PART 1 : SECTION 3

CHAPTER 11

STARTING SYSTEMS

Introduction

1. Owing to the wide variety of starters in service, only representative types are described in this chapter. There are three main classes of starters to be considered :—

(*a*) Electric starters.

(*b*) Cartridge turbo-starters (single, twin, and triple-breech types).

(*c*) Compressed air starters.

Pilots' Notes give detailed operating instructions for the type of starter fitted to a particular aircraft.

ELECTRIC STARTER

Principles

2. Electric starters are used on some types of engines but they suffer from the disadvantage of a relatively low-power output from the motor, and a period of about ten seconds or more is therefore required before the engine r.p.m. reach a self-sustaining speed ; this delay, although seemingly negligible, can have a marked effect on the time taken to scramble fighter aircraft. The starting procedure is carried out by an automatic starter panel which controls the entire sequence of starting.

3. An electrical ignition system is used in conjunction with the starter panel and booster coils. The starter motor, torch igniters, booster coils, and torch-igniter feed-pump, are all connected to the starter panel, which has a time switch and relays. When the starter button is pressed and released the time switch automatically controls the correct sequence of the starting cycle. On later engines the torch igniter system is replaced by high-energy igniter plugs.

4. Ground batteries are normally used to power the starter motor, although aircraft batteries may be used in emergency. Each engine in twin or multi-engined aircraft normally has its own starter panel. Switches are fitted to isolate the ignition system during servicing operations.

5. Some engine installations use either the electric starter or the cartridge turbo-starter, the starter engaging mechanism being designed to cater for both.

SINGLE-BREECH CARTRIDGE TURBO-STARTER

Description

6. The Rolls Royce single-breech turbo-starter consists of a small impulse turbine unit driven by the gas generated by a burning cordite-charged cartridge. The drive from the turbine is transmitted to the engine by two epicyclic gear trains giving an overall starter-rotor to engine ratio of 26·5 to 1. Engagement with the engine is effected automatically by the cartridge gas pressure. The peak output of the starter is about 250 H.P. At normal air temperatures the starter accelerates an Avon engine to about 1,700 r.p.m. in roughly two seconds. At this point the engine is self-sustaining and able to accelerate to idling r.p.m. under its own power.

7. The turbo-starter is inside the engine nose fairing where it is readily accessible for reloading and conveniently situated for driving the compressor shaft through its compound gear train and an engagement dog. An automatic time switch controls the starting cycle when the starter button is pressed. The automatic time switch runs for 30 seconds after the starter button is momentarily pressed. The time switch fires the cartridge and switches on the current to the torch-igniter valves, torch-igniter feed-pump, and booster coils.

8. The burning charge produces a pressure of about 1,000 lb./sq. in. for just over two seconds under normal working conditions, and a safety disc is provided to protect the unit in the event of this pressure being exceeded. When the cartridge is fired, pressure builds up and forces an operating valve on to its seat. This permits the gas pressure to pass through two inlet pipes to two nozzles which direct the gas on to the blades of the turbine (Fig. 1). Two exhaust pipes carry the gas from the turbine and discharge it clear of the engine air intake.

9. The cartridge has a cordite composition charge which is retained by a grid in the mouth of the case. The grid prevents the plastic charge from moving into the breech while burning, thereby blocking the outlet passages. In the end of the cartridge case there is a primer which

consists of a small container filled with a gunpowder mixture. This container is in electrical contact with the cartridge case, and has an insulated centre contact connected to a fuse wire running through the gunpowder mixture to earth on the primer body. The passage of electric current through this wire heats it sufficiently to ignite the primer gunpowder and fire an igniter charge consisting of a gauze bag of larger grained gunpowder positioned between the primer and the cartridge.

Overspeed Device

10. A shroud ring is located between the inlet casing and the exhaust casing of the turbine housing. The fine clearance between the tips of the turbine blades and the shroud ring is such that any overspeeding of the rotor causes the blades to stretch and rub on the ring with a consequent braking effect, thus constituting an overspeed safety device.

Breech

11. The breech consists of three separate sub-assemblies : a cap, a barrel, and base. In the breech cap, which screws on to the breech barrel, there are two pairs of spring-loaded claws. One pair form a positive locking device to prevent the cap vibrating loose from the barrel, and until pressure is applied on the plunger in the centre of the cap these claws lock in the serrations on the barrel. The other two claws hold the rim of the cartridge and extract it when the breech cap is removed. To remove the cartridge case from the breech cap the claws are retracted by finger pressure on two small plungers adjacent to the large central plunger. The breech barrel is screwed into the breech base which houses the safety-disc holder and a guide for the operating valve. The safety-disc is of the shear type and is designed to rupture should the pressure within the breech rise to about twice the normal working pressure, but after continued use it may fail from fatigue. The sheared disc is retained by a perforated safety-disc housing shown in Fig. 1 and Fig. 2.

Electrical Connections

12. A lead from the engine starting circuit is connected to a resistor on the breech case. From the resistor the current flows through the spring blade connector (Fig. 2), which contacts the slip ring in the breech cap when the cap is screwed fully on to the breech barrel. The slip ring is connected to the spring-loaded firing pin in the breech cap by strip connections. The firing pin bears on an insulated centre contact in the base of the cartridge to complete the electrical circuit, through the cartridge fuse, when the firing button is pressed.

