

Chapter 3

Starting and Ignition Systems



Ignition systems

Gas turbines unlike piston engines employ a continuous combustion process to provide the heat input that releases energy in to the engine working cycle. Once ignited the fuel burns continuously until the engine is shut down, at this point the combustion is extinguished by cutting off the fuel supply. When a gas turbine is started, a means of igniting the fuel is required, in most cases this is provided by an electric spark.

One or more igniter plugs (Spark Plugs) are placed in the combustion chamber usually close to a fuel burner nozzle. When the HP fuel cock is opened a fine mist spray admitted by the burner mixes with the surrounding air, reaches the plug and ignites. Many small gas turbines only employ one igniter plug, but in some cases when an engine is constructed with an annular combustion chamber, two are fitted at opposite sides of the combustion chamber.

Warning

Gas turbine ignition systems are dangerous! Lethal voltages are present particularly in the high-energy types. Always allow several minutes to elapse before dismantling an ignition system so that any capacitors will fully discharge. Always make sure the casing of any igniter unit is electrically bonded to the engine casing. Poor or loose connections can develop potential differences whilst the sparks occur. Never operate an igniter unit without the igniter plug connected!

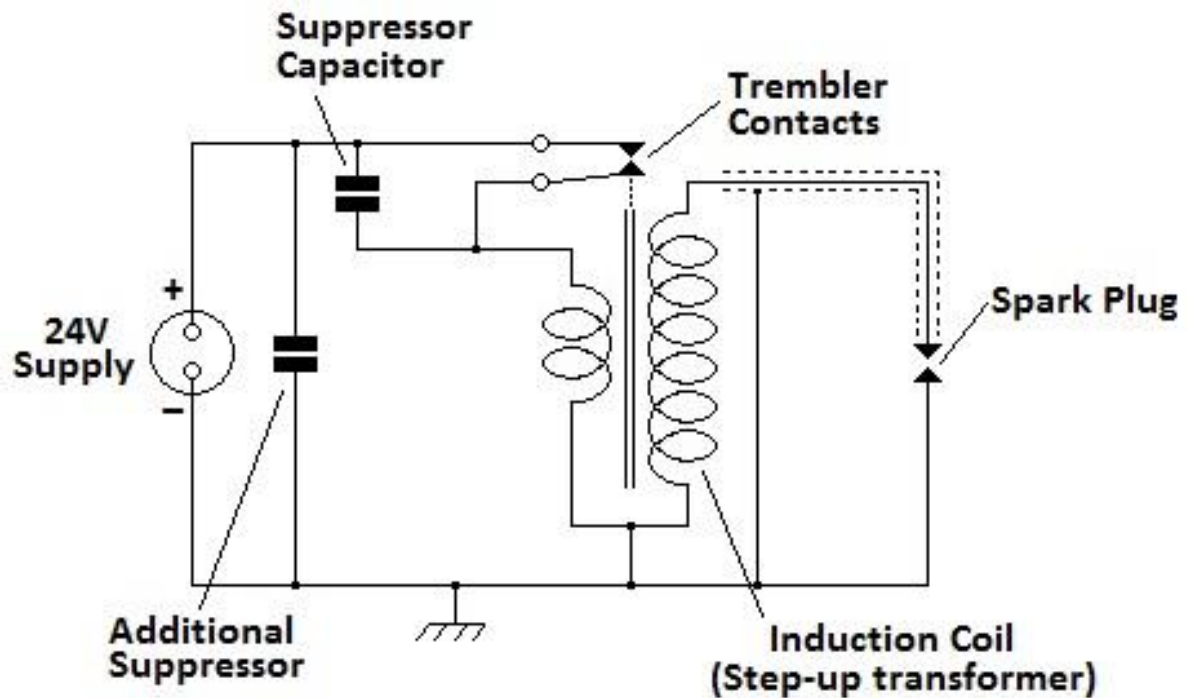
There are three basic types of ignition systems that are used in small gas turbines, high tension (High Voltage), high-energy capacitor-discharge types and torch (Pilot) ignition types.

High tension ignition

This process is not dissimilar to piston engine ignition systems. A step up transformer or "ignition booster coil" provides a high voltage to a spark plug. A DC current is applied to the transformer primary and is interrupted by contacts in a trembler mechanism. The trembler mechanism is operated by the magnetic field from the transformer windings and continually oscillates between open and closed. This arrangement is similar to a classic electric bell mechanism and vibrates many times per second; this produces a stream of sparks at an igniter plug that is connected to the transformer secondary. A capacitor connected across the trembler contacts, suppresses arcing across them and reduces radio frequency interference. The capacitor often forms a partial resonant circuit with the transformer windings and will increase the power of the spark.



High tension igniter plugs

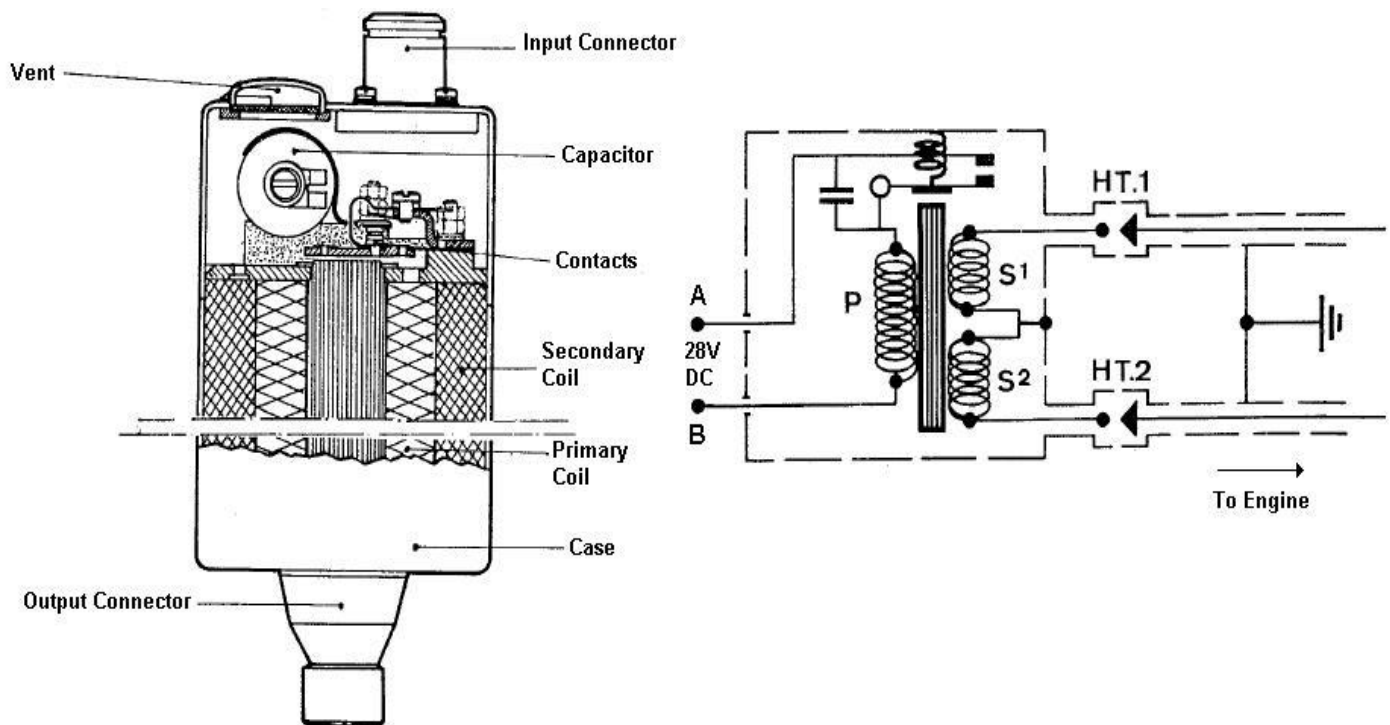


Simple HT mechanical exciter circuit

A high-tension igniter usually consists of an integrated unit that has been designed to work from a 12 to 30 V battery DC supply. The high tension voltage potential developed by the unit may be up to 30,000 volts, but at a low current of a few milliamperes (mA). Igniter unit housings and enclosures are sealed to prevent the ingress moisture from causing unwanted arcing of the high-tension voltage. It is possible for igniter units to be fitted with two outputs that feed two separate igniter plugs. Care must be taken to ensure that igniter unit is not operated when the plugs are disconnected; otherwise it may flashover, breakdown internally and become permanently damaged.

High-tension igniter plugs resemble piston-engine type spark plugs. An insulated central electrode is placed inside an earthed casing with an exposed gap. The high voltage flashes over across the gap providing a near continuous arc. The gap is usually relatively large (When compared to piston-engine plugs) up to about 4 mm. Fuel is sprayed through the spark and quickly ignites, sometimes a partial shield is placed around the plug which controls the air flow through the spark, excessive air flow may "blow" the spark out.

The HT cables that connect the igniter units and plugs together are usually screened coaxial type cables to reduce radio interference. The outer screen may also form a conducting earth return for the system.



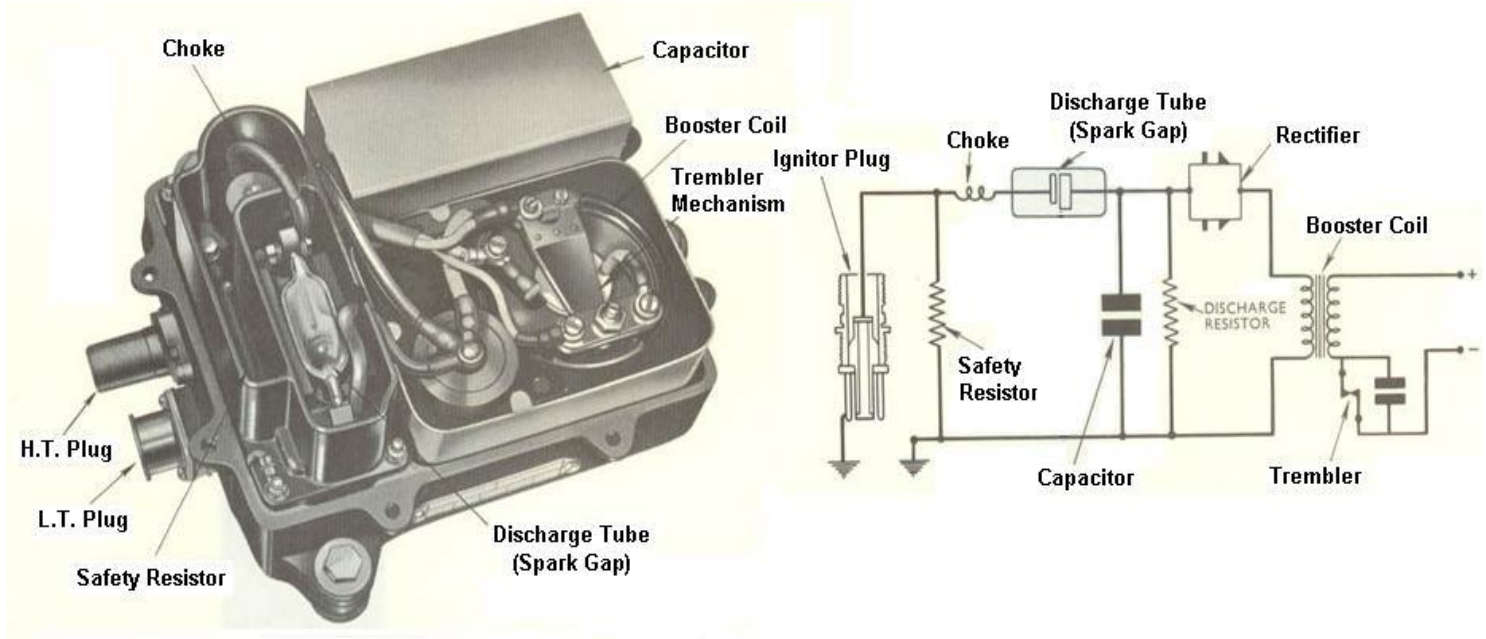
Twin plug high tension igniter unit

Over a period of time the igniter plug may become fouled with carbon deposits, this may interfere with its operation. Gap-type igniter plugs may be cleaned with solvents. As with automotive plugs, the spark gap may require adjustment for best performance.

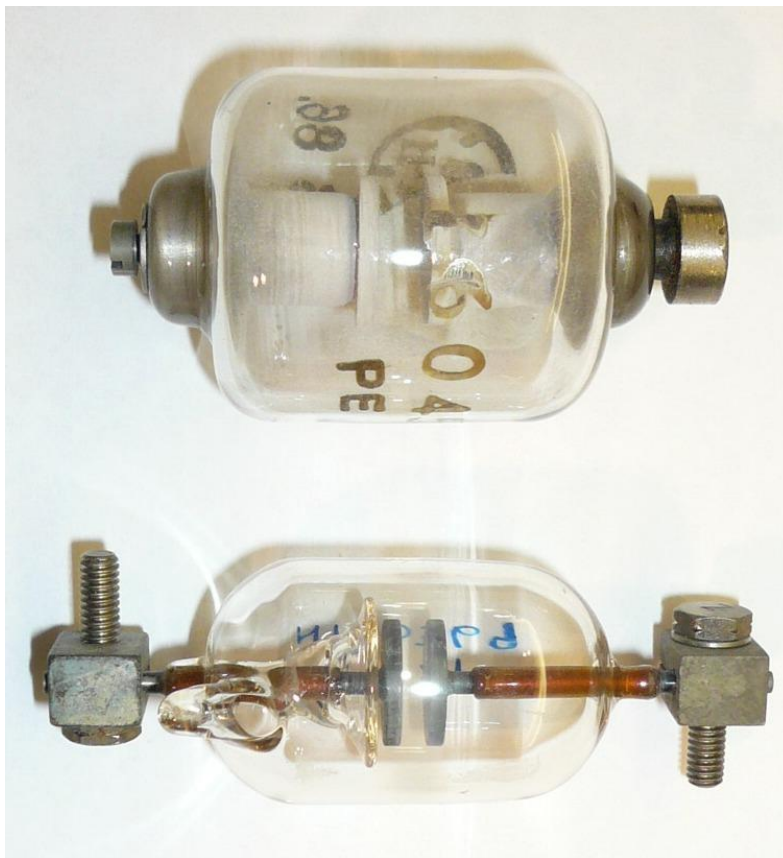
The Plessey Dynamics Solent unit and some Microturbo engines use high-tension ignition systems.

High energy capacitor discharge ignition

This system differs from the high tension coil system, instead a lower voltage high current spark is achieved by discharging a capacitor into a special igniter plug. A trembler system and a step up transformer provide a source of high voltage. A rectifier converts the transformer output to a DC voltage that charges a capacitor of a few microfarads capacity; the capacitor subsequently acquires a charge of up to several thousand volts. A special sealed discharge spark-gap tube is connected between the capacitor and the igniter plug, as the capacitor charges, a predetermined voltage is reached and the discharge tube breaks down sending a pulse of energy to the igniter plug and the capacitor rapidly discharges. The process repeats itself several times per second as the capacitor repeatedly re-charges producing a succession of very violent and hot sparks.



High energy discharge igniter unit (Exciter)



Discharge spark-gap



High energy igniter plugs (Surface and air-gap)

High-energy ignition generally use two types of specially constructed igniter plug:-

1: A surface discharge plug that breaks down at a relatively low voltage. A central electrode is surrounded by a semi-conducting material provides a low resistance path that flashes over and dissipates the spark energy. The magnitude of the energy released is expressed in joules; this energy stored in the capacitor amounts to several joules. The spark energy fills the area around the plug tip as a burst of hot plasma (Ionized air) and is very effective at igniting the fuel.

When attempting to clean a high-energy surface discharge plug care should be exercised. The semiconductor surface will be damaged by abrasives and should only be cleaned with mild solvents. Carbon deposits (A plug may appear fouled) may aid in providing a leaky discharge path across the surface of the plug and are not detrimental to the plug operation.

