terminal 11 (25) of the afterburner control unit plug connector.

Contacts 4 and 5 of relay 40 (40a) open the supply circuit of booster coil КПМ-IA 8 (8a).

By this time stable fuel combustion should take place in the afterburner. The engine starts to operate at augmented rating.

To prevent fuel supply to and its combustion in the afterburner, with the jet nozzle shutters closed, the afterburner control equipment is provided with hydraulic switch УГ34/I ;

the contacts of the switch open when pressure is supplied into the pipe line feeding hydraulic fluid into the interpiston spaces of the shutter control cylinders.

Hydraulic switch УГ34/I operates in conjunction with timing relay PBB-1, accommodated in afterburner control unit КАФ-2 ; the contacts of hydraulic switch УГ34/I and timing relay PBB-1 are connected into the circuit of the coil of blocking relay 36 (36a).

When the contacts of fuel pressure warning mechanism ДСД-2 12 (12a) close, contacts 2 and 1 of relay 38 (38a) cut off supply from the coil of relay PBB-1 37 (37a), and the contact system of relay PBB-1 closes for 0.3 to 0.5 sec.

If, by the time the contacts of relay PBB-1 close, there is no pressure in the pipe line feeding hydraulic fluid into the interpiston spaces of the shutter control cylinders, the contacts of hydraulic switch УГ34/I 32(32a) will remain closed, as a result of which relay 36 (36a) will pick up, opening the supply circuit of the HP-11A pump by its contacts 4 and 5.

Thus, the flow of afterburner fuel will be stopped.

Augmented rating can be switched on for the second time only after the engine control lever is removed from the "Afterburner" (Форсаж) stop, as energized relay 36 (36a) will be blocked by its contacts 5, 6 and 3, 2 and will remain switched on until the engine control lever is shifted from the "Afterburner" stop.

To switch off augmented rating, the engine control lever is removed from the "Afterburner" stop; this causes limit switch Ф to open the supply circuit of the afterburner pump solenoid and of intermediate relay 39 (39a). Fuel supply into the afterburner manifold is cut off. When the value of excess fuel pressure in the afterburner manifold(the value above the full pressure of gases aft of the turbine) drops below 0.2 kg/sq.cm., fuel pressure warning mechanism ДСД-2 will open its contacts thereby de-energizing relay 38 (38a).

Depending on the position of the engine control lever, the jet nozzle shutters will shift to the maximum, normal, or augmented position (at idling speed).

Functioning of Electric Equipment during Corrosion Preventive Treatment of Engine

To subject the engine interior to corrosion-preventive treatment or to remove corrosion-preventive compound, the engine fuel system should be flushed with oil or fuel, respectively, without switching on ignition. This is done by setting control panel ПУ-3 switch ВК in the "Corrosion-preventive treatment" (Консервация) position.

As a result, the contacts of switch ВК will open the supply circuit of booster coil unit КП-21БІМ 10 (10a) and switch on the solenoid of НР-11А fuel pump 9 (9a), current being supplied directly from the aircraft mains via circuit breaker 22 (22a) and terminal 11 of plug connector 15 (15a).

To treat the engine interior or to remove corrosion-preventive compound, the starter-generator is switched on by pressing the button, and operates through the entire starting cycle.

Switch ВК, opening the supply circuit of booster coil unit КП-21БІМ prevents ignition from being switched on, while energized solenoid of the НР-11А pump provides for pumping of oil through the afterburner fuel system.

Supply of Aircraft and Engine Power Consumers and Boost-Charging of Aircraft Storage Battery (Starter-Generator Operates as Generator)

After the starting cycle is completed, the starter-generator driven by the engine automatically passes over to the generator duty. The shunt winding is connected in parallel with the armature to terminal Г of differential-minimum relay 53 (53a) via terminal 1(3) of the plug connector of starting box 50, contacts 8 and 5 of relay 46 (46a), terminal 2 (4) of the plug connector of starting box 50, and terminals А and Б of voltage regulator Р-25А 52 (52a).

Under the influence of self-excitation, the generator starts to deliver increasing voltage.

When voltage reaches 18 V, relay 28 (28a) picks up and opens the circuit of button "Starting" (Запуск) 29 (29a), preventing the starter-generator from passing over to the starting duty with the engine running.

When switch 56 (56a) is closed, differential-minimum relay 53 (53a) connects the starter-generator into the aircraft mains in parallel with the storage battery.

This connection is accomplished as follows.

Current ("plus") from terminal Г flows to the "plus" terminal of relay 53 (53a) via switch 56 (56a), and is further delivered into the coil of relay П . The contact system of relay П closes, as a result of which the winding of relay Р polarized by a permanent magnet, is kept at P.D.
of the generator and the aircraft mains (terminals Г and Бат).

So far as the voltage delivered by the generator remains lower than that of the aircraft mains, the contacts of relay Р are kept open. As soon as voltage supplied by the generator exceeds the voltage of the aircraft mains, the contacts of relay Р close and current is supplied to the winding of contactor К which will connect the generator into the aircraft mains.