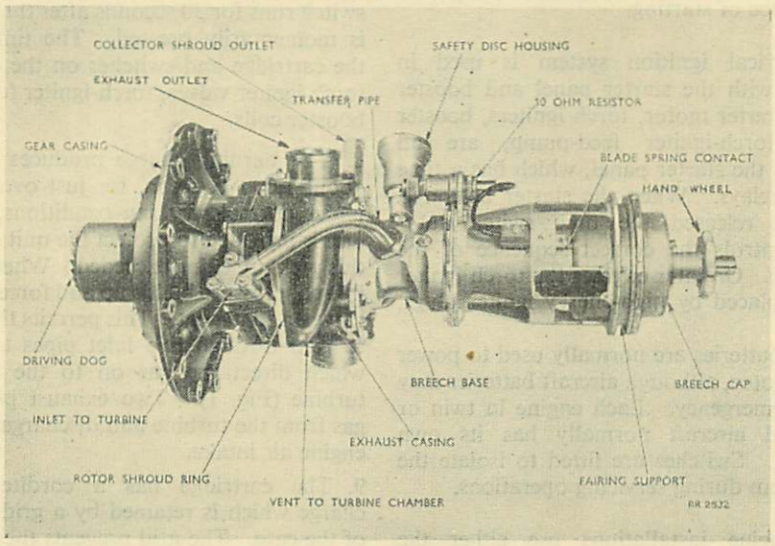


Fig. 2. Turbo-Starter Unit.

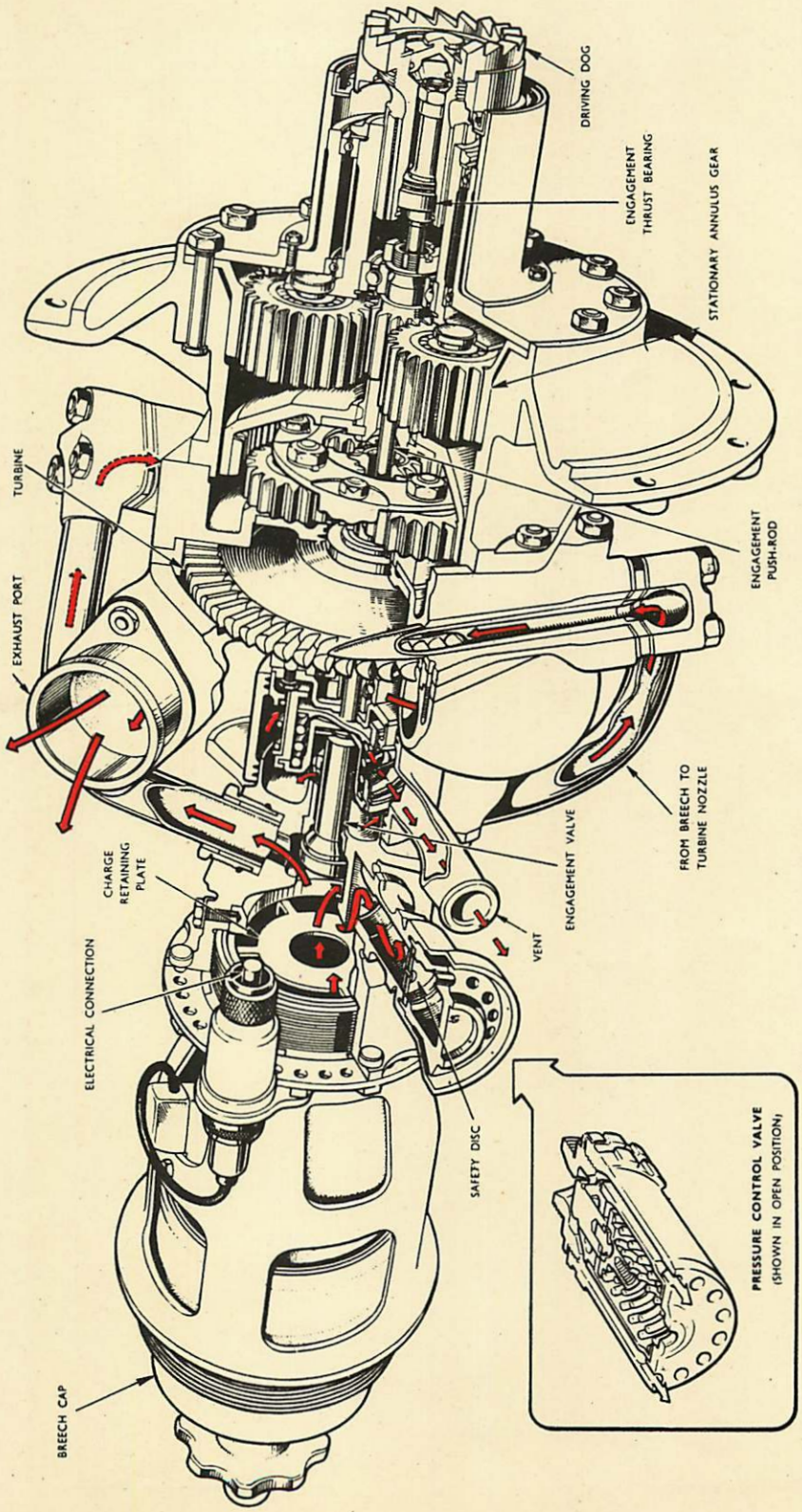


Fig. 1. Sectional Perspective View of a Turbo-Starter

Engagement Mechanism

13. Details of the engagement mechanism are shown in Fig. 3. The operating valve is carried in a guide in the breech base and restricts the passage from the breech to the transfer pipes until gas pressure in the breech forces the valve forward on to its seat. Any gas leaking past the operating valve while it is travelling forward is collected in a shroud which encloses the starter-dog spring-loading mechanism, and is passed through the shroud outlet to atmosphere. The forward movement of the valve pushes the valve end cap and push-rod assembly against the driving-dog return spring, and the dog, which is secured on the push-rod, is moved forward into engagement with the engine dog. Should the starter-dog teeth engage tip-to-tip with the engine dog, the thrust from the buffer spring within the valve end cap assembly ensures that engagement takes place as soon as the starter-dog begins to rotate.