2: Some types of high energy plug consist of an air gap type construction. The high voltage (Positive) electrode is surrounded by the grounded negative electrode and the small air gap separated them. To set off the spark the exciter unit provides an initial small high voltage ($>10\text{kv}$) pulse that breaks down a path across the air gap and provides a route of ionized air. Immediately the high energy discharge follows providing a fierce spark for the ignition of the atomized fuel in the combustion chamber.

The air-gap type of igniter plug is common place in Garrett auxiliary power units. This type of exciter may not function properly if an attempt is made to connect it to a surface discharge type plug. Conversely an exciter unit designed to work with surface discharge plugs may not function with gapped type plugs as insufficient voltage will be generated to jump the air gap and the unit will not fire



Igniter plug tips

High-energy igniters are commonplace in gas turbines and are required to operate in temperatures well below freezing. Jet fuel at low temperature is difficult to ignite, it is for this reason that high energy igniters have become popular in small gas turbine engines.

The original high-energy ignition systems used a trembler coil system to provide a high voltage to charge the storage capacitor from a nominal 24V battery supply. More modern igniter units make use of an electronic inverter to step up the voltage; these units are characterized by a whistling sound that rises in pitch between successive sparks. Care must be exercised when connecting up electronic igniter boxes as they may be damaged if the correct DC input polarity is not observed.



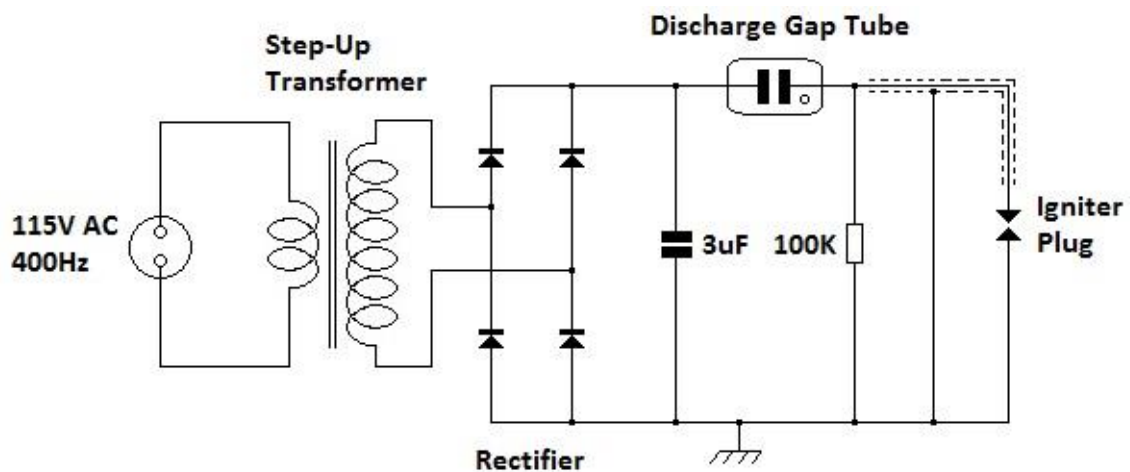
28V DC ignition exciter units

Igniter units or ignition exciter units are also available that may be powered from an aircraft AC supply. In this case a 400Hz 115V single-phase supply is stepped up with a transformer without the need for an inverter or mechanical trembler mechanism.

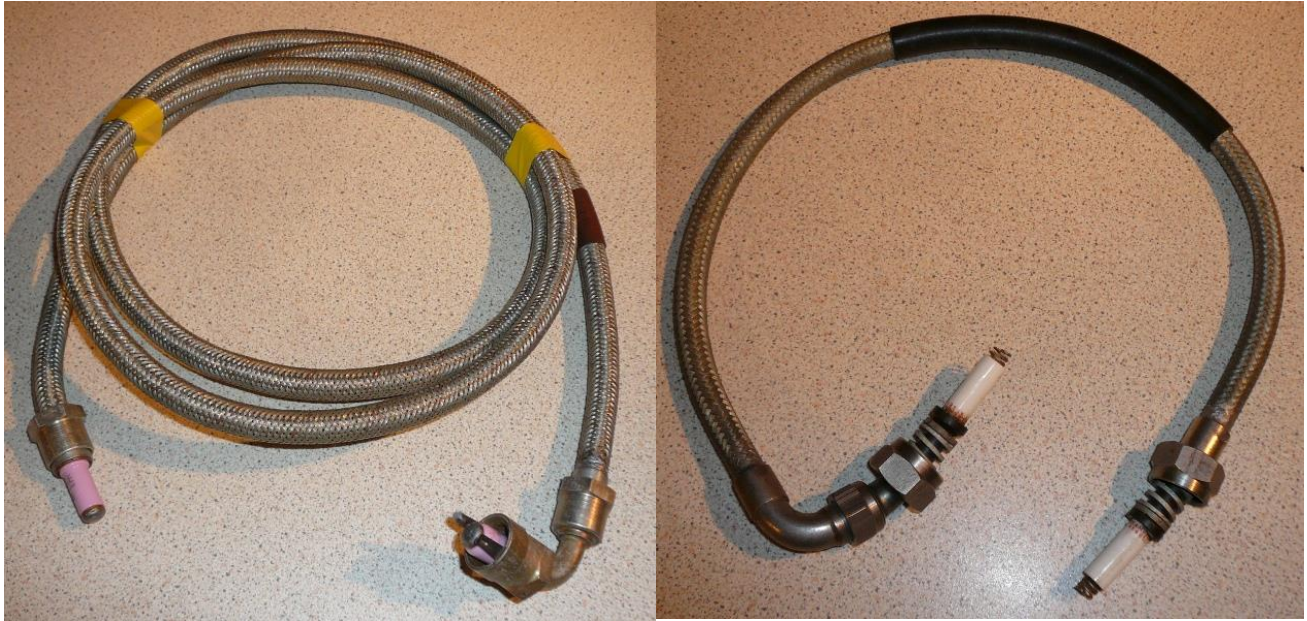


400 Hz 115V ignition exciter unit

If an igniter unit is to be dismantled care must be exercised as there is a risk of electric shock, the capacitor may remain charged for a period of time after disconnection from the DC supply. Always allow several minutes to elapse before opening up an igniter unit. Many igniter units are sealed to prevent the ingress of moisture, other units may be stripped down to their component parts which eases repairs.



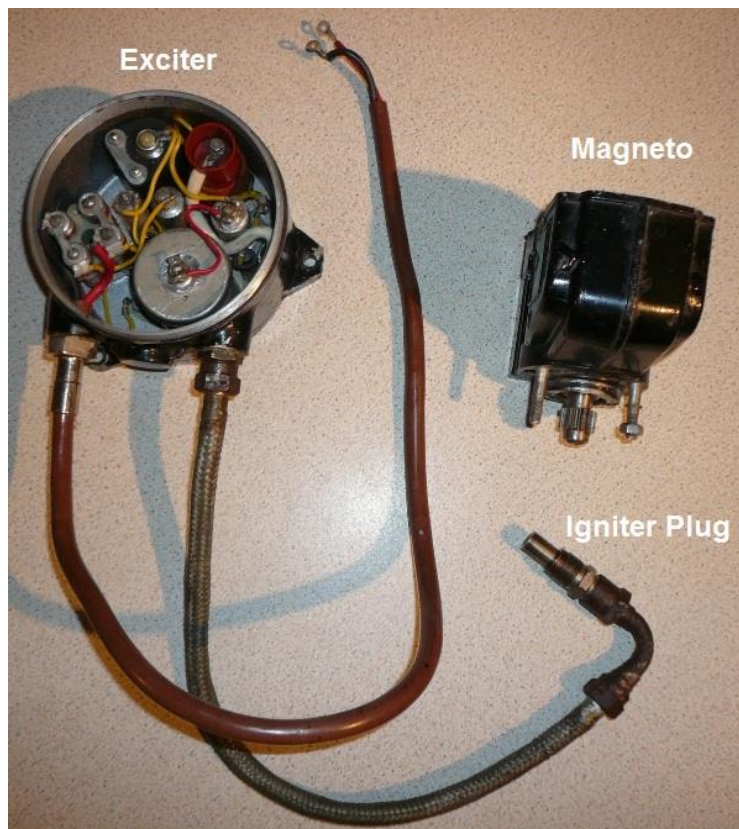
400Hz ignition exciter unit



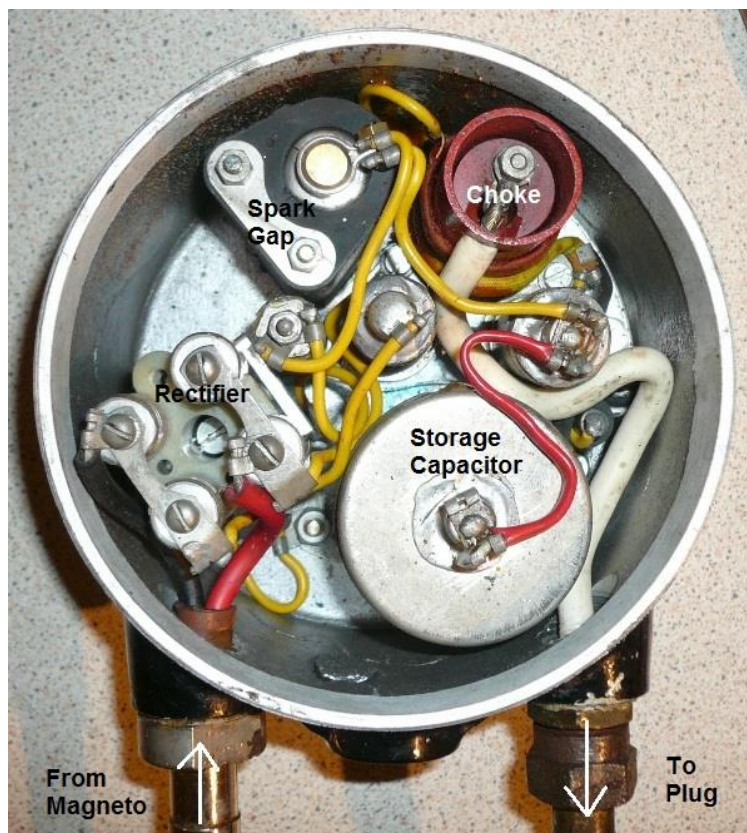
HT cables British (RR) and USA (Garrett)

The interconnecting cable between the igniter unit and its plug is made up off a heavy-duty coaxial cable. The cable maintains effective electrical continuity so that the spark energy is not reduced by the cable's electrical resistance, the outer conductor also provides a solid earth return. The connections made by the HT cables should always be cleaned and checked for tightness so that good electrical conductivity is maintained. The Rover 1S series and Garrett engines use high-energy ignition. A hand-started version of the rover also uses a little generator to provide power for a high-energy igniter.

The Rover 1S60 engine may be found fitted to a portable fire fighting pump. The unit is hand started by means of two winding handles that drive the engine through a chain drive and a series of step-up gears. As the engine is cranked a magneto unit is rotated that produces a steady high voltage. A rectifier inside the exciter unit charges up a DC storage capacitor that periodically discharges into the igniter plug via a sealed discharge gap.

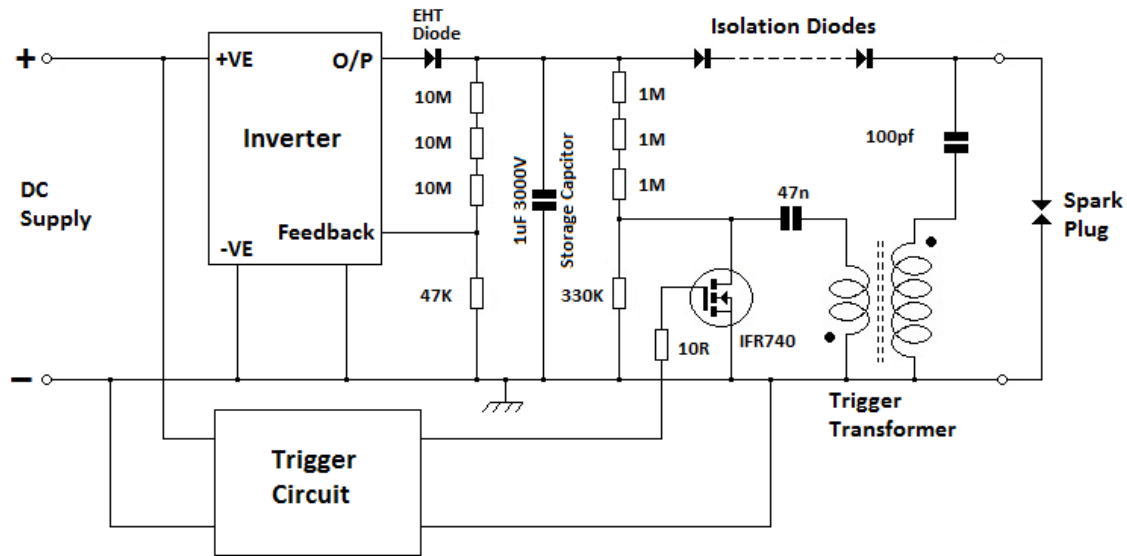


Hand start ignition components



Inside exciter unit

Igniter unit circuits

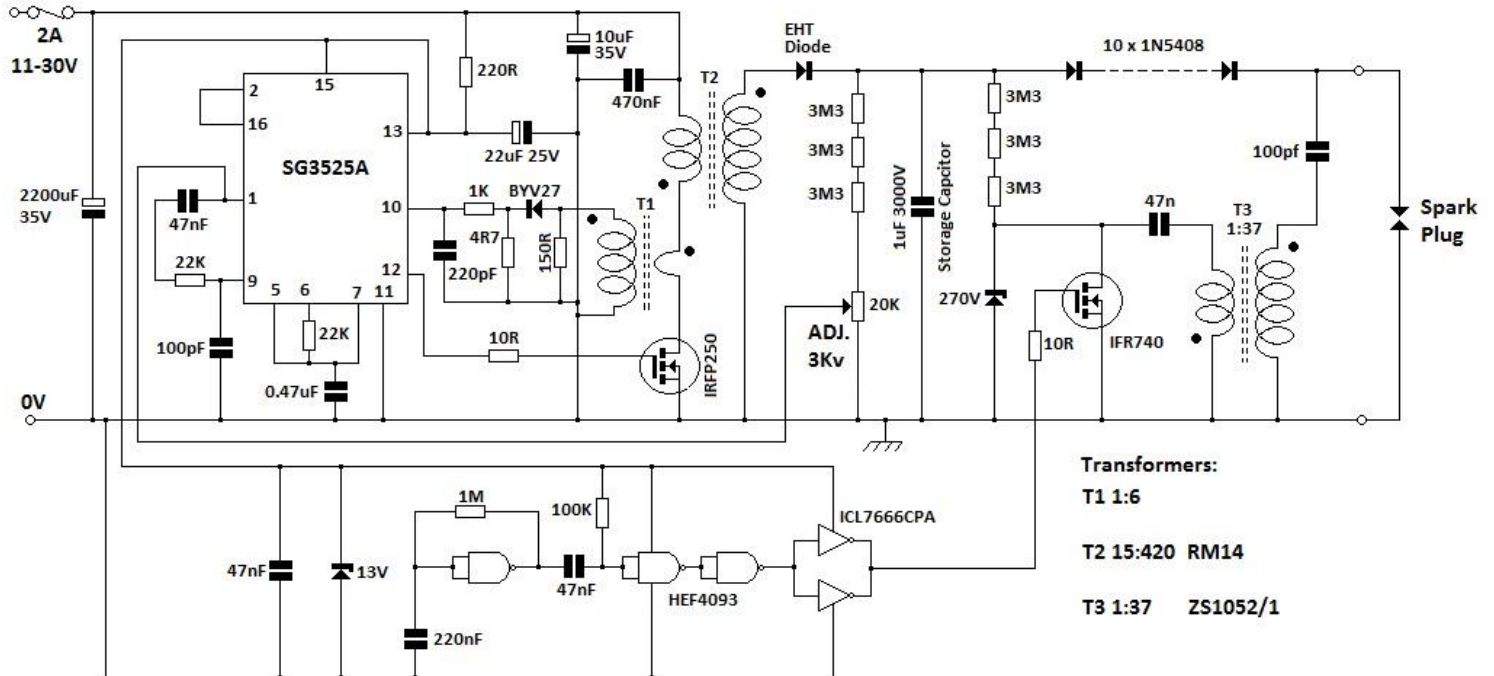


Basic solid-state ignition exciter circuit

The diagram shows a basic hi-energy exciter for use with air-gapped discharge igniter plugs. A high voltage storage capacitor is charged up by an inverter circuit running from a nominal 24V supply. The capacitor charges up to approximately 3Kv, a feedback circuit is used to ensure the inverter does not charge it beyond the limit of 3Kv. A second small capacitor is also charged from the inverter and is placed in series with a step up transformer. A trigger circuit sends a periodic pulse to a MOSFET transistor that closes short circuit and causes the capacitor to be discharged into the transformer. The resulting high voltage pulse from transformer secondary winding is fed to the spark plug via a small capacitor and discharges across it. The small discharge across the spark plug gap provides a breakdown path for current coming from the main storage capacitor and it discharges across the gap with a violent high-energy spark. The trigger circuit creates a small spark the “Fires” the larger discharge from the storage capacitor. Diodes are placed in the circuit so that the trigger pulse is directed at the spark plug alone and cannot discharge back into the storage capacitor. The process is repeated, the trigger circuit periodically fires the plug and allows the inverter to re-charge the storage capacitor between discharges. The inverter re-charge timing and the trigger timing should be matched so that the circuit only fires once the storage capacitor has had chance to fully re-charge

The diodes placed in the discharge circuit must withstand the high reverse voltage of the firing-trigger circuit so 10 or so 1200V PIV diodes are used to isolate the trigger circuit from the storage capacitor. The forward current pulse of the capacitor discharge is very large but only momentary and so the small 3A rated diodes survive the current pulse with no damage!