Voltage across the generator terminals is maintained at a constant level, irrespective of engine speed, by voltage regulator Р-25А 52 (52a).

The main component of the regulator is a carbon rheostat connected into the circuit of the starter-generator shunt excitation winding.

A change in voltage across the generator terminals due to a change in the engine speed causes the carbon rheostat to change its resistance. Excitation current will change too thereby making up for the change in the engine speed, as a result of which the voltage across the generator terminals will be restored to its preset constant value.

Equal distribution of loads between the generators operating in parallel is ensured by corresponding connection of the windings of carbon pile voltage regulators Р-25А and ballast resistors БС-6000.

The voltage regulator operates in conjunction with stabilizing transformer ТІГ .

Generator operation is checked by the indications of pilot lamp 55 (55a). The pilot lamp lighting up indicates that the generator is cut off from the aircraft mains; with the engine running normally, it testifies to a faulty electric system.

Chapter XI

ENGINE MEASURING INSTRUMENTS

Engine operation in flight is checked by the indications of the instruments measuring engine speed, oil pressure at the engine inlet, and the temperature of gases aft of the turbine (Fig.152).

Engine speed is measured by an electric tachometer consisting of generator ДТ-3 and indicator 2ТЭ-I5-I.

Tachometer generator ДТ-3 is mounted on the engine accessory gear box flange, while indicator 2ТЭ-I5-I is arranged in the cockpit.

Oil pressure at the engine inlet is measured by oil pressure warning mechanism 2СДУ5-I.3-3, mounted on the bracket of the engine control equipment wire bundle jacket and connected to the pilot lamp arranged in the cockpit.

Two-stage oil pressure warning mechanism 2СДУ5-I.3-3 indicates (by the pilot lamp) a drop in oil pressure down to 1.3 kg/sq.cm. when engine speed is below 9700_{-100} r.p.m., and down to 3 kg/sq.cm., with the engine speed exceeding the above value.

Gas temperature aft of the turbine is measured by thermometer ТВГ-II, which is a thermoelectric set consisting of a moving coil millivoltmeter and four thermo-couples connected in series.

The thermo-couples are inserted into the pipe unions located on the afterburner diffuser at a distance of 250 mm from the flange attaching the diffuser to the turbine.

The engine is furnished with four thermo-couples, the remaining five pipe unions being plugged.

Arrangement of the thermo-couples for the right-hand and left-hand engines is illustrated in Fig.152.

The millivoltmeter graduated in °C is located in the cockpit.

Thermo-couples ТВГ-II are installed at the aircraft manufacturing plant. For carrying out special or periodic checks when adjusting engine operation on a stand or in the field, the engine is furnished with special pipe union-valves, located in accessible places.

The pipe union-valves serve for measuring the pressure of:

(1) fuel in the auxiliary manifold;

(2) fuel in the starting manifold;

(3) fuel in the pipe lines to the pumps;

(4) fuel in the afterburner pipe line;

(5) oil at the engine inlet; in this case oil pressure is also measured by oil pressure warning mechanism 2СДУ5-I.3-3.

A pipe connection is provided for measuring oil temperature at the engine inlet.

Chapter XII

ATTACHMENT OF ENGINE ON AIRCRAFT AND DURING SHIPMENT

The following attachment fittings serve to mount the engine on the aircraft: side brackets 3 and 4 (Fig.153) and lower bracket 6.

Side brackets 3 and 4 are secured to the flanges of the compressor middle and rear housings by fitted bolts.

Lower bracket 6 is also fastened to the flanges of the compressor middle and rear housings; besides, it is attached to the flanges of the compressor middle housing halves.

Brackets 3, 4 and 6 transmit the stresses arising in the engine to the aircraft load-carrying components.

Bracket 6 is provided with a sphere, facilitating engine mounting and preventing excessive stresses in the joints.

The side brackets differ by their arrangement on the right-hand and left-hand engines (See Fig.153).

The front portion of the engine is fastened to the aircraft by means of three studs 11 provided in the nose bullet support. The front portion is not fixed axially, which permits free temperature extension of engine components.

Two brackets 9, secured to the flange of the rear pipe shell, serve for additional attachment of the afterburner to the aircraft structure. Each of the brackets has two holes 10 for hoisting devices.

The split ring of the diffuser-to-afterburner pipe telescopic joint has two plates 8 which receive shipping and hoisting hangers secured by bolts 2.

With the hangers removed, the bolts are fitted in place and locked.

The compressor inlet housing-to-middle housing joint is fitted with six bolts 1, while the joint between guide vane assemblies has six holes 7; two upper bolts and two holes are used for hoisting the engine, whereas four lower holes serve to secure the engine inside the case during shipment.

Two holes 5 made at the joint of the flanges of the compressor middle and rear housings serve for attachment of the engine to the truck when installing the engine in the aircraft.

Chapter XII

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