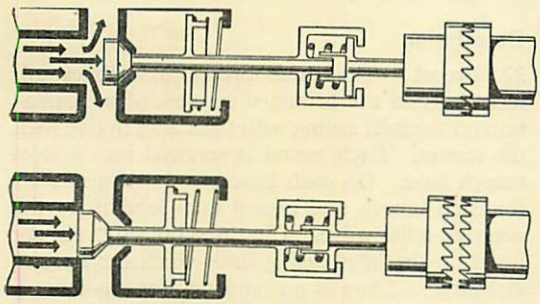


Fig. 3. Details of the Engagement Mechanism.

Loading and Unloading

14. To load the starter, depress the large central plunger in the breech cap and unscrew the cap from the barrel. After removing the cover from the cartridge mouth, fit a cartridge into the breech cap, pushing the cartridge right home so that the two extractor claws clip over the cartridge base ; then insert the assembly into the breech barrel. Screw the breech cap fully home by hand, finger tight only ; this is important as over-tightening may cause jamming and subsequent difficulty in removal after firing. To unload, depress the central plunger and unscrew the breach cap from the barrel, then depress the two small plungers in the breech cap to lift the two spring-loaded extractor claws which grip the rim of the cartridge case so that this can be withdrawn from the breech cap. A check should be made to ensure that no loose residue is left in the breech barrel.

Firing

15. The cartridge is fired electrically from a push-button switch in the cockpit. This switch usually operates a small electric motor, driving a series of cam contacts arranged to switch on the igniters and fire the starter cartridge in a predetermined time sequence.

Precautions

16. All personnel must keep clear of the engine intake, starter exhaust outlets, and jet pipe when an engine is about to be started.

17. If a cartridge fails to fire, wait one minute before unloading, in case of a hang-fire.

18. If the engine fails to light up when the first cartridge is fired, a second cartridge may be fired as soon as the engine stops turning : if two cartridges are fired in quick succession, *not less than ten minutes* must be allowed for the breech to cool before loading each subsequent cartridge.

19. If at any time it is necessary to work on the engine or starter, or to check electrical circuits, ensure that the breech does not contain a live cartridge.

20. If the safety-disc ruptures, a new disc must be fitted before another cartridge is fired. A sudden reduction of breech pressure caused by failure of the safety disc may result in extinction of the charge. If this is suspected, wait until it is certain that no further burning is taking place, then remove the cartridge and check whether any of the charge remains. If so, this must be disposed of according to the safety precautions for the handling of explosives. Cartridge cases are reclaimable after use and care should be taken to avoid damage to them.

Safety Disc Replacement

21. Ensure that the starter breech does not contain a live cartridge (para. 20). Break the locking wire between the safety-disc holder and adaptor, and remove all pieces of wire. Unscrew the safety-disc holder using the special tool. Remove all parts of the sheared safety disc ; the outer portion of the disc remains in the holder and is removed by levering from the small slot in the holder. The safety-disc housings should be thoroughly cleaned out, and engine oil smeared on the disc faces and the housing threads. Fit the new corrugated safety-disc and screw the holder into the adaptor. Lock the disc holder to the adaptor with stainless steel wire.

TRIPLE-BREECH CARTRIDGE TURBO-STARTER

Introduction

22. The type T.B.S.–720 Mk. 1 triple-breech starter consists of a single-stage impulse turbine which is rotated by the kinetic energy of gases liberated from a burning cordite charge. This type is a development of the single-breech turbo-starter. The burning time of the cartridge is about two seconds and during this time the turbine rotor reaches roughly 40,000 r.p.m. and develops about 250 B.H.P. The drive from the turbine is transmitted through an epicyclic reduction gear to the output shaft which drives a second reduction gear in the engine, thus giving the required overall starter-rotor/engine gear ratio. The pressure generated by the burning cartridge is limited to 1,200 lb./sq. in. by pressure relief valves, and this, in conjunction with the sliding shaft arrangement of the rotor, provides an overspeed prevention device.

Starter System

23. This turbo-starter is a self-contained unit which is bolted to the front casing of the engine. The output shaft is splined to engage with the drive shaft of the engine-starter reduction gear ; and with the reduction gear on the starter an overall ratio of 7·5 to 1 is obtained. Since the maximum speed of the starter is 40,000 r.p.m. this raises the engine speed to 5,200 r.p.m. Current for the starter circuit is supplied to the motor, and a resistor is placed in parallel with the firing circuit to prevent electrical leakage firing the starter. The wiring circuit is arranged to ensure that while the selected cartridge is being fired no other cartridges may be fired by a short circuit. The complete starter unit is enclosed in a fairing attached to the starter, and a detachable panel provides access to the starter for loading and unloading. Exhaust gases are conveyed to the outer skin of the aircraft structure clear of the air intakes.

24. The cordite cartridge is contained in a thin brass cylinder with a flanged base in the centre of which is a primer. To ensure a constant gas pressure the cartridge is hollowed out in the centre. The charge becomes plastic while burning, and an expendable grid plate is inserted in the mouth to prevent the burning charge creeping into the breech base and possibly blocking the gas passages.

Method of Ignition

25. The method of ignition is the same as that used for the single-breech cartridge (para. 9).

Gas Flow

26. Each cartridge is fired electrically from a selector switch in the cockpit, and the gases pass to nozzles that discharge into the turbine wheel casing. Each breech barrel is connected to two convergent/divergent (venturi shaped) nozzles from which the gases discharge against the impulse turbine at supersonic velocity. In reaching this high velocity the gas pressure drops from 1,000 lb./sq. in. at the cartridge to atmospheric pressure at the discharge orifice of the nozzle. This conversion from high pressure to high velocity is effected through the convergent/divergent shape of the nozzles, the initial acceleration up to sonic velocity taking place in the convergent passages. After escaping through the narrow throat orifice the gases continue to expand in the divergent section of the nozzle and reach supersonic velocity. After passing through the turbine blades, the gases are deflected by a shield towards three equally spaced exhaust ports, which also prevents the gases swirling back against the turbine.