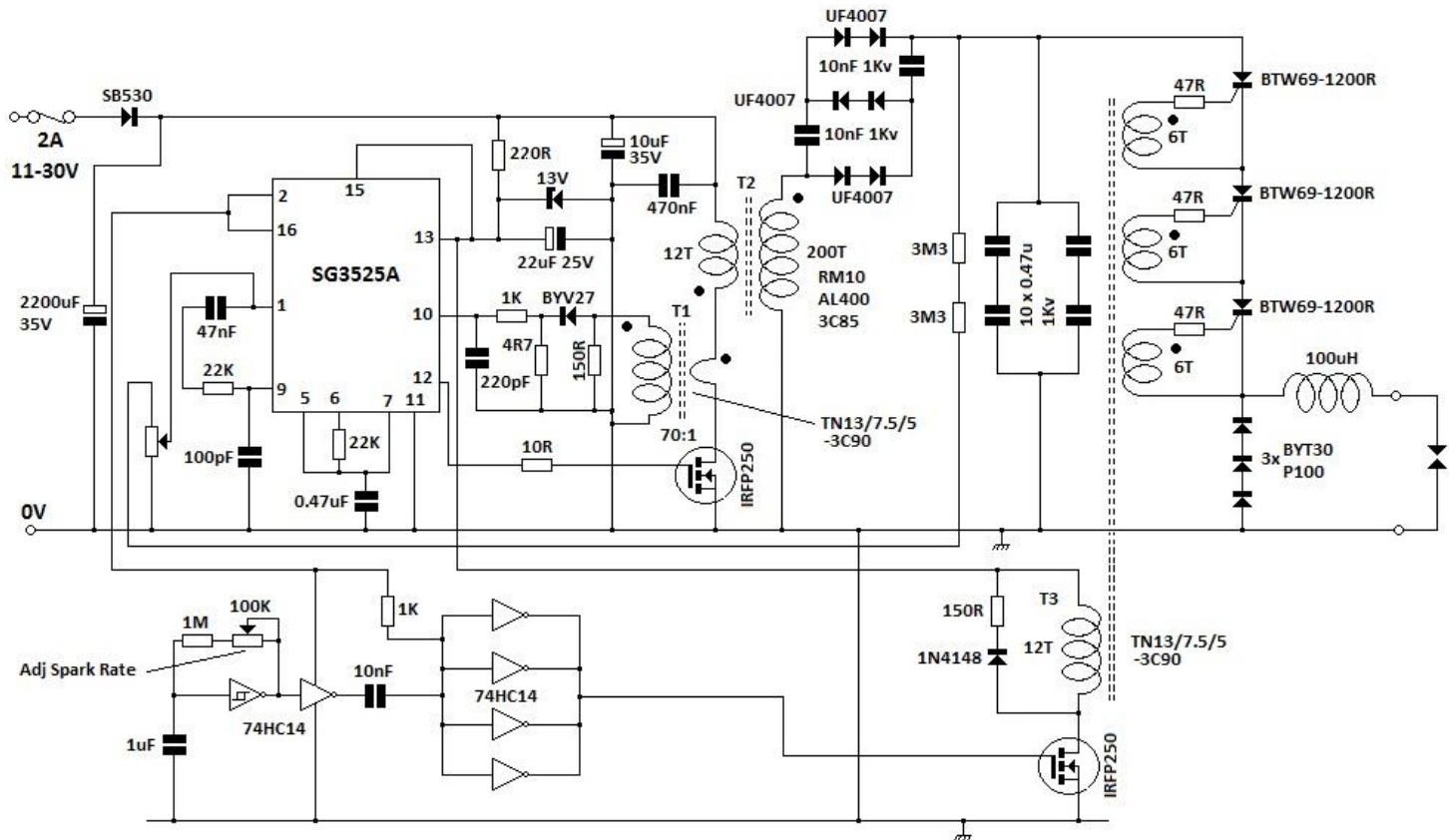
The energy stored by the exciter circuit may be measured in Jewels. A 1uF capacitor stores 1 Jewel of energy when charged up to 1000V.



Solid-state ignition exciter circuit (Output 3J)

The diagram shows a circuit that was developed for use with motorsport type surface discharge spark plugs (no internal resistor). A 1 uF microwave oven capacitor was used for the high voltage storage capacitor. The advantage of this circuit is that it does not make use of specialized sealed spark-gap type units; it instead uses only conventional components that are readily available.

Thyristor (SCR) solid state ignition exciter



Thyristor (SCR) ignition exciter (Output 2.3J)

A device known as a thyristor or silicon controlled rectifier (SCR) may be used as the pulse switching element in an ignition exciter unit. The circuit shows how an experimental exciter may be built. A conventional switch mode inverter is used to step up the battery supply voltage to approximately 2000v and charge up a storage capacitor bank made up of standard polyester capacitors, a group of three series connected thyristors supply a pulse of energy to the igniter plug that discharges the capacitors.

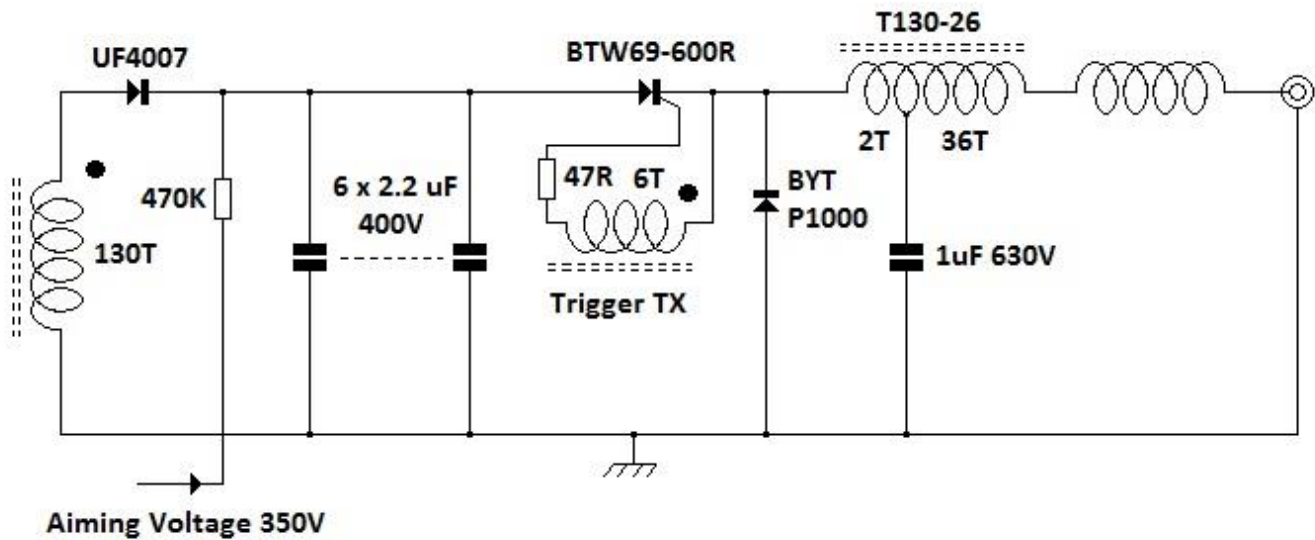
A trigger circuit comprising of a simple oscillator sends a trigger pulse to the thyristor gate circuits via individual windings on a pulse transformer. The spark rate may be adjusted so that the inverter has time to fully charge the capacitor banks before a spark occurs. This circuit is capable of a spark rate of 3 per second with an equivalent discharge energy of 2.3 joules.

An important feature of the circuit is an output series choke, this choke limits the pulse rise time and hence peak discharge current supplied from the capacitors to a value within the capabilities of the thyristor units. Omitting this output choke will cause immediate damage to the thyristors as the peak current will destroy them.

Three series connected diodes placed across the output circuit prevent any back e.m.f. pulses or reverse bias currents from damaging the output circuitry.

This circuit supplies a spark output suitable for semiconducting surface discharge igniter plugs of the type often used with discharge tube circuits. The output pulse potential is relatively low at only 2kv and so it will not function with air gapped type plugs such as the common units found in Garrett gas turbine engines.

Thyristor circuit with step-up output

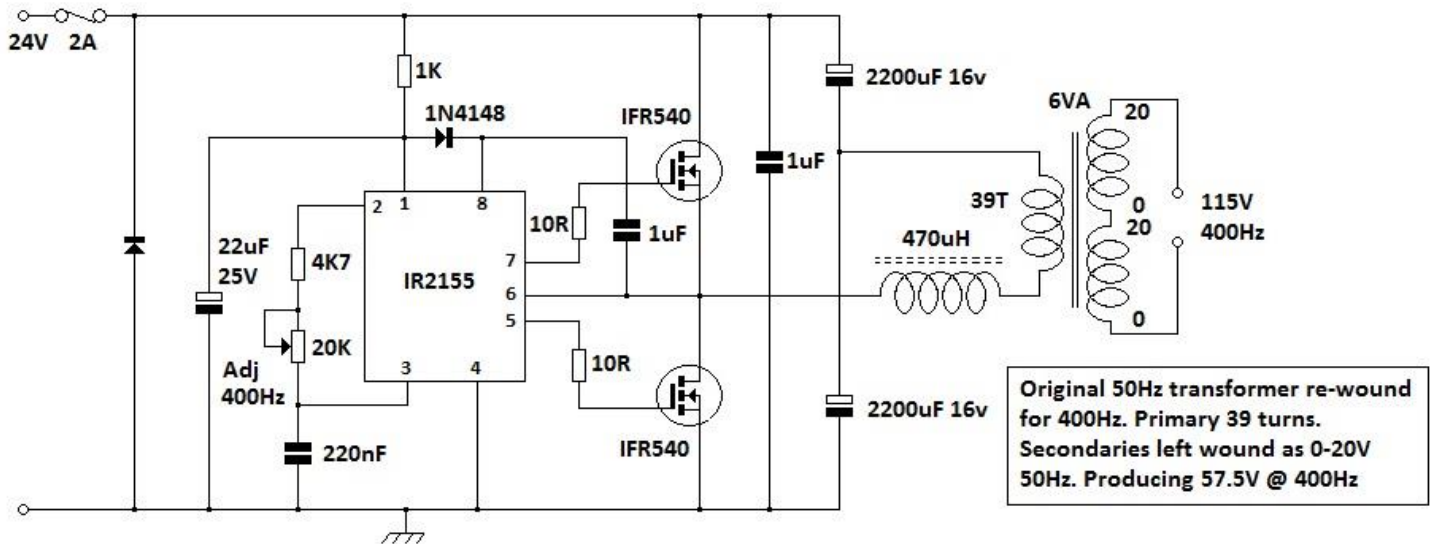


Thyristor unit with booster step-up transformer output circuit.

An exciter unit built for use with a common micro-turbine type gas turbine engine features a step up transformer (wound on a toroidal core) placed in the output circuit. A single thyristor is used to discharge a bank of polyester capacitors charged to some 350V. When the thyristor is fired by an external trigger circuit the resulting discharge is initially passed to ground through an auto transformer winding and capacitor. A second connected winding creates a stepped up voltage at the output that fires a surface discharge plug. When the plug fires the resulting high current surge saturates the transformer and the remaining capacitor current flows through the plug to ground creating a large fierce spark. An output choke is also employed to limit the resulting current to a safe value that may be handled by the thyristor.

The simplified circuit above may be built as a variation of the previous circuit with the higher voltage output thyristor chain and is suitable for surface discharge plug types.

Simple 400Hz inverter for exciter units



400 Hz inverter, output 115V AC 400Hz

The diagram above illustrates a simple design for use with 400Hz 115V igniter units. A standard 50Hz mains power supply transformer is re-wound for use with 400Hz. The original mains winding is removed and replaced with a reduced turns winding of thicker wire. The transformer is driven from a push-pull MOSFET bridge circuit operating at 400Hz.

At 400Hz the requirements of a power transformer are reduced in terms of core size and coil size so a small 6VA rated unit may be operated at greater power at 400Hz and is capable for powering a typical 400Hz exciter unit.

This simple square wave circuit is adequate for ignition power supplies. The inductance of the transformer will partially filter the square-wave edges. A more superior inverter design would be required for other 400Hz applications for example in an instrumentation system.

Torch (pilot light) igniter

A third type of gas turbine igniter is known as a torch igniter. The simplest way to describe it is to say it works like a pilot light burner. A small nozzle sprays fuel through a burner unit that is similar in construction to a blow lamp. A small engine driven or motor driven pump provides the fuel spray that is ignited by a high tension spark or a high energy spark, a portion of air from the engine compressor is also diverted into the burner to aid a stable flame. The torch igniter is used to form an initial flame in the combustion chamber from which the main fuel burn is ignited. An electrical solenoid valve is used to shut off the fuel supply to the torch igniter when the engine has successfully lit up. The torch igniter shut off valve is normally operated by an automatic sequencing system that is controlling the engine start cycle.

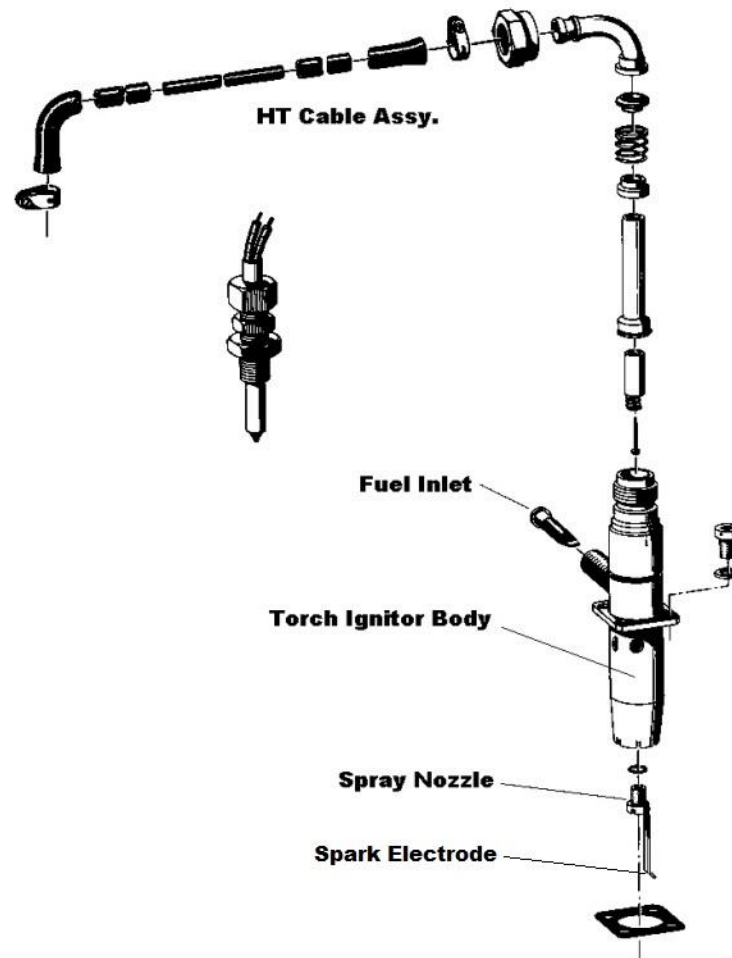
Torch igniters are usually used in engines that incorporate vaporizing type burners. The initial heat is created by the small torch flame, this initiates the vaporizing process and the main engine burners take over. At the end of a start cycle the torch igniter is turned off.