Description

27. **Breech.** The three breech assemblies are identical and are arranged in clover-leaf formation on the inlet casing with their axes in line with the starter. Each barrel is screwed into a steel breech base. On each base are the two nozzles for each breech and also a duct leading to the pressure-relief valve. The three breech b ses are fitted on the inlet casing into which the nozzles discharge. There is no tendency for gas from a burning charge to affect the remaining live cartridges, since the nozzles of each breech are only open to each other in the low-pressure region where the gases discharge against the turbine.

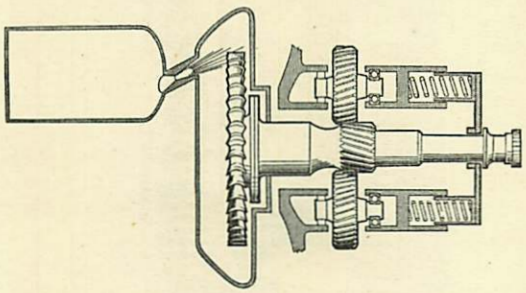
28. The breech cap is secured to the barrel by the method described in para. 11, which also covers the system of extracting the cartridge.

29. **Turbine Wheel.** The sliding turbine shaft passes through the centre of a heat shield where a labyrinth seal is fitted to ensure a gastight joint. The turbine disc is attached to the shaft. The whole assembly, including a sun-wheel which is integral with the shaft, is carried on two roller bearings and slides in a sleeve formed in the front plate of the reduction gear casing. The sun-wheel pinion engages with the three idle wheels of the epicyclic reduction gear ; the sun-wheel pinion is of wider section than the three idle gears to ensure that it is fully in mesh throughout

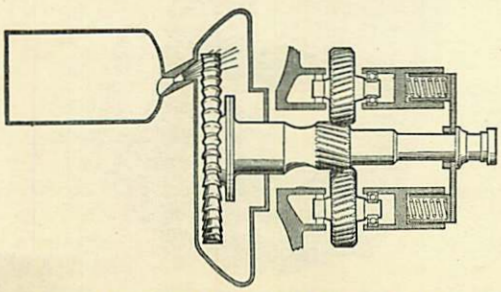
the axial movement of the shaft. Housed in the front plate behind the turbine are the three return springs which control the axial (fore-and-aft) position of the turbine.

30. **Reduction Gear.** The sun-wheel on the turbine shaft meshes with the idle gears, which, in turn, mesh with and rotate an annulus which is carried inside a bell-housing and drives the output shaft. The whole assembly revolves round the turbine shaft pinion. This gear train provides a step-down of 4·5 to 1 between the turbine wheel and the output shaft; a further reduction is obtained through the gears in the engine to which the starter is connected.

31. **Torque Control.** To prevent overspeeding, the gas torque on the turbine can be varied according to the external load. This is achieved by an axial displacement of the turbine wheel on its sliding shaft (Fig. 4) to ensure that the blades receive the full force of the gases from the cartridge *only* when the load imposed calls for the maximum amount of torque. The drive is taken from the sun-wheels, through the three idle gears to the rotating annulus. Helically-cut gearing is used; its effect is to make the sun-wheel move axially when any resistance to turning is being overcome. In overcoming this resistance the turbine slides progressively nearer to the full gas stream, the limit of travel being where the maximum torque is obtained. When sliding to the position of maximum torque, the turbine shaft compresses springs that return the turbine shaft to the starting position as the torque decreases.



A. TURBINE UNDER NO-LOAD CONDITIONS



B. SPRINGS COMPRESSED AND TURBINE RECEIVING FULL TORQUE

Fig. 4. Diagrammatic Illustration of Torque Control.

32. **Overspeed Prevention.** With this provision for axial movement of the turbine between positions ranging from minimum to maximum gas torque the starter becomes, in effect, load conscious and is safeguarded against overspeeding. If a cartridge is fired to start the unit when the engine is already running, the turbine remains in the low gas-torque position until it is actually called upon to drive the engine. Only when the starter is driving under load is sufficient reaction exerted through the helical gears to compress the return springs. The time taken by the starter to overtake the speed of the engine is the same as would be required to accelerate the engine to this speed from rest. This means that there is still sufficient energy in the remaining gases to enable the turbine to accelerate the engine up to its normal starting speed.

33. **Gas-Pressure Control.** Increase in gas pressure creates a rise in torque, therefore the gas pressure must be limited to a suitable maximum under all conditions. The burning characteristics of cordite vary considerably according to climatic conditions, and any increase in temperature causes a rise in gas pressure with a corresponding increase in the torque. Gas pressure is kept within the required limits by the setting of the springs used in the pressure relief valves on each breech. By limiting the gas pressure to 1,200 lb./sq. in., the maximum speed of the starter is limited, even under tropical conditions where the burning time may be accelerated.

34. **Lubrication.** The starter is lubricated by the engine oil system. After every start about 6 c.c. of oil is delivered to the starter. Surplus oil drains back into the plunger cylinder when the engine is shut down. Before starting an engine which has been standing for more than seven days, or using a newly installed starter, the reduction gear should be primed with half a pint of the correct grade of oil.

35. **Loading and Unloading.** This is done for each breech as described in para. 14. Before unloading or reloading the breeches the precautions mentioned in para. 39 must be observed.

36. **Firing.** The cartridges are fired electrically from the cockpit by a push-button which selects the cartridge and energizes a time switch. After pressing the starter button to fire the cartridge, the button is held in until the time switch completes its 30-second cycle, after which the button is automatically reset in readiness for the next start.

Precautions

37. All personnel must keep clear of the engine intake, starter exhaust outlets, and jet pipe when an engine is about to be started.