Engine designs may be found that use a small electric motor driven pump to supply a torch igniter with fuel whilst the starter is energized. The Turbomeca Astazou unit employs this system with the addition of a pressure switch to indicate the correct pressurization of the torch system.

BMW/MAN TURBO engines that are started by hand employ a torch igniter. When the engine is cranked, a small magneto is turned over which produces a spark. At the same time a small gear pump pressurizes a burner nozzle that produces a burning spray inside the torch igniter. The torch igniter only functions when the engine starting-handle is turned, so the torch igniter is extinguished when the start cycle is completed.



Torch igniter unit



Dissembled view of torch igniter (Man/BMW)

The Blackburn/RR Palouste/Artouste series of engines use a torch igniter to ignite the main fuel as it is released from the burners.

Ignition systems in gas turbines may be heard operating if the engine is kept stationary for test purposes. High-tension systems usually produce a "hissing/buzzing" sound that may be heard at the engine exhaust. High-energy systems produce a series of "Cracks" or "Ticks" these can also be heard from the engine exhaust when the igniter system is operated. High-energy igniters may also be heard during the initial stages of a gas turbine spooling up via the starter.

Failure of a gas turbine ignition system usually results in an accumulation of un-burnt fuel in the combustion chamber during an attempt to start the engine. A drain system is provided to allow this fuel to run away, this must always be allowed to occur before a second start cycle is attempted. Any excessive delay in the light up of the engine will result in a "Wet" or "Torched" start, here the fuel will burn out from the combustion chamber, through the turbine and into the exhaust system. Wet starts produce flames in the exhaust and are detrimental to the engine operation; wet starts will also lead to high

exhaust gas temperatures. A wet start is sometimes spectacular but should be avoided as it is also likely to become a fire hazard. Normally continuous flames in the exhaust of a gas turbine engine indicated a fault, the engine should be shut down and the cause investigated.

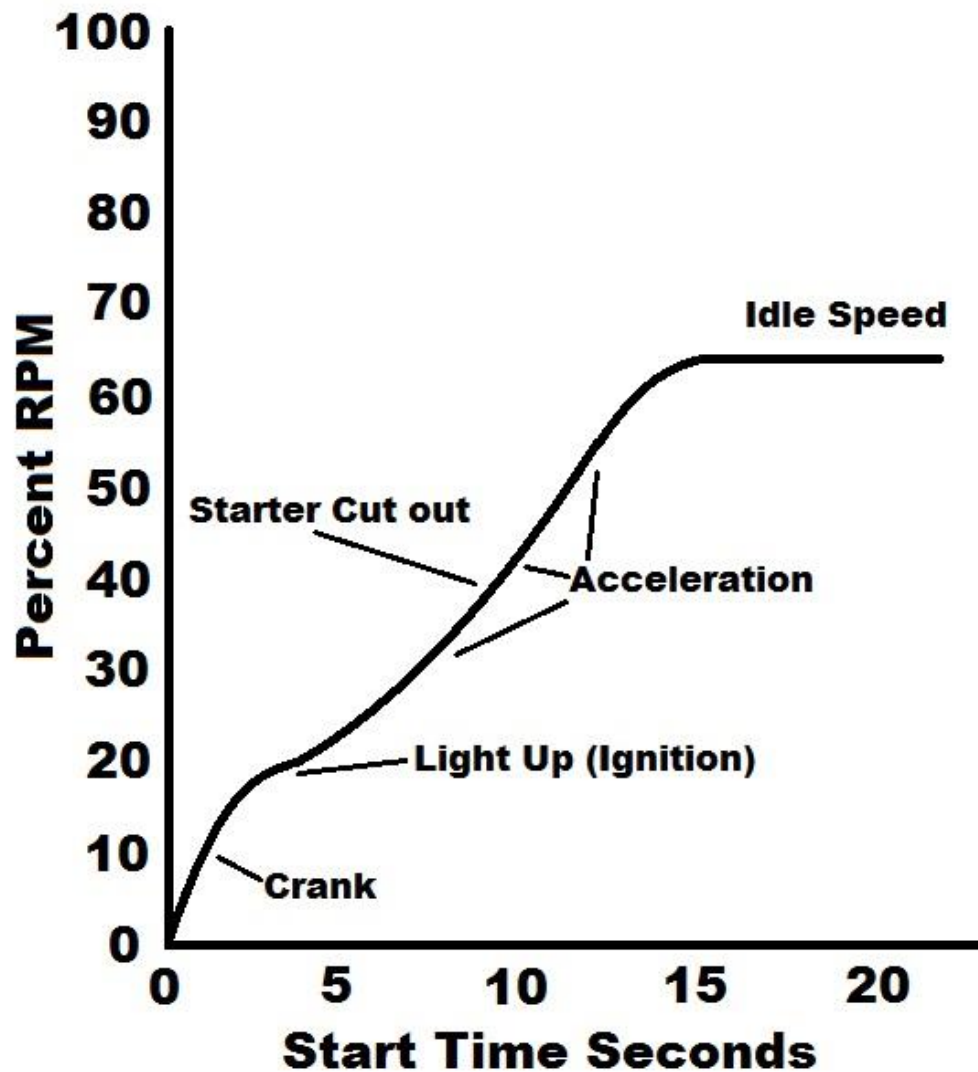
Faults in ignition systems may be approached in a similar way to any other electrical system problem. Individual components may fail and bad connections may exist between components. Old surplus igniter units are affected in many ways, the capacitors become electrically "leaky" or go short circuit. The trembler mechanism employs contacts that become dirty or fall out of adjustment. A suppresser capacitor is fitted across the trembler contacts that may also fail. The discharge-gap tube fitted to an igniter unit consists of two graphite electrodes sealed in a glass envelope; the envelope is filled with a rarefied gas such as argon. The glass envelope may become cracked or the seals around the metal electrodes can fail. Certain types of discharge tube are connected with nuts and bolts, care must be exercised when attempting to undo these fasteners as any force on the tube will break it.

Ignition systems are operated during the start cycle of an engine and during the period when power is supplied to the starter motor. Engines employing an automatic start cycle shut off the ignition after a predetermined time delay or when the starter is cut out. It is often useful to be able to rotate an engine with the ignition turned off, a switch on an engine control panel will normally be provided to facilitate this. Rotating a gas turbine engine with the ignition and fuel turned off (HP cock closed) is often referred to as a "Dry cycle" or "Blow out". Rotating a gas turbine engine with the fuel turned on (HP cock open) and the ignition switched off is referred to as a "Wet Cycle".

It is often useful to test the ignition system with an engine stationary; when an engine is hot after the previous run, care should be exercised in case fuel vapor has collected in the combustion chamber. It is advisable to dry cycle the engine first to clear any flammable fuel vapor.

Starting systems

Gas turbine engines may be started in a number of different ways, the most common being by the use of an electric starter motor. The starter is required to rotate the engine sufficiently quickly so that air and fuel flow into the engine to obtain stable combustion. Once alight, the motor will accelerate the engine to “self sustaining” speed where by it will continue to run under its own power and the starter supply may be cancelled.



Typical small gas turbine starting sequence

Electric starters

Many small gas turbine engines are equipped with an electric starter motor. The motor used is constructed in a similar way to an automotive piston engine starter motor. Usually the motor is of a heavy-duty construction and will carry an intermittent rating of up to several HP. Most starter motors consist of a double series wound or compound configuration, that is, two twin pole motors are built into one case with a common armature. The brush gear will consist of four heavy-duty copper/carbon brushes which are spring loaded onto a commutator.

Series motors exhibit useful characteristics for gas turbine starting. The motor will provide sufficient acceleration to spin the engine up to a light-up speed, the motor will then continue to provide useful torque (as the rpm rises) to enable the engine to accelerate to self-sustaining speed. When self-sustaining speed is reached the starter motor will no longer make any useful contribution to the engine rotation and is shut off.

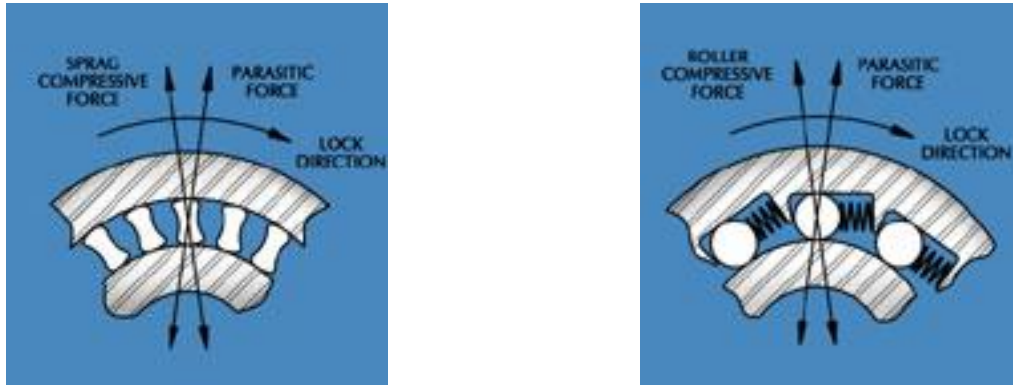


Starter motor suitable for gas turbine engine starting

The starter motor is normally only required to be mechanically coupled to the engine during starting operation. An over-running clutch type device is fitted to the starter motor drive so that the engine is allowed to accelerate freely beyond the starter motor speed and also prevent the starter motor from being driven when it is switched off.

A common type of over-running mechanism makes use of a sprag-type clutch. A sprag clutch consists of a number of specially shaped hardened steel rollers that lie between two concentric rotating cylinders. The rollers or sprags are angled in such a way so that they pick up on the cylinder walls and transmit rotation from one cylinder to the other but in one direction only. In the driven direction the sprags become wedged in place and grip

the cylinder wall. When the rotation or relative rotation of the cylinders is in the opposite direction the sprags slip and allow one cylinder to over-run relative to the other. Springs are sometimes used to further bias the operation of the sprags.

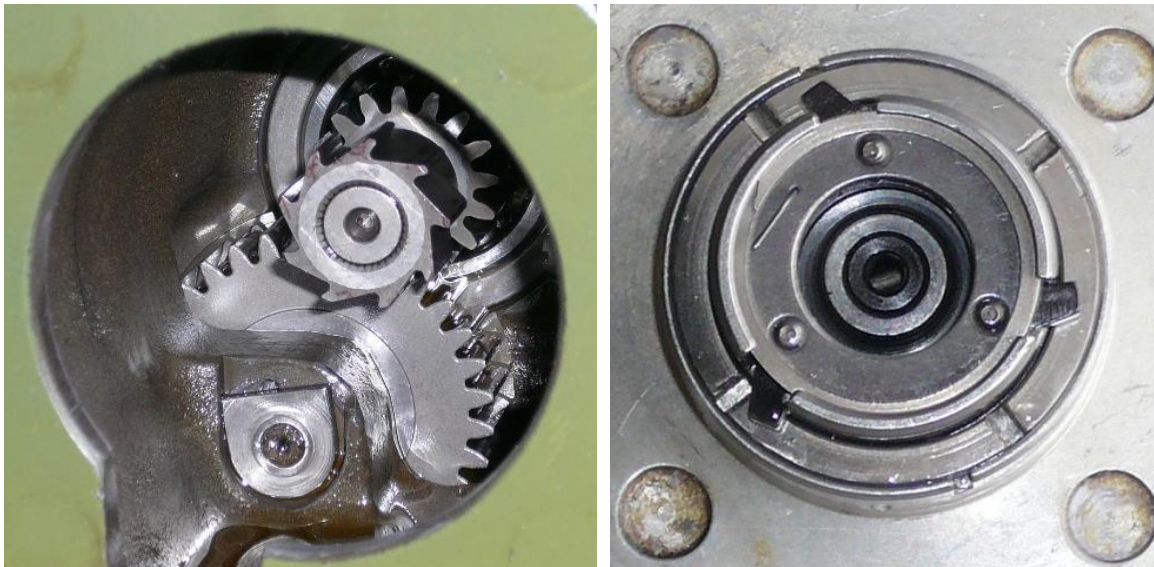


Over-running clutches: sprag type and roller type

Sprag mechanisms often employ centrifugal force to aid the disengagement mechanism of the sprags and help them to "lift off" the shaft and thus prevent wear. In this case the centre cylinder is driven by the starter motor and the outer cylinder rotates with the engine.

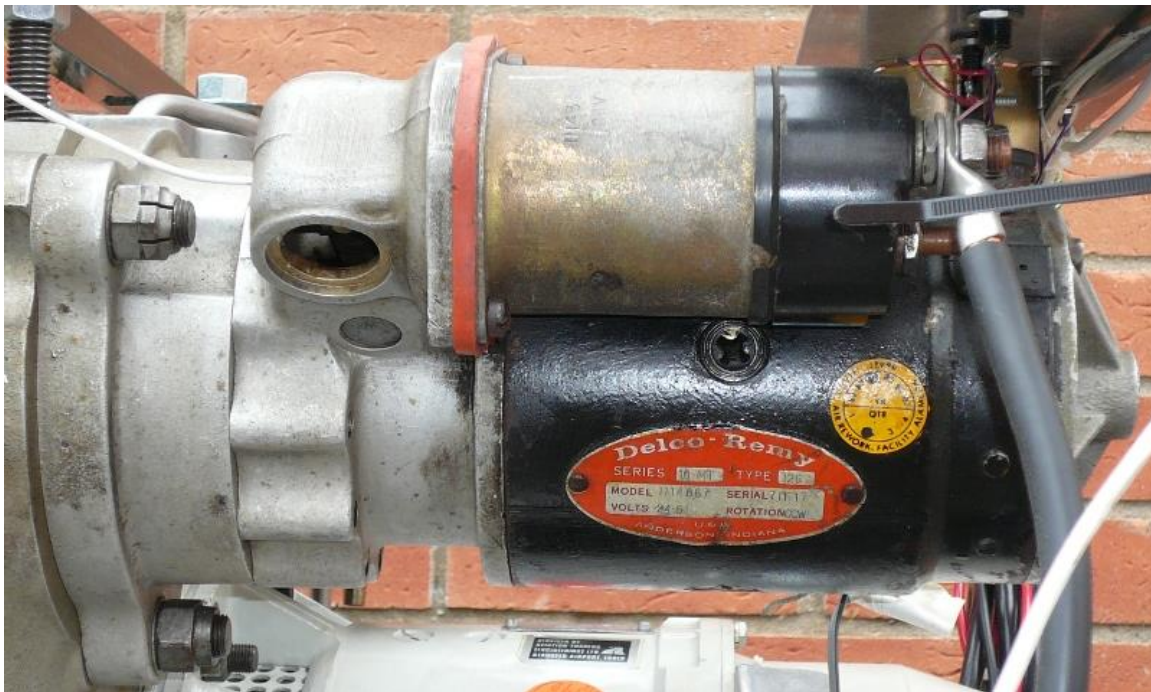
Roller Clutch. The Palouste and Artouste series engines employ a roller type overrunning clutch with which to engage the starter motor. A Roller clutch consists of steel rollers held inside tapered cavities that rotate around a shaft. The rollers are held at the narrow end of the cavity by a spring. Rotation against the direction of the spring force moves the rollers into the wider portion of the cavity and the shaft slips relative to the roller casing. If the shaft turns with the spring direction the rollers travel to the narrow end of the cavity and lock between the casing and the shaft and hence transmit drive in that direction.

Many Garrett engines use a ratchet mechanism to engage the starter. Here three pawls are thrown into a central stationary ratchet as the starter motor quickly begins to rotate. The pawls transmit drive to the ratchet until the ratchet turns faster than the motor, the pawls then disengage and the motor is turned off. The pawls are spring loaded so that they move clear of the ratchet whilst the engine is running and the starter is stationary.



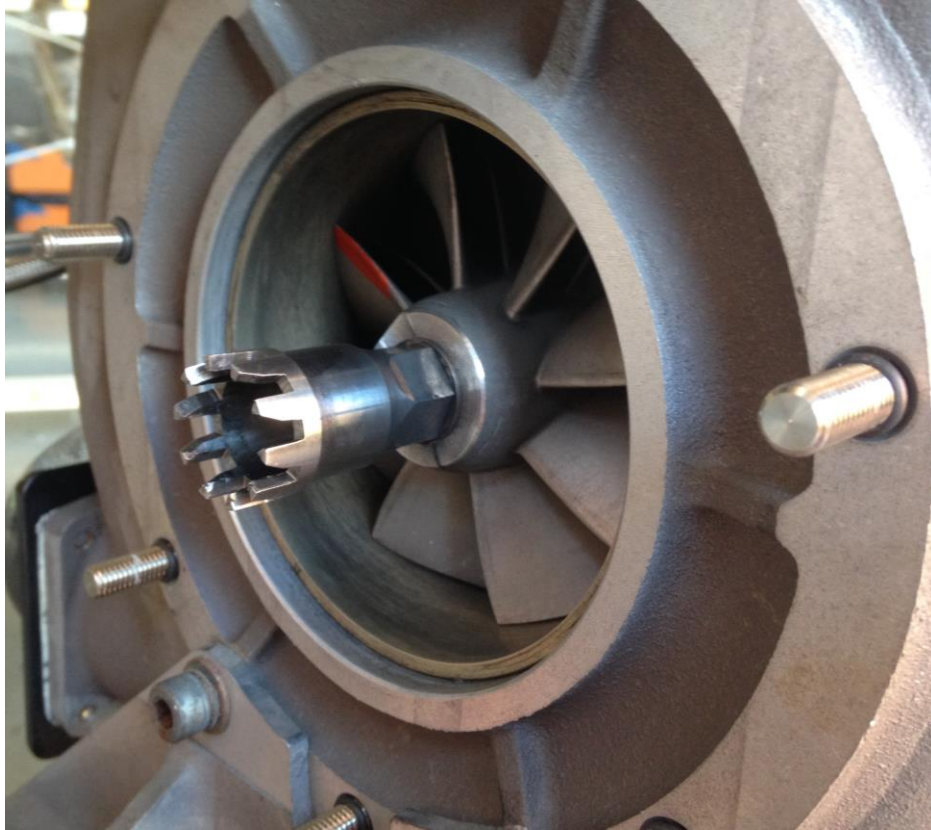
Ratchet type starter engagement mechanism (Garrett GTP30/70/85)

It is possible to use a pre-engaged starter to rotate a gas turbine engine. A similar arrangement to an automotive pre-engaged starter is used to transmit drive into the engine. A heavy duty solenoid is used to throw an engagement pinion into an engine mounted hollow spline at the same time closing electrical contacts which energize the starter motor and the whole assembly rotates.



Pre-engaged starter motor (Solar T62T32)

A few gas turbine designs do not make use of a disconnection mechanism for the starter. The starter motor is simply mechanically connected to the engine at all times, this means that the motor may revolve at a high speed during the engine operation. Motors intended for use with a permanent mechanical connection to a gas turbine must be built to withstand high speeds and have to be specially balanced and re-enforced armatures.



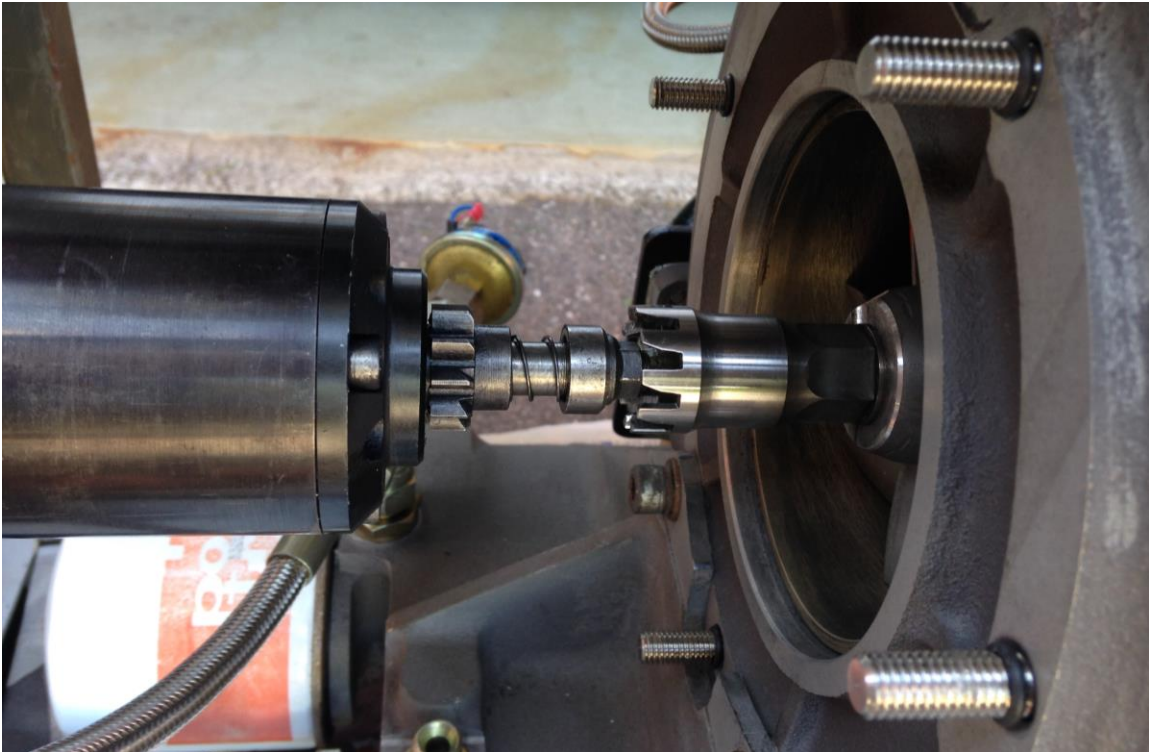
Gas turbine impeller female bendix receptacle for starting

It is possible to directly couple a starter motor to a gas turbine rotor using a bendix system. This was once common practice with automotive piston engines fitted to automobiles, modern systems feature the solenoid operated pre-engaged mechanism. In the case of the piston engine the bendix was used to “throw” the starter pinion in to engagement with the engine flywheel ring gear. When the driver releases the starter the pinion is over run by the starting engine and thrown out of engagement. A similar arrangement may be employed in a gas turbine with some detail differences.

The Bendix system consists of a pinion gear or a coarsely splined component that is mounted on the starter motor shaft. The mounting of the pinion incorporates a steeply angled groove that forms a spiral screw thread, the pinion is free to wind up and down the screw thread over a limited axial distance. The distance is sufficient to allow the pinion to move in and out of a female receiving receptacle mounted on the compressor shaft. The pinion movement is biased with a spring so when at rest the pinion resides in the dis-engaged stationary position. The starter motor is mounted axially in-line with the gas turbine compressor shaft positioned in the air intake of the engine. When the starter is energized, the pinion’s rotating inertia lags the motor shaft and so it is thrown in to engagement with the female receptacle and it cranks the engine. The torque transmitted by the starter holds the pinion in to the driven receptacle. When the gas turbine acquires self-sustaining speed the starter is de-energized and the pinion retracts out of the receptacle and runs down to rest. The receptacle is cut in such a way that the engagement

jaws are angled to aid the pinion disengagement process and prevent it jamming or sticking in place.

The directly coupled Bendix starting system couples the starter motor at engine speed, consequently the starter must withstand high rotational speeds. Care is needed to ensure the bendix mechanism is adequately lubricated to prevent jamming. Care is also needed to ensure the starter is not engaged for too long as the engine could over-speed it and the starter damaged. Also the starter must be engaged only once during the start cycle and if disengaged no attempt must be made to re-engaged it until the starter and the engine have both run down to rest.



The picture shows the starter motor offered up to the compressor shaft with the air intake casing removed. The starter is not shown fully home for clarity, the bias spring may be seen around the shaft. The pinion in the non-engaged position sits just in front of the receptacle and moves left to right when engaged.

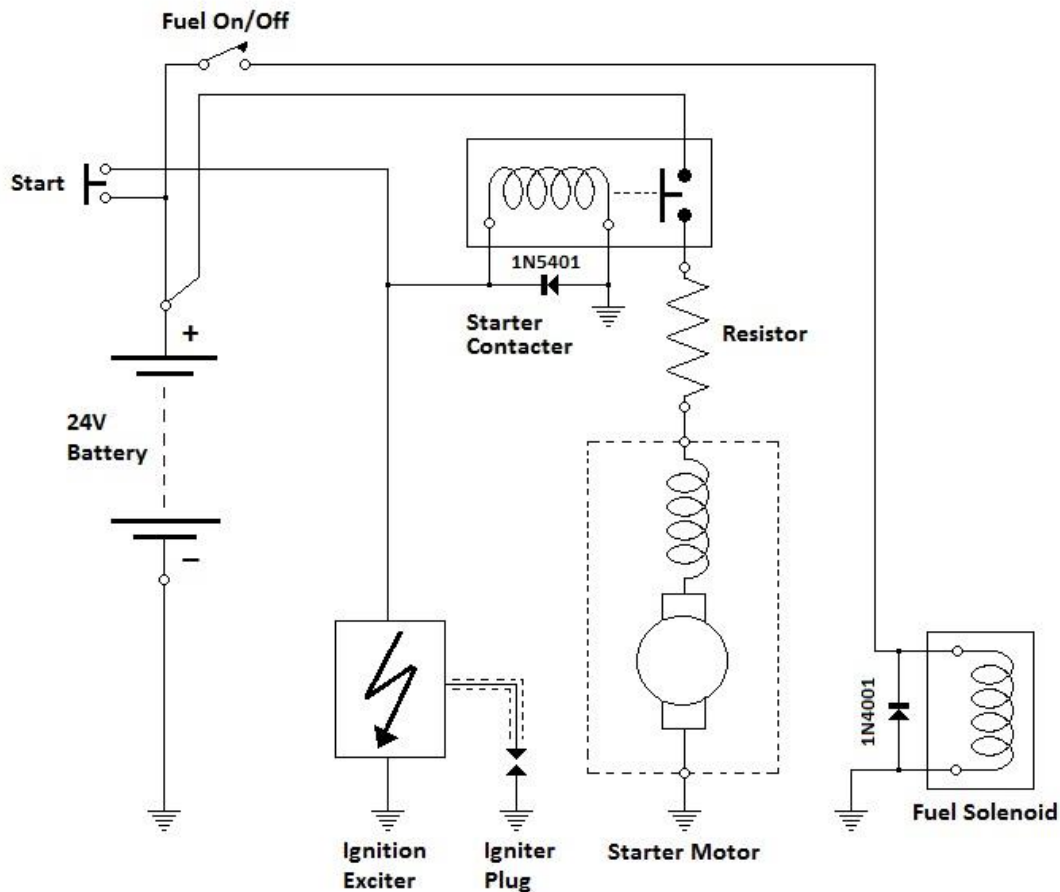
The example shown here features a simple gas turbine constructed from an automotive turbo-charger core. The simple single shaft arrangement has no gear box just the single hydro-dynamic plain bearing arrangement between the compressor and the turbine. Fuel and oil services are provided by electric motor driven pumps so the remaining mechanical task is the starting function, this is achieved with the simple bendix engaged coaxially mounted starter motor.

Many designs of DC generator may also be operated as an electric motor. This feature allows a generator to be used as a starter motor when coupled to a gas turbine engine. The generator windings are re-configured so that the unit is wired as a motor, current is then supplied to it and it rotates the engine. Starter-generators remove the need for separate starter motors and generators and also a disconnecting mechanism is not required. Once started the starter/generator is reconfigured (With the use of switches or relays and sometimes additional motor windings) as a generator and can then supply power to a load.



DC starter generator fitted to gas turbine engine (Turbomeca Astazou)

When rotating a gas turbine by means of a starter motor either for starting or engine cycling, care must be exercised so that the motor is not overheated. Always monitor the temperature of the starter motor and allow time for it to cool between cycles or starts.



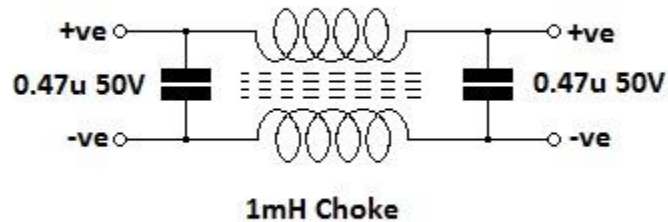
Simple gas turbine starting circuit

The diagram shows a simple gas turbine starting circuit. A heavy-duty contactor is used to pass current from a battery to the starter motor. Often a low value resistor (typically 0.01R) is placed in series with the starter motor to act as a current limiting device that will provide a “Soft Start”. Excessive current may damage the starter motor and also excessive starting torque may result in damage to the gearbox components or drive splines. Connected in parallel with the contactor an ignition exciter unit supplies sparks to the engine to ignite the fuel. The exciter operates when the starter button is depressed. A switch supplies current to the HP fuel solenoid to turn the fuel supply on and off. When starting the engine the starter button must be depressed and held down until the engine reaches self-sustaining speed in which case it may be released.

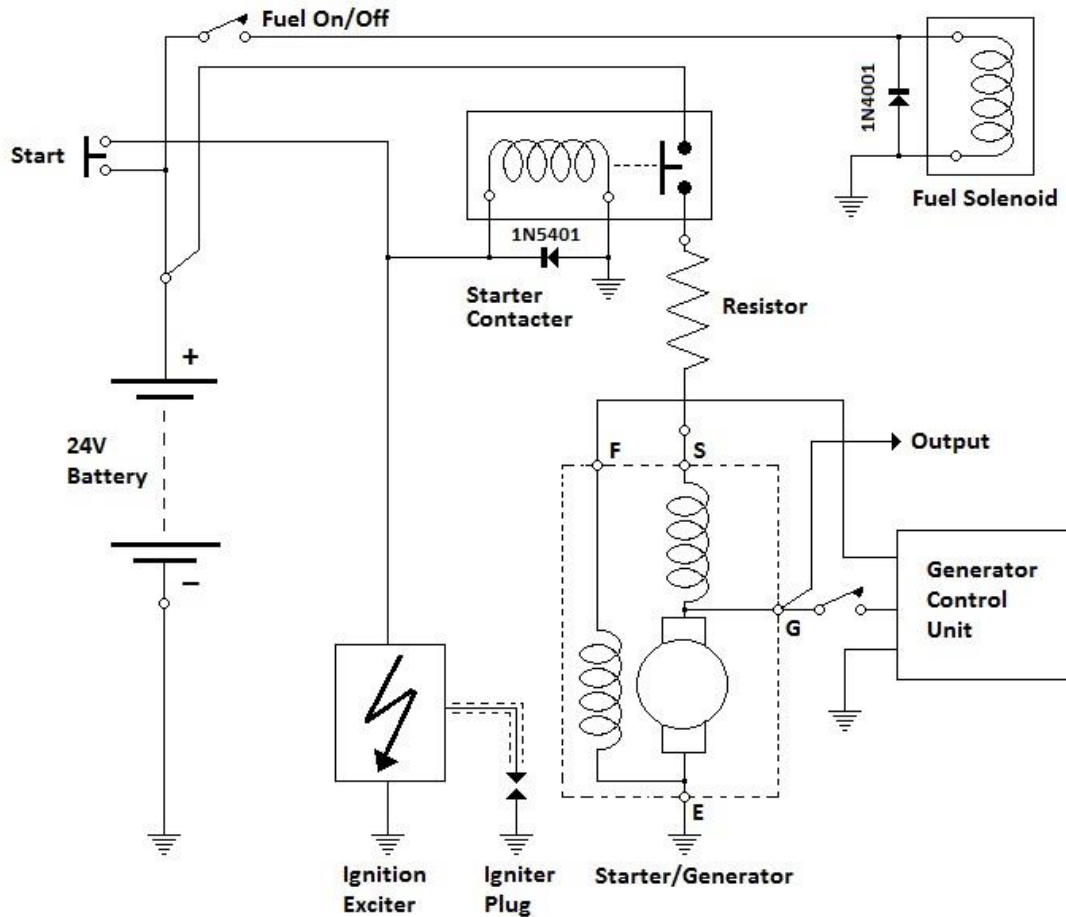
Warning: *Do not depress the starter switch if the engine is already rotating allow it to come to rest before re-engaging the starter. If the starter is released too early, do not – re-engage it, close the HP cock and stop the engine.*

Diodes are placed across the devices that contain coils so that the back-e.m.f. generated by their self inductance is discharged preventing electrical spikes and sparks. It is important to reduce back-e.m.f, spikes to a minimum, otherwise electronic circuits associated with the engine systems may become damaged due to spikes reaching them through the power supply wiring.