38. *If a cartridge fails to fire, the next cartridge must be fired only after one minute has elapsed.* After the three cartridges have been fired in the quickest succession allowed (see para. 41), an interval of 10 minutes must be allowed for the breeches to cool before reloading. If another three cartridges are then fired, the next interval before reloading must be extended to 20 minutes to ensure adequate cooling of the breeches.

39. If a cartridge that has failed to fire, or the remnant of a partly burned cartridge, has to be removed from any of the breeches, it must be disposed of according to the recognized precautions for explosives.

40. The starter should be unloaded before anyone starts working on the engine, or the starter, or on electrical circuits.

Use of the Starter Push-Button

41. The starter button should be given a firm push—never jabbed. After a failure to start and before firing the second cartridge, it is normal practice to wait until the starter button is reset after 30 seconds by the time switch. However, this wait is not essential *provided that the first cartridge has fired correctly ;* after an unsuccessful start during which the cartridge has fired normally, switching the ignition OFF and then ON resets the starting cycle and obviates the waiting period, and the next cartridge can then be fired immediately. *This must never be done after a cartridge fails to fire or does so in an unusual manner, e.g. the engine r.p.m. rise is low due to a burst safety disc ; in such cases the full waiting period (one minute) must be observed. Failure to do so can result in severe damage and a strong risk of fire, since two cartridges may be burning simultaneously.* Further, if the button, for some reason, resets immediately or shortly after it has been pushed, two sets of circumstances are possible reasons :—

(*a*) *The Cartridge Fires.* In this case, a light-up may be obtained by pressing the relight button until the engine has lit up. The normal ignition system will have been de-energized by the button resetting. If this fails to start the engine, the full waiting period must be observed.

(*b*) *The Cartridge does not Fire.* In no circumstances should the button be pushed in again until the full waiting period (one minute) has elapsed, otherwise two cartridges may fire and cause severe damage.

ROTAX TURBO-STARTER (TYPE C.T.0103)

Description

42. The Rotax turbo-starter (Fig. 5) is a single-stage impulse turbine driven by the gas generated

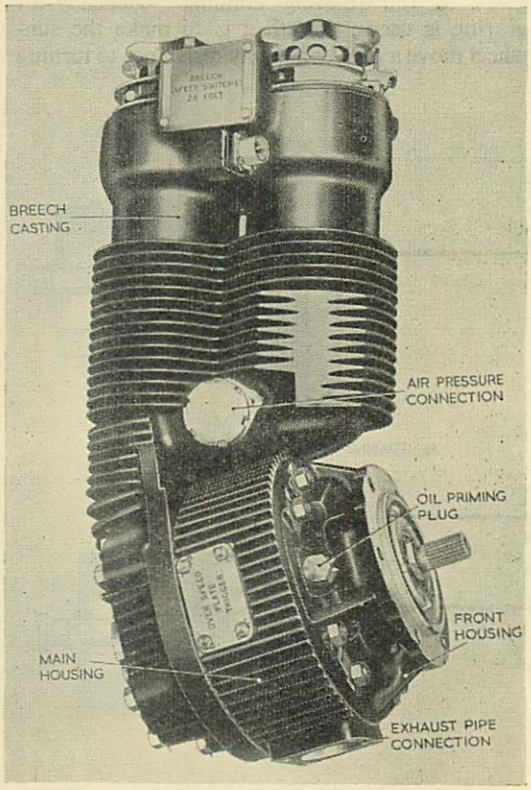


Fig. 5. The Rotax Twin-Breech Turbo-Starter.

by the burning of a cordite charge in an enclosed chamber. The expanding gas passes through four tangentially spaced nozzles, impinges on the rotor blades, and passes between them to the exhaust chamber and thence to atmosphere through the exhaust pipe. The torque output of the rotor shaft is transmitted to the starter drive shaft by a single-stage epicyclic reduction gear and a limiting torque clutch. Engine self-sustaining r.p.m. are reached in about three seconds.

43. The twin-breech chambers provide two consecutive starts between loadings ; the operating switch has a delay mechanism to prevent the second charge firing before the starter turbine rotor has ceased to rotate. The cartridge is fired electrically and has a safety device to interrupt the igniter circuit if either of the breech caps is not screwed fully home. A safety disc, fitted in a removable housing positioned at the base of the twin barrels, prevents excessive gas pressure causing damage to the starter.

44. A multi-plate metal-to-metal clutch is spring-loaded to a predetermined torque setting and acts as a shock absorber during the initial engagement of the drive. An overspeed cut-off device diverts the gas flow from the turbine blades if the turbine speed exceeds a limiting figure ; return springs reset the cut-off after the charge has burned out. To rotate the engine at slow speed for servicing, and as an alternative starting method, the starter can be operated by compressed air.

Operating Cycle

45. The cordite cartridge fits into the chamber that is sealed by the breech cap. One end of the cartridge contains an igniter which is fired electrically from a spring-loaded contact in the breech cap, while the other end is closed by a screwed cap drilled for the escape of the burning gas and closed by a thin disc outside the drilled holes. The base of the cartridge is flanged and is retained by a leaf spring in a groove which is machined in the breech cap. The leaf spring extracts the cartridge from the barrel when the breech cap is unscrewed.

46. The breech caps are screwed into the barrels when loading and turned clockwise until the two sets of ratchet teeth (Fig. 6) are engaged. Final engagement of these locking ratchets lines up the spring contact of the safety-switch on the breech with the insulated slipper-block on the cap and completes the firing circuit. The current is fed through the spring-loaded plunger in the breech cap to a contact in the end of the cartridge. This contact is connected to the igniter filament which glows when the circuit is energized, ignites the primer, and fires the charge. The duration of burning is from three to four seconds, depending on the air temperature. The cockpit control for the starter is a spring-loaded plunger which trips a rotary barrel-type switch ; when the plunger is pressed to fire a cartridge, it is held down by a latch for one minute, afterwards being allowed to return to the firing position by the time-switch mechanism. An override button is incorporated for use in emergency, when delay in firing the second cartridge may be serious, as in the case of loose fuel burning in the engine after a faulty start ; after turning off the fuel supply the second cartridge can be fired to clear the engine.