Ignition systems may also produce spikes and noise that may interfere with engine control and instrumentation systems. DC filter chokes and capacitors may be placed in the supply to the ignition unit to suppress power supply borne interference.



DC filter circuit for the reduction of ignition interference



Simple starting circuit incorporating a starter/generator

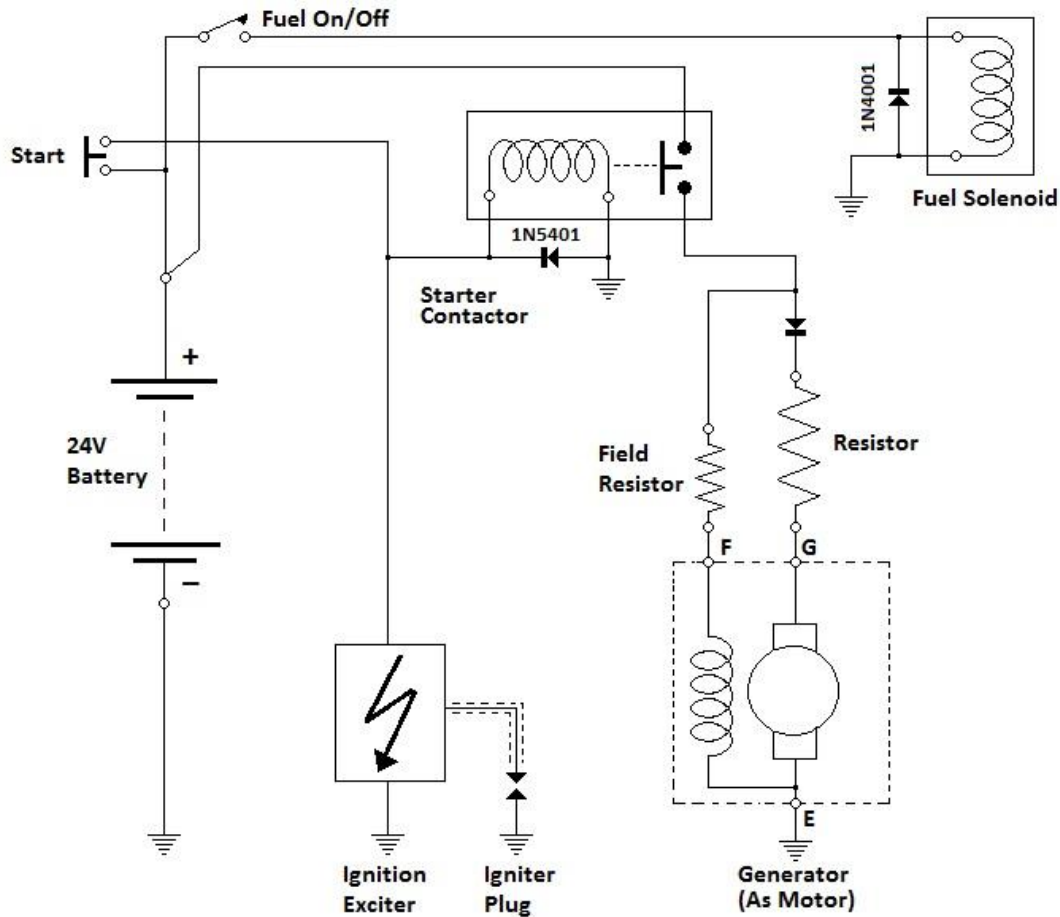
The diagram shows the simplified wiring of a starter-generator unit. The unit is fitted with a number of electrical terminals that allow it to be wired in starter or generator mode. During the starting phase current is fed to the start (S) terminal only and the engine starts as with a conventional motor. Once running beyond self-sustaining speed and successfully started, the current is cut off to the starter.

Whilst the engine is running at idle or governed speed the starter may be operated in generator mode. The generator (G) terminal is connected to the control box, as the control box is connected to the field (F) terminal the generator will excite and power becomes available at the G terminal. The control box will control the generator output and ensure it remains within acceptable limits.

The generator excitation is the process were by some residual magnetism in the poles generates a small current which is fed back into the field winding and quickly becomes magnified and the generator excites. Some systems may use battery current to initiate the excitation process instead of relying on residual magnetism.

Configurations of starter generators do vary according to type and application. In some cases the field circuit is used during starting. The correct manufacturers circuit

connections should be used otherwise an incorrectly connected starter/generator may overheat and be damaged.

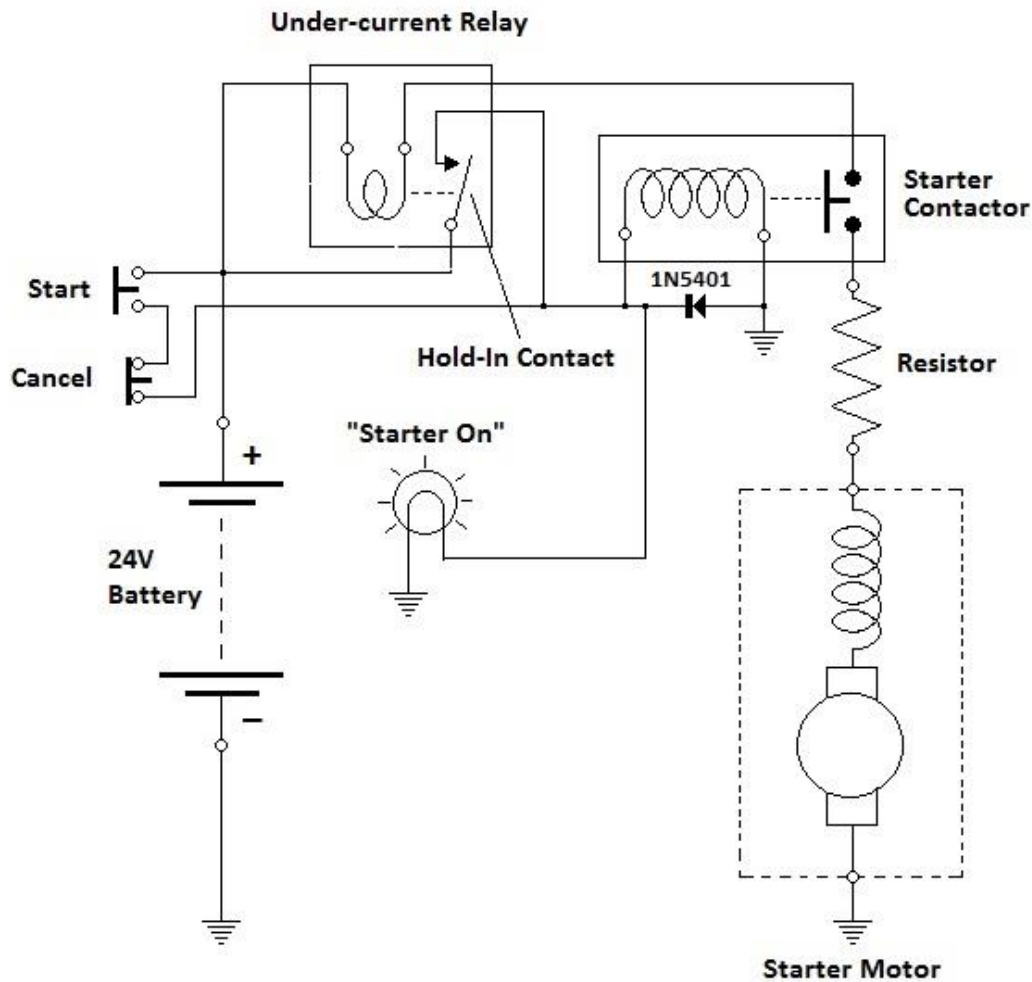


Starting circuit utilizing a DC Generator as a starter motor

The diagram shows how a DC generator may be used as a starter motor. By connecting the field and generator terminals together will result in the unit running as a “Shunt” wound electric motor. A shunt motor has undesirable characteristics as a gas turbine starter motor as it tends to run at constant speed and will not accelerate the engine to self sustaining speed efficiently. Placing a resistance into the field circuit has the effect of weakening the magnetism within the motor which actually tends to make it run faster with better characteristics for gas turbine starting. Experimentation and testing is required to establish the optimum values for both the field and current limiting resistors. Typical values for a 35A 28V DC generator as 22R for the field and 0.01R for the series resistance. A high current diode is placed in the generator supply to prevent the circuit from exciting and generating in an un-controlled manner as the engine self-sustains.

It is possible to augment the starting characteristic further by using relays to switch in and out resistances during the start cycle. Initially the field circuit is strengthened and the

series resistance applied. As the engine accelerates a circuit may be used to detect the speed and switch in the field resistance and at the same time switch out the series resistance for maximum rotational power.

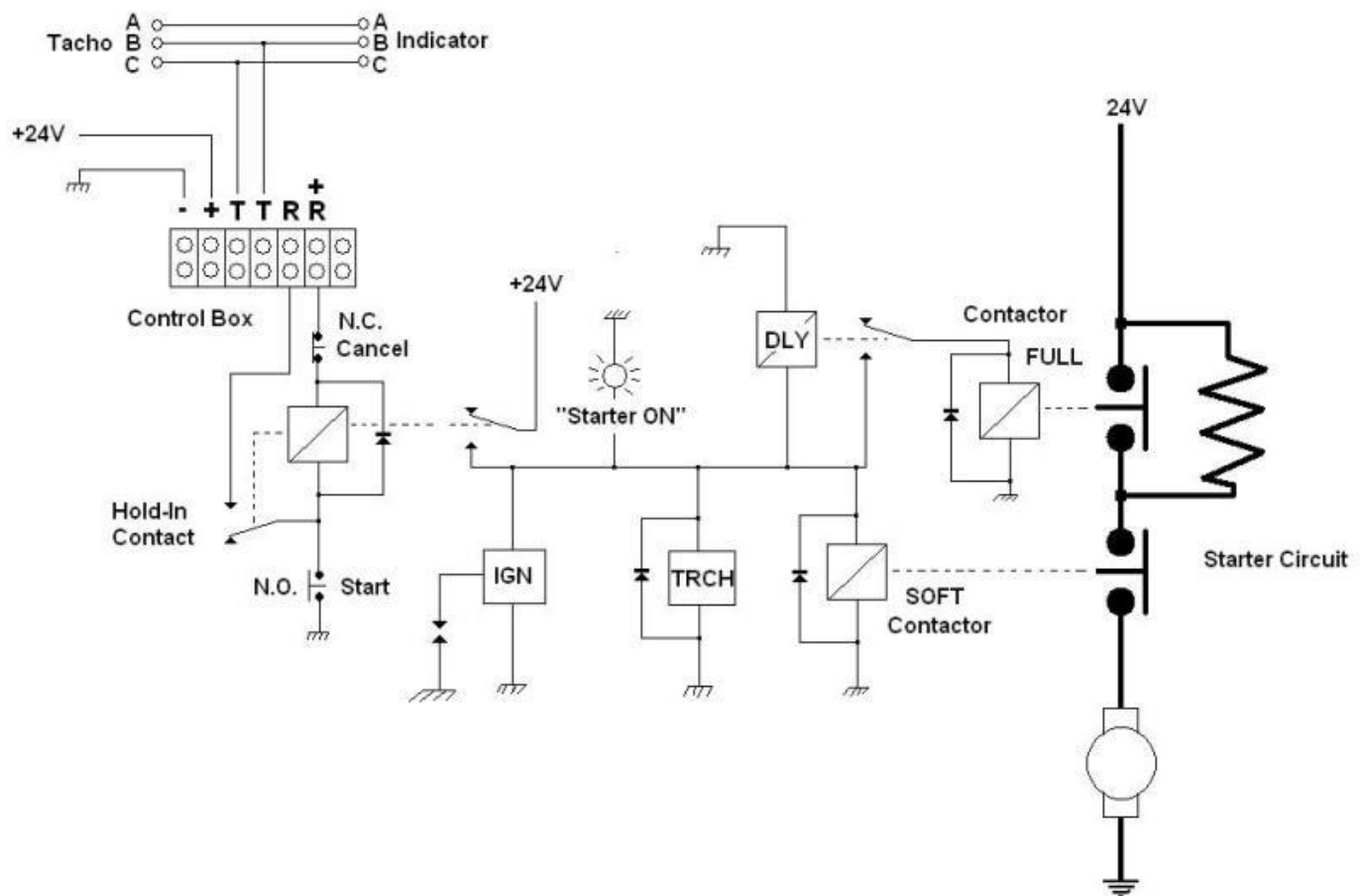


Starter circuit with under-current sensing relay

The diagram shows a starter circuit with the addition of an under-current relay. The starting current is passed through this special high-current relay. When the start button is depressed the current consumed by the starter motor closes the under-current relay, by means of a hold-in contact the starter button may be released, the relay remains closed and the starter continues to rotate. As the engine accelerates and becomes self-sustaining the current consumption of the starter drops considerably, the under-current relay is specially adjusted to drop-out and release the circuit when the current consumed drops below a pre-determined minimum. Hence the circuit automatically switches off the starter at the end of the start cycle. Should the gas turbine fail to start, the starter may be cut manually by interrupting the current with a normally closed switch placed in series with the hold-in contacts. A lamp is used to indicate when the starter circuit is in operation and it will extinguish when the engine self-sustains and starting cycle is complete.

Electric starters are often incorporated into an automatic starting system. Here a single button push initiates a process where by the starter motor, ignition system and fuel supply are sequenced automatically to start the engine. Usually a system of electric timers or pressure switches may be used to sequence the engine start cycle.

Timer controlled systems employ an electric time delay unit. The unit cuts out the starter and ignition system after a pre-determined period, also an under current relay may be used to cut out the starter motor. When the start button is depressed the starter solenoid supplies current to the starter motor, this current also closes an under current relay. The undercurrent relay also closes a pair of contacts that are then used to hold-in the starter solenoid. This arrangement supplies current continuously to the starter motor and the engine rotates. When the engine reaches self sustaining speed the load on the starter motor reduces which intern reduces the starter current consumption, at this point the undercurrent relay drops out and breaks the starter solenoid hold-in circuit. The ignition system is normally operated in parallel with the starter and so it is also cancelled when the starter drops out. The engine will now accelerate to running speed under its own power. If the engine failed to light up, the starter would continue indefinitely due to the high load current, this will burn it out (Or flatten the battery, which ever comes first). A timer is used which will cancel the starter after about 30 seconds in the event of a failed light up.



Starting circuit installed in Viper 535 powered track drier vehicle

The diagram shows a starting circuit installed in a drag strip track drier vehicle. A semi-automatic starting system is used to start a RR Viper 535 jet engine. The circuit operates as follows:-

Depressing the start button energizes the start relay which intern energizes the ignition units, the torch igniter relay, a time delay and a "Soft Start" contactor. The soft start contactor energizes the starter motor via a current limiting resistance. The engine begins to rotate slowly towards approximately 5%. After a period of 3 seconds, the delay circuit expires and closes the "Full" contactor further accelerating the engine to light up speed and beyond. By means of the electronic control box, an engine speed of approximately 40% is detected and the control box interrupts the current to the hold in contact and the whole starting system drops out of operation.