Gas Flow

47. The gas passes into a distribution chamber, and then radiates through the four ducts to the turbine nozzles. Emerging from the ducts in the breech casing, the gas, still expanding, is directed through the four tangentially-spaced nozzles of the convergent/divergent type which impart a high velocity, then through coinciding ports in the overspeed cut-off plate, to impinge on the rotor blades and pass through them to the exhaust annulus and thus to the exhaust pipe and atmosphere.

Loading and Unloading

48. The interior of the barrels and the threads of the breech cap and barrels should be clean, lightly greased, and free from any coke deposit.

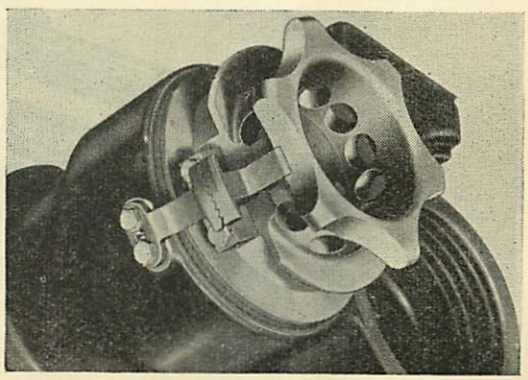


Fig. 6. Breech Cap Locking Device, Fully Engaged.

To load :—

(*a*) Place the flange of the cartridge under the cap spring, then, exerting a pressure towards the spring, centralize the cartridge and push it right home until the flange enters the groove machined in the head of the cap. Check that the cartridge rotates freely within the cap ; if it is difficult to turn, detach the cartridge from the cap and remove any burrs or roughness from the flange.

(*b*) Insert the cartridge into the appropriate barrel and screw down the breech cap, holding the locking pawls clear of the fixed rack until they align correctly on the last turn of the cap ; the cap should screw home without undue force. Note that the breech caps are numbered to correspond to similar numbers on the breech casting, and therefore are not interchangeable.

Excessive force should never be necessary when loading the breech ; if a breech cap becomes difficult to screw into the locked position, the interior of the barrel should be inspected for carbon deposits and other matter and a new cartridge fitted if necessary. The electrical circuit through which each cartridge is fired is not complete until *both* breech caps are fully screwed home.

49. **Unloading.** Depress the spring-loaded locking pawl until the cap is unscrewed enough to clear the ratchet. Remove the cap and cartridge from the barrel. To remove the cartridge from the breech cap, force it against the spring until the extractor flange is clear of the groove in the cap head, then lift the cartridge out. Used cartridges and unfired defective cartridges should be handled carefully, since they can be recharged if undamaged.

Precautions

50. All personnel must keep clear of the engine intake, starter exhaust, and jet pipe when an engine is about to be started.

51. If a cartridge fails to fire, wait one minute before firing the second cartridge or unloading the breech.

52. If the engine fails to light up when the first cartridge is fired, the second cartridge may be fired after 15 seconds ; or, in an emergency, immediately. If two cartridges are fired in quick succession, one minute must be allowed to elapse before reloading the starter.

CARTRIDGE TURBO-STARTER (TYPE C.T.0201)

Description

53. The C.T.0201 turbo-starter (Fig. 7) is a self-contained unit developing about 230 B.H.P., and is attached to the air intake casing of the engine so that the splined output shaft engages with the engine starter reduction gear. The maximum speed of the turbine shaft (44,500 to 49,500 r.p.m.) raises the engine speed to 1,800 to 2,000 r.p.m. The exhaust gases from the main and safety disc outlets are discharged to atmosphere through pipes which finish flush with the aircraft skin. This type of starter is fitted to the Sapphire Mk. 10101 engine in the Hunter F. Mks. 2 and 5.

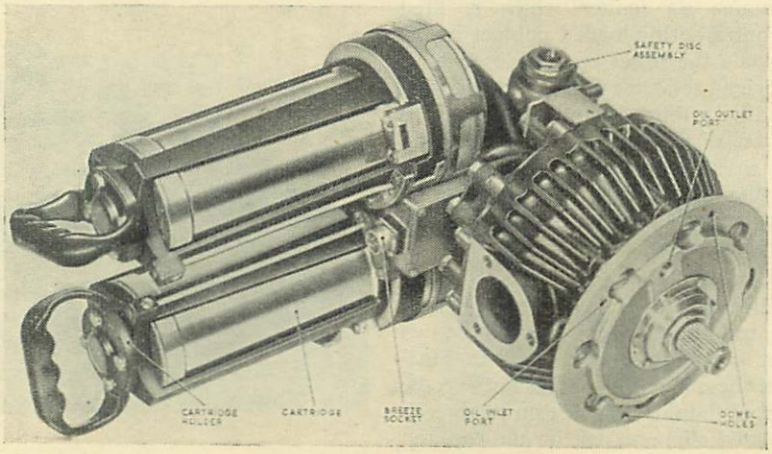


Fig. 7. Cartridge Turbo-Starter (Type C.T. 0201).

54. The starter has a single-stage impulse turbine wheel rotated by gas energy from a cordite charge which has a burning time of about four seconds. The starter accommodates two cartridges for two separate starts.

55. The starter turns the engine through a self-contained epicyclic reduction gear and clutch which drives a second reduction gear in the aero-engine, thus giving the desired gear ratio between starter and engine.

56. The gas pressure is limited to 2,500 lb./sq. in. by a replaceable safety disc, and this, together with a cut-off plate, constitutes the overspeed safety device. The cut-off plate diverts the gas flow away from the rotor wheel blades if the turbine overspeeds.