If the engine fails to light up and hence does not reach 40% speed, the starting cycle may be cancelled at any time by depressing the cancel button which stops the start process.



High current starter contactors



Starter current limiting resistor

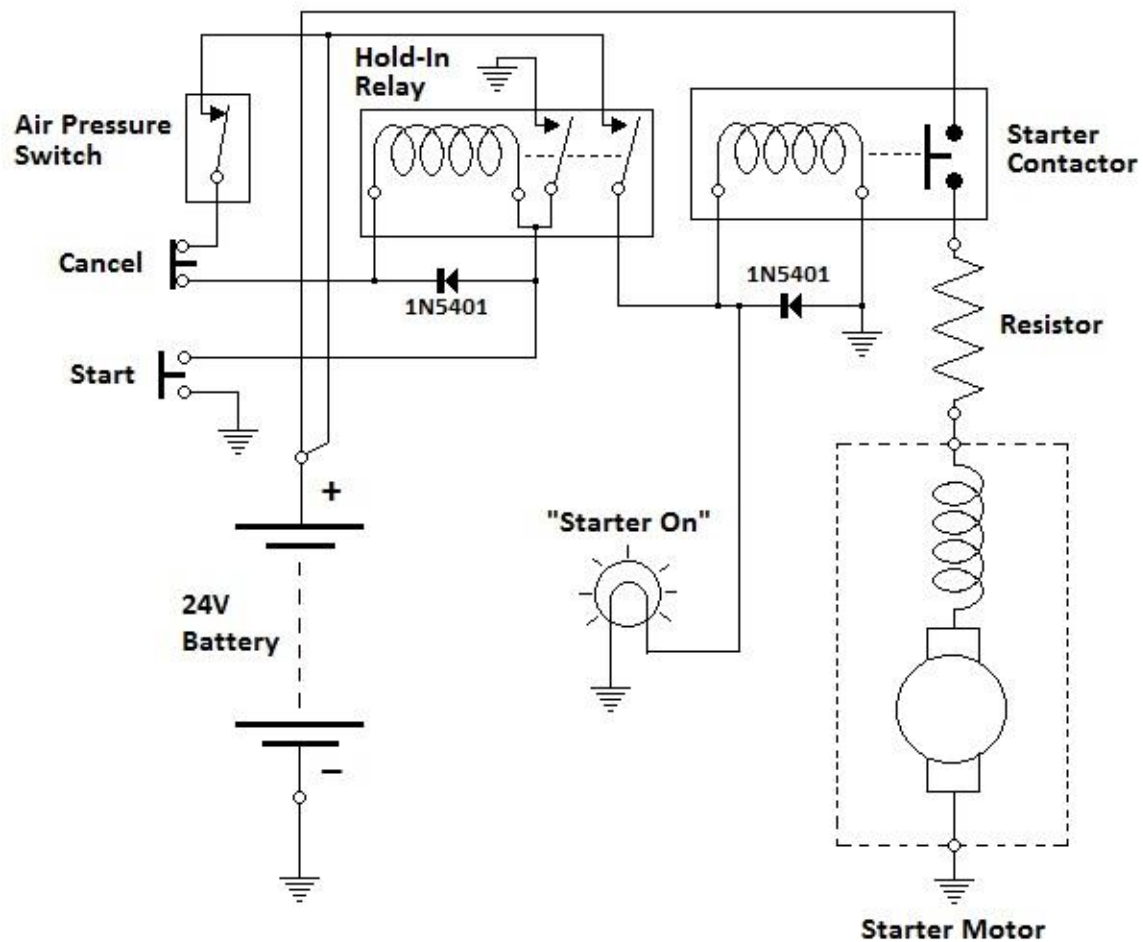


Starter circuit under-current relay

Pressure switches may be used to control a gas turbine engine start cycle. A pressure switch can be connected to a sample of the “P2” compressed air supplied from the compressor. P2 air pressure rises as the engine speed increases, a pressure switch set to open at a few PSI (typically 3-5 PSI) is used to detect a successful start condition and cancel the starting sequence. A time-delay switch may be used in addition to the pressure switch to cut out the starter if the engine fails to light up and the value of P2 does not increase sufficiently to operate the switch.



Sensitive pressure switches



Starter circuit incorporating air-pressure switch

The diagram shows a starter circuit incorporating a sensitive pressure switch. Depressing the start button supplies current to a hold-in relay and the starter contactor. The hold-in circuit is broken when the air pressure switch opens cancelling the start cycle. The start cycle may be canceled manually by depressing the normally-closed cancel button.

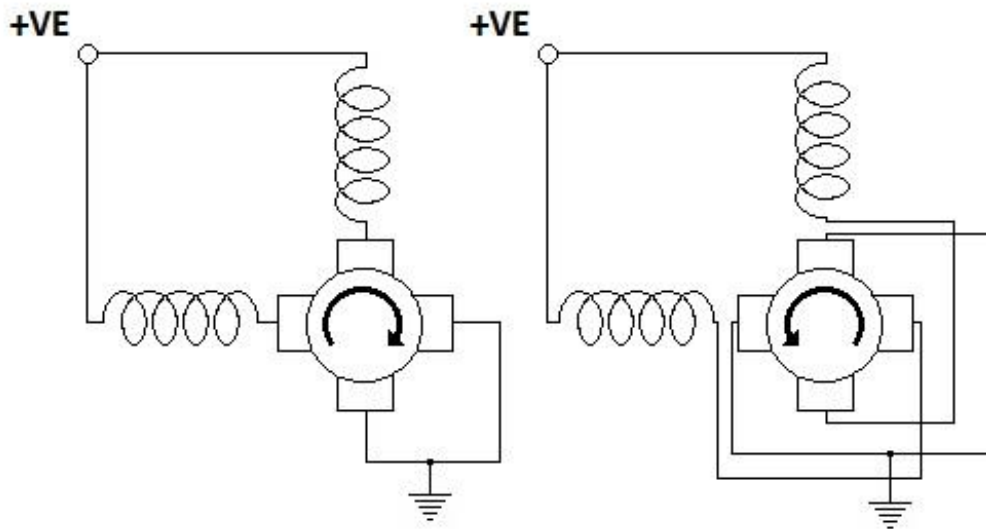
The pressure switch is supplied with air from the gas turbine compressor. It is adjusted to operate at 3PSI, as the engine self-sustains the rising compressor delivery pressure exceeds 3PSI and the switch operates cancelling the starter.

Electronics may be used to control the starting sequence of a small gas turbine engine. Microprocessors may also be used to provide sophisticated control and may react to different fault conditions.

Electric starter motors are the most common means of starting small gas turbine engines. When obtaining scrap of surplus units the starter motors are often found to be missing. It is common practice when removing an engine from an aircraft or other installation to remove the starter. Motors and generators are often classed as separate re-conditionable items and so are not included with a replacement engines. Gas turbines and aircraft engines are often referred to as an "Engine Change Unit" or "ECU". An ECU defines what constitutes a replacement engine and what other systems remain aboard an airframe. Starters and generators are often not part of a standard ECU.

If an electric starter is missing from an engine, obtaining a suitable unit is often difficult due to the specialized nature of aerospace equipment. One solution is to adapt an electric motor from another purpose. For ground stationary use, motorcycle starter motors are often compact and powerful units, if the appropriate mechanical engineering facilities are available such a motor may be modified and fitted as a replacement for the original.

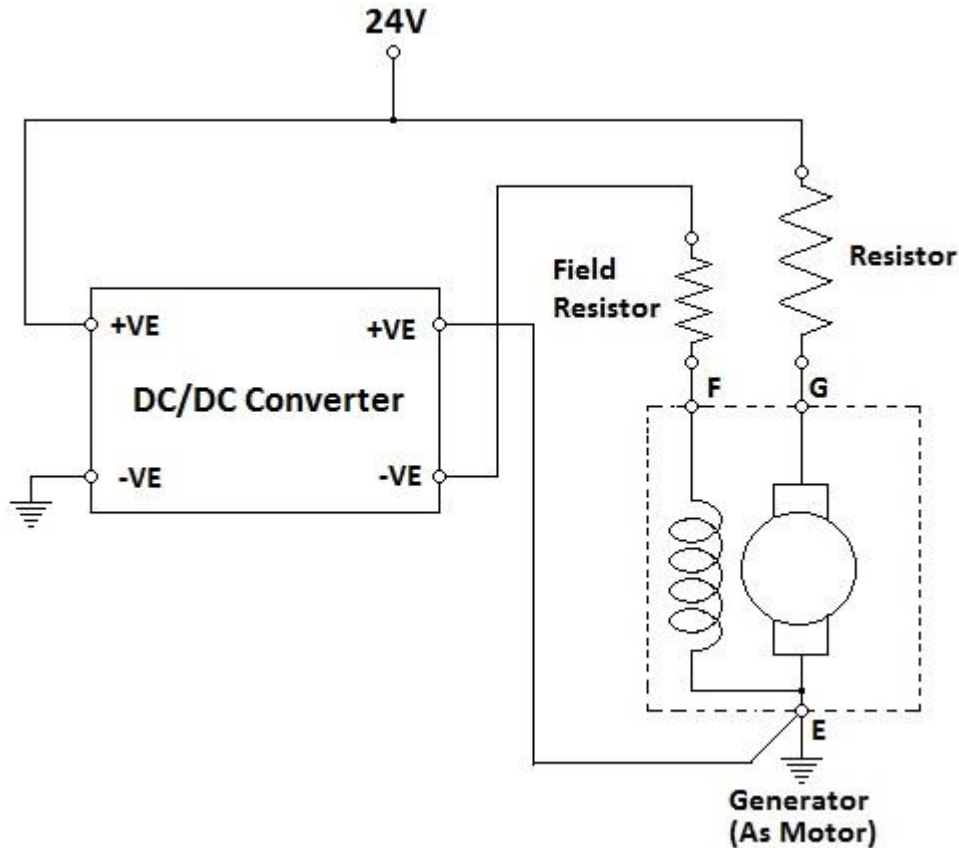
Reversing the direction of electric motors and generators



Reversing a double series wound DC motor

It is sometimes possible depending on the design and construction of a series-wound DC motor to reverse the direction of rotation. The diagram shows a double series wound motor (4 pole) of the type that might be suitable for adoption as a gas turbine starter motor. The electrical connections to the brush gear are reversed relative to the field coil windings. Depending on the design and construction of the motor it may be more practical to reverse the field (Stator) windings rather than the brush connections. In some cases the brush holders may be grounded to the motor casing in which case they cannot be electrically isolated from it.

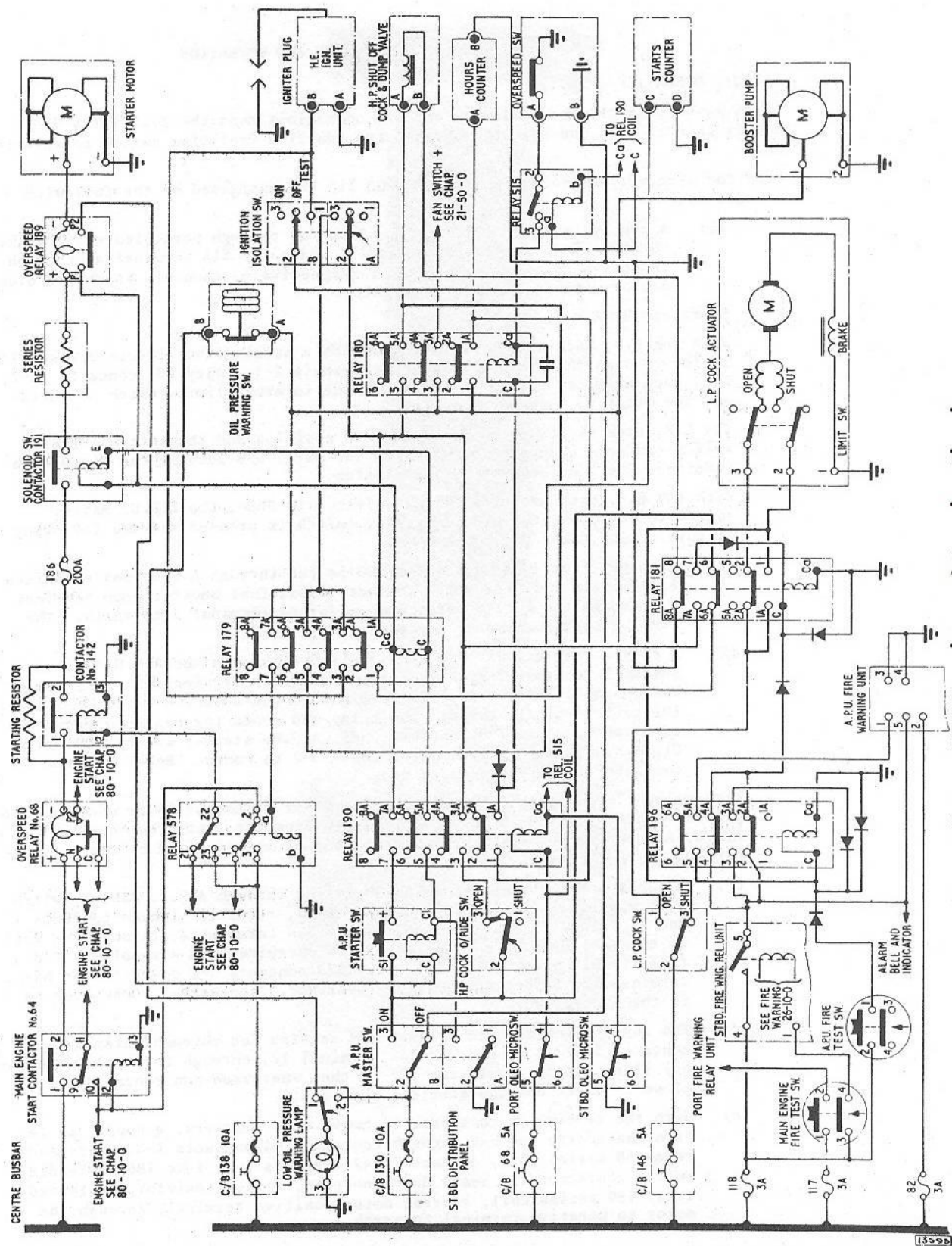
Certain designs of DC motor employ rotationally offset brush gear, reversing the electrical connections alone may reverse the motor but some performance may be lost as the brush timing is not reversed unless they may be mechanically rotated through the equivalent reverse angle.