Cartridges

57. The cartridge (Fig. 8) is a substantial steel cylinder containing the charge and forming part of the combustion chamber. The two cartridge holders are secured to the appropriate breech on the inlet casing. Each cordite charge is in the form of a hollow cylinder, this shape ensuring a constant gas pressure during the burning time.

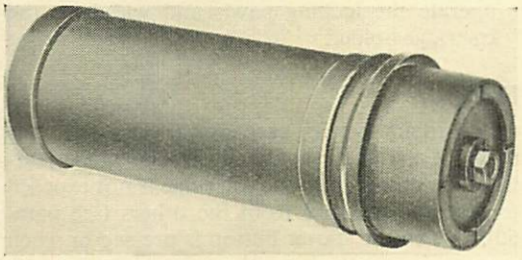


Fig. 8. Cartridge for Type C.T. 0201 Starter.

58. In one end of the cartridge is an igniter, fired electrically through a spring-loaded contact in the head of the cartridge holder, while the other end is closed by the coolant chamber which contains a coolant fluid through which pass the discharge tubes for the gas.

59. The coolant chamber is a hollow steel cylinder closed at both ends by integral diaphragms. Open-ended tubes, secured in the diaphragms, pass through the chamber and form the escape passages for the gas flow. The outer ends of these tubes are closed by a thin magnesium disc, kept in position by a central plug screwed into the outer diaphragm of the coolant chamber. This cap is easily disintegrated by the heat and pressure from its own cartridge, but as it is supported by the solid portion of the outer diaphragm it can withstand the pressure applied to it when its companion cartridge is fired, both cartridges being in communication with the gas passage in the inlet distribution chamber.

60. When an unfired cartridge is removed from the starter for any reason and then subsequently replaced, it *must* be reloaded in the starter breech to be used for the next start. This is essential because repeated exposure of the sealing cap to the heat and pressure from the firing of other cartridges causes it to weaken and fail, allowing ignition of the unfired cartridge. This causes failure of the safety disc owing to the simultaneous burning of two cartridges.

61. The coolant chamber is filled with a water/methanol mixture (60%/40%) through holes in the outer diaphragm. The holes are then plugged by a substance (Wood's metal) having a melting point of 178° C. The methanol lowers the freezing temperature of the mixture, ensuring efficient operation at low air temperatures.

62. When the cartridge is fired, the water/methanol is heated by the gas flow through the tubes. At a certain temperature and pressure, the cooling plugs are forced out and the mixture is injected into the gas flow and evaporates to limit the gas temperature to the design working figure. The amount of coolant and the rate of discharge is such that the injection is spread over the burning time of the cartridge.

63. Full constructional details of this starter are given in A.P.1181C, Vol. 1. Each cartridge is loaded into its cartridge holder, which in turn is screwed on to the thread of the breech on the inlet casing until two sets of ratchet teeth, one on the inlet casing and the other on the cartridge holder, are engaged. Final tightening of the cartridge holder aligns the plunger of the breech safety switch with an insulated slipper block on the cartridge holder, thus depressing the plunger and completing the firing circuit. The firing current is fed through the spring-loaded plunger in the head of the cartridge holder to the contact in the end of the cartridge. The contact in the cartridge is connected to the igniter filament, which glows when the circuit is energized, ignites the primer and fires the charge.

Loading

64. To load this starter the following method should be used :—

(*a*) Stand the cartridge on a support with the firing head upwards, then lower the cartridge holder over the cartridge and push down until the locking claws are located under the extractor flange of the cartridge.

(*b*) Offer up this assembly to the appropriate breech position on the inlet casing, *keeping the cartridge square with the breech shroud.*

(*c*) Push the assembly into position in the breech, then rotate the handle of the holder in a clockwise direction, thus screwing on the breech nut. Continue turning until the two sets of ratchet teeth are in contact.

(*d*) Pull on the cartridge holder handle to part the ratchet teeth, then continue to rotate the handle until the breech nut is tight. The nut should be tightened firmly, but undue force should not be used.

65. At this stage the cartridge is fully tightened by the breech nut, but the ratchet may not be positively locked owing to overriding of the teeth. Push on the cartridge handle holder and rotate it slightly anti-clockwise to ensure that the ratchet teeth mesh fully. Do not pull the handle while checking the locking. On some installations this operation can be checked visually, but on others, owing to the position of the starter, the entire operation may have to be done by feel.

66. If the teeth mesh fully initially, the cartridge holder is firmly locked and the anti-clockwise torque applied to the handle indicates that this is so (Fig. 9).

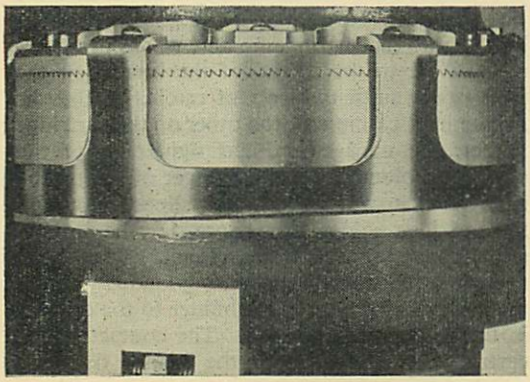


Fig. 9. Locking the Cartridge Holder—Teeth Properly Meshed.

67. The operation of " inching " back the holder must be done carefully to ensure that the ratchet teeth do not ride over one another and allow the holder to unscrew more than is necessary to fully engage the ratchet. It will be found that when the cartridge is correctly secured and the cartridge holder locked, a rocking movement about the cartridge seat can occur between the holder and the inlet casing, and the cartridge and its holder. This type of movement is normal, but there should be no *axial* movement of the cartridge.

Unloading

68. Unloading should normally be done when the starter is cold, but if it is necessary to reload a hot starter the removal of the cartridge holder is facilitated if it is rocked to free the cartridge. To unload the starter proceed as follows :—

(*a*) Pull the cartridge holder handle to release the ratchet teeth, then rotate the holder anti-clockwise to unscrew it and release the cartridge. Since the cartridge is water cooled, when unloading a hot starter on installations where the operator must carry out the work in a confined space below the starter, the released cartridge and holder should be lowered vertically to prevent any hot coolant from spilling onto the face.

(*b*) Place the cartridge on a clean surface, then operate the locking pawls and withdraw the cartridge holder.

Firing

69. A rotary type of cartridge selector switch is used. Cartridges should always be fired alternately to ensure that one cartridge is not exposed to repeated pressure from the others (see para. 60). When the starter button is pressed or when current is supplied to the starter during the automatic engine starting sequence, current is fed through the safety switch on the cartridge holder to the contact button in the head, and the cartridge fires immediately. *All the considerations of para.* 41 *apply also to this starter.*

Precautions

70. The following precautions must be taken during starting :—

(*a*) All personnel must keep clear of the engine air intake and jet pipe, and the starter exhaust pipe.

(*b*) If a cartridge fails to fire, an automatic delay of 30 seconds occurs before the second cartridge can be fired (see also para. 41).

(*c*) If the engine fails to light up on firing the first cartridge, the second cartridge may be fired after 30 seconds have elapsed, or, in an emergency, immediately. If two cartridges are fired in quick succession, one minute must be allowed to elapse before reloading the starter.

(*d*) If at any time it is necessary to work on, or make adjustments to, the engine or starter, or to check the electrical circuits, it must be ensured that the cartridges are removed from the starter and that the aircraft master switch is off.

Burst Safety Disc

71. If the safety disc ruptures, a new disc must be fitted before the next cartridge is fired. The sudden reduction in breech pressure caused by a burst safety disc may result in the extinction of the charge ; if this is suspected, wait until it is certain that no further burning is taking place, then remove the cartridge and check whether any of the charge remains. If so, this must be disposed of in accordance with the regulations for the handling of explosives. A burst safety disc is indicated by a thick yellow smoke from the exhaust pipes, mostly from the safety disc exhaust pipe. When a safety disc ruptures and the cartridge continues to burn, it does so for about 45 seconds, during which time smoke is emitted accompanied by pressure surges.

COMPRESSED AIR STARTING SYSTEMS

Introduction

72. There are two turbine compressed air starters in use at present : the low-pressure (150 lb./sq. in.) turbine starter and the high-pressure turbine starter (1,000 lb./sq. in.). Compressed air starter systems are used with some turbo-prop aircraft.

Air Starter Trolley

73. The air starter trolley can supply air for either the low-pressure or high-pressure starter. When fully charged, the unit (which is fully mobile and equipped with brakes) contains enough air for six engine starts. Details of this unit, method of recharging, and preparation for air-starting the engine are given in A.P. 4272C, Vol. 1, Part 2. Nine air bottles contain a pressure of 3,600 lb./sq. in. and, by suitable reducing valves and controls, will supply starting pressures for either low- or high-pressure starters. The unit is equipped with three pressure gauges, indicating the main pressure and the two reduced starting pressures. The main pressure for high-pressure starts should not be allowed to drop below about 1,500 lb./sq. in. so that, in the event of a wet start, enough air is available to clear the engine immediately. Pilots' Notes for the aircraft give details of starting by air starters. To ensure a satisfactory start it is important to have good co-operation between the pilot and ground crew.

Turbo-Starter

74. This starter is a standard twin-breech cartridge starter, one breech having air from the air starter trolley supplied to it from a convenient point on the outside of the engine nacelle via a dummy cartridge-end loaded into the breech. With this starter, starts may be made either by cartridges or compressed air provided that the necessary pipe adaptor is fitted.

LIQUID FUEL STARTING SYSTEMS

Introduction

75. Self-contained starting systems, using a liquid fuel as a source of power, are often used instead of cartridge starters. Present types of liquid fuel turbo-starters use iso-propyl nitrate (I.P.N.) for a fuel. I.P.N. is a *mono-fuel*, *i.e.* once combustion has been initiated, no air is required to sustain combustion.

Advantages of the Liquid Fuel System

76. One advantage of using a liquid fuel over the cordite cartridge system, in addition to the greater power of these systems which is essential for the higher performance engines, is that the necessity of unloading and loading cordite cartridges is dispensed with, the I.P.N. being contained in a small tank. Another advantage is that the system is operated from a single push-button for each engine.

Plessey Liquid Fuel Starter

77. In the Plessey system, fuel is sprayed into a small combustion chamber and ignited, the combustion gases turning a small impulse turbine geared to the engine. An electric motor is used to drive a fuel and an air pump. The air pump scavenges the starter combustion chamber prior to starting, and supplies air to the liquid during the *initial* stages of combustion. The mixture of air and I.P.N. is ignited by a starter sparking plug which is supplied with current from a small ignition unit. The resultant increase in temperature and pressure automatically cuts off the air supply, the fuel supply being maintained, and the products of combustion are guided to the

starter turbine. Safety devices are built into the control system to prevent overspeeding, to guard against the effects of sustained fuel injection after a starter ignition failure, and the continued running of the starter if the engine fails to light up. Sufficient fuel is carried for three starts.

B.T.H. Liquid Fuel Starter

78. The B.T.H. system utilizes a small cordite cartridge to ignite the I.P.N. in a reaction chamber, the resulting pressure rise being passed to the starter turbine. With this method the fuel and the air pump, the sparking plugs, and starter-fuel ignition units are unnecessary thus making a simple, light-weight, self-contained system.

Use of the Starters

79. The starter button should be pressed for 2 seconds. After any failure to start, a period of 2 minutes must elapse before the next attempt, otherwise the starter can overheat to an extent that causes severe damage. The precautions to be taken are the same as for cartridge starters in that all personnel must keep well clear of aircraft intakes and starter exhausts.