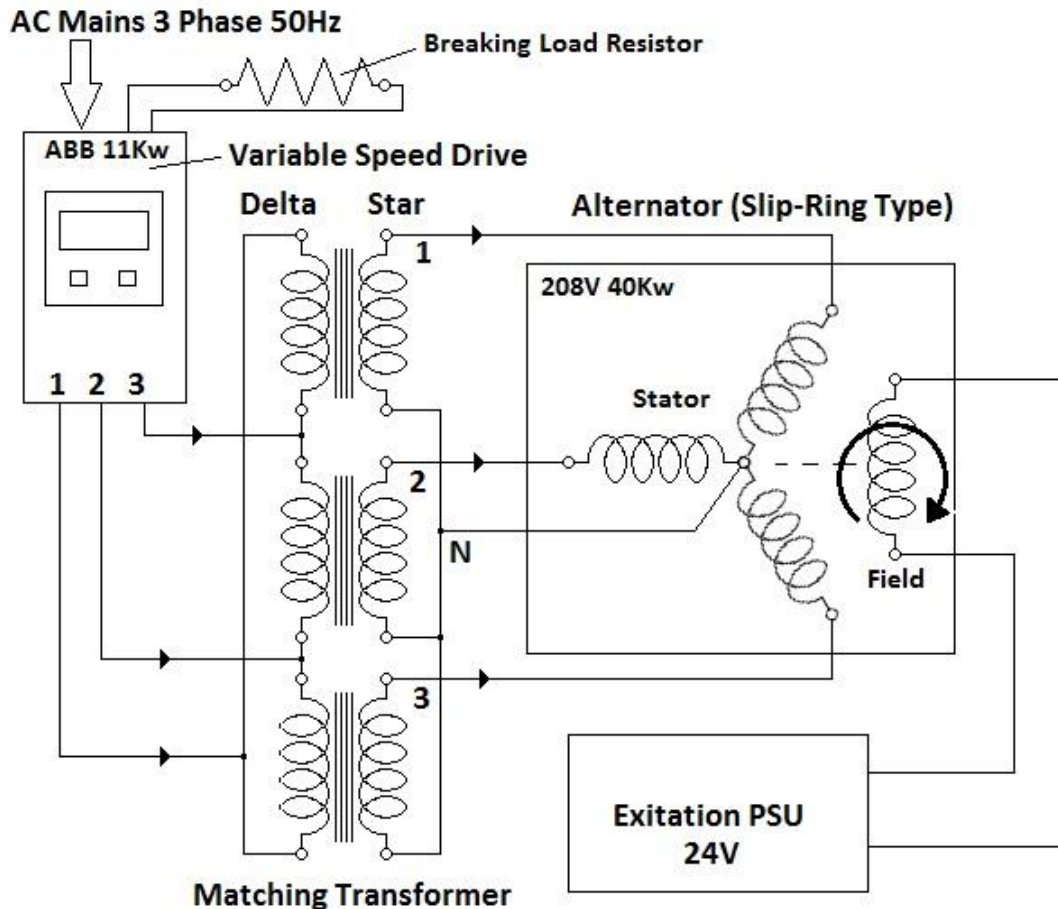
Reversing simple shunt-wound type motor

The diagram shows how a DC/DC converter may be used to reverse a shunt-wound type motor. The direction of current in the motor field windings has been reversed and so the motor direction is reversed also. In many cases it may not be possible to access all the field winding connections and they may be grounded internally within the motor frame. An isolated DC/DC converter power supply features a “Floating” output circuit and so a positive earth supply is obtained without the use of a second isolated power source negating the need for second battery.

Unfortunately not all designs of shunt wound motor or generator may be suitable as advanced types may feature partially rotated brush gear and may incorporate special compensating poles known as “Inter-Poles”.



Rover APU Starting and Running Circuit



Back-driving an alternator for gas turbine starting

The drawing shows how a 40Kw 400Hz alternator may be used as a starter motor. If greater starting endurance and power is required (After modification to combustion systems increasing thermal inertia etc) it is possible to use a slip-ring type alternator as a powerful synchronous motor when driven from a variable speed drive unit. Variable speed drives are common place devices that are often used for industrial process control and machine tool drives. The 11kw drive unit consists of a rectifier and storage capacitors to create a high voltage (600V) DC bus that feeds a solid state variable frequency inverter. The output of the inverter may be connected to a three phase motor or in this case a three phase alternator. A programmable microprocessor control system may be set up to control the frequency and voltage to accelerate the alternator-motor and hence the gas turbine engine to self-sustaining speed.

The alternator is of aircraft 8000 rpm 400Hz type so the AC drive will be programmed to accelerate the motor to several hundred Hz. Some experimentation is necessary to obtain the optimum acceleration characteristic. Because of the synchronous-motor characteristics of the alternator, the gas turbine will try to “over-run” the drive but will be held back by it. At self-sustaining speed the alternator will begin to function as a

generator, so a special breaking resistor bank attached to the drive unit will dissipate any excess generated energy that is passed back through the inverter circuit. At the point of self-sustaining the drive system should be cut off and the engine allowed to accelerate freely under its own power. The cut-off point may be detected by a pronounced increase in power dissipation within the breaking resistance. The breaking resistance dampens a rise in the rectified “Bus” voltage within the drive, the drive will have a protection circuit to detect excessive bus voltage that will cancel the drive output.

To operate the alternator as a synchronous motor a power supply is needed to excite the rotating field coils inside the unit. In the case of aircraft derived alternators a large (15Kw) three phase matching transformer is used to match the nominal 240V drive output to the nominal 110V input of the alternator. The variable speed drive output may be programmed to ramp-up in frequency and voltage as the alternator is accelerated to ensure unnecessary power dissipation is kept to a minimum.

The “commutation” of the alternator is simply achieved by running it as a synchronous motor. A loss in synchronism will result in a rapid loss of power and speed, this should be avoided so a rapid cut-out system should be implemented. AC drives are over-current protected so the unit is likely to cut itself out if synchronism is lost. Some systems may suffer from hunting and torsional oscillation if acceleration is too rapid, the breaking system will help dampen and reduce this. The engine compressor wheel and turbine effectively acts as a flywheel at the end of a step-up ratio gearbox. Sophisticated AC drive units may accept external rotational feed-back devices so the commutation and acceleration could be improved.

The arrangement described here was able to accelerate a 60HP gas turbine to approximately 50% (Far beyond the original DC starter motor capability!) cold, and before combustion was initiated. As soon as the engine lit up, power was developed sufficient for self-sustaining and the drive would cut out instantly!

Starter performance testing

It is often useful to test crank a gas turbine engine to ascertain the effectiveness and performance of the starting system. A typical small APU size gas turbine engine of up to 100HP is required to turn over at about 20% rpm with the fuel turned off (Dry) to ensure enough power is available to accelerate it to self-sustaining speed. Reduced starting power due to a faulty starter or partially discharged battery could result in a slow, hot or even hung start. A hung start is where a gas turbine engine lights and partially accelerates (under the assistance of the starting system) but does not reach idle speed but instead “Hangs” at an undesirable intermediate speed. Hung starts usually result in high temperatures and even damage to the engine hot section and so should be avoided.

An incorrectly adjusted or faulty fuel control system may also produce the symptoms of a hung start. Incorrect scheduling of the fuel flow may stifle acceleration during starting and produce a hung start. Fuel supply starvation (due to low fuel pressure or head, blocked filters etc) will also lead to a hung starts.

A gas turbine should typically be allowed to reach around 40% rpm before the starter is cut off. A healthy engine should then continue to accelerate to around 60%. Many small units may not operate at an idle speed and will simply accelerate to the full 100% rated speed.

Larger gas turbines (up to 1000HP) such as helicopter engines are likely to crank around 15% cold, larger still jets around 5000Lbs thrust crank around 10-12% under electric power. Air-start engines generally crank much faster due to the greater availability of cranking power from small air turbine units. A big turbofan may be required to rotate at up to 25% (N3) before initiating combustion.

Warning: Do not test crank an engine with a dry fuel system. It is bad practice the fuel pump may be damaged if rotated dry. A fuel supply should be applied to the engine (and if necessary bled) with the ignition off and the HP cock closed.

Batteries

There are two types of battery suitable for starting gas turbine engines, that is conventional Lead-Acid types and more exotic aircraft Nickel-Cadmium types.

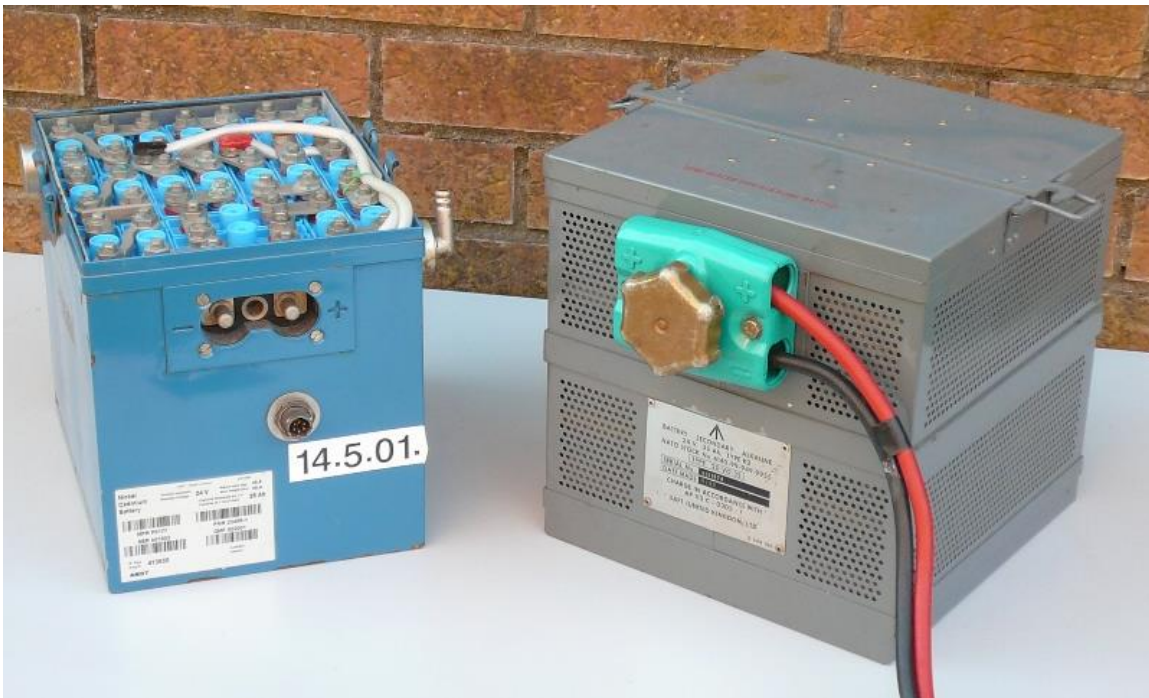
Lead-acid batteries

Two 12V lead-acid automotive batteries are usually wired in series to provide a nominal 24V supply for engine starting. Most small gas turbine engines are fitted with 24V starters, some small stationary types such as some versions of the Rover 1S60 were 12V only. Batteries with sufficient capacity for several starts should be used and if possible re-charged or float charged between start attempts. For a small 60HP unit automotive batteries of at-least 500A cranking capacity and 60 Ah are recommended. Batteries of undersize will result in a slow crank with the possibility of a hot start. As an engine cranks the terminal voltage of the battery is often depleted to as low as 15V this may result in igniter exciter units functioning slower and hence a slower engine light-up response.

Consideration should be given to potential cranking currents when using very large lead acid batteries such as lorry and truck batteries that may often be conveniently mounted on a "Battery Trolley". In some cases very high cranking currents from large batteries of low internal resistance may damage or shear engine drive components. Often in an aircraft installation, some distance of high airframe current cabling will introduce a small amount of current limiting resistance. Large truck batteries placed close to an engine starter may over stress it. If in doubt a "soft" start resistance or other system should be employed to prevent potential damage. Using long cables (5M length 25mm²) is sometimes an appropriate way to introduce some small cranking resistance.

Nickel-cadmium batteries

Wet type Nickel-Cadmium batteries may be used to start small gas turbine engines. Ex-aircraft units if in reasonable condition may not pass a serviceability or capacity test for aircraft use but may still provide adequate cranking power on the ground. Typical capacities range from 23-45 Ah. Ni-Cad batteries for aircraft use exhibit longer life and better cranking capacity for a given size and capacity.



Wet Ni-Cad batteries consist of between 19 and 20 individual 1.2V plastic cased cells placed inside a metal enclosure with a terminal connector placed on it. The individual cells are wired in series to produce nominal voltages from 22-24V. When fully charged the terminal voltages of these units will approach 28V. The construction of Ni-Cad batteries is such that they may be fully serviced and individual cells may be checked and replaced if under-performing or are faulty.

Servicing Ni-Cads involves testing the capacity of each cell and if necessary individually discharging them to equalize out any charge states. A battery may be fully discharged without the risk of reverse charging a cell by placing resistors across each cell individually. A 1R resistor fitted across a Ni-Cad cell of nominal 1.2V will discharge it over 24hrs or so, the whole battery may then be re-charged.

When storing Ni-Cad batteries the cells should be fully discharged and then shorted out to prevent any small or reverse charge forming. Manufacturers such as Marathon, Varta and Saft all manufacture Ni-Cad aircraft batteries. The manufacture's servicing information should always be closely followed when maintain Ni-Cad batteries.

The electrolyte stored in a Ni-Cad battery is potassium hydroxide, this may be topped up with de-ionized water, never use sulphuric acid or implements that have come into contact with sulphuric acid with a Ni-Cad battery!

Ni-Cad batteries should be charged from a constant current charger source with also a voltage limit applied so that as the fully charged state is approached the battery consumes less current preventing the risk of thermal run-away. Typical charging voltage should be set to 28V and the maximum current limit set to 4A. Nic-Cad batteries may be fitted with a thermal monitoring device so that sophisticated charger system may detect a rising battery temperature and reduce charging current accordingly.

Many Aircraft Ni-Cad batteries are fitted with an “Elcon” type quick release connector, this makes removal and fitting convenient and also partially protects against exposed terminals.

Hand starters

A number of stationary gas turbine engines that are designed for portable operation are equipped with a hand crank or manual starter. Hand starters consist of one or two connected cranking handles that are used to turn over the engine via a step up ratio gearbox. The ratio of the gearbox may be up in the order of 40:1, this is to ensure that the engine reaches sufficient speed for starting will become self-sustaining. An over-running mechanism is also fitted to allow the engine to accelerate and the operator to stop cranking.



100HP hand-crank stationary gas turbine (Deutz T216)

Hand crank starters are fitted with a small magneto or generator that is used to provide sparks to ignite the fuel in the engine. The Rover gas turbine uses a small generator to supply electrical power to a high-energy igniter box, as the engine is cranked the plug should fire in regular succession. The hand crank mechanism also rotates a small air pump that assists light up by passing air to the burner.

The Saurer GT15 gas turbine uses a totally unique system for starting. A pull-cord is used which incorporates a sprag clutch mechanism. Instead of one pull that might be required for a piston engine, a number of quick successive pulls are required to accelerate the engine to self-sustaining speed. This engine apart from being probably the smallest production gas turbine engine in the world circa 1966 must also be the only gas turbine engine ever to be started in this way.



Small gas turbine engine equipped with pull starter (Saurer GT15)

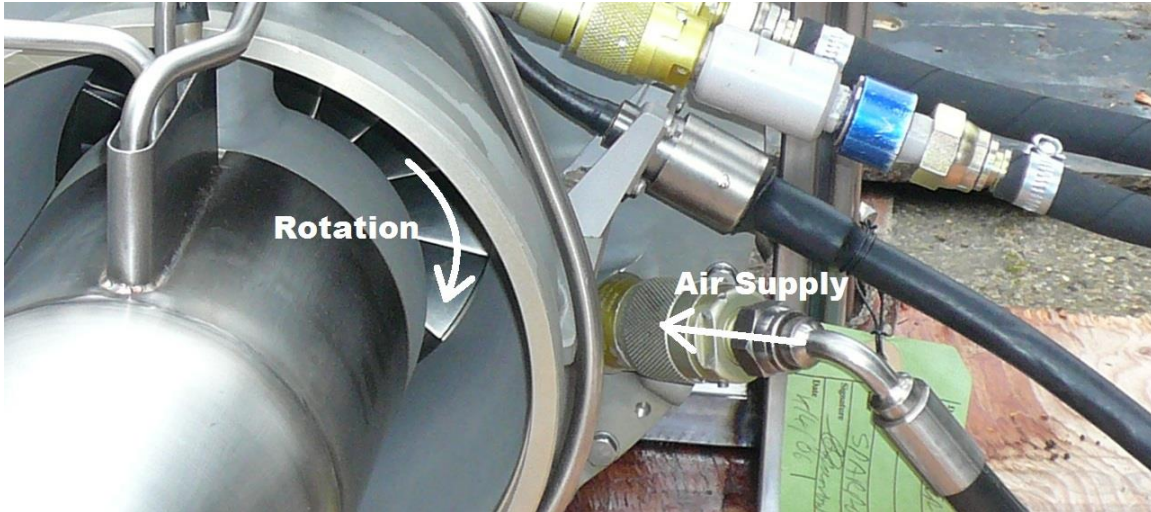
Considerable effort is required even to start a small gas turbine engine. Hand starters require several horse powers worth of human effort for a duration up to 30 seconds, this is to enable an engine to attain self sustaining speed. Many manually equipped engines employ two handles to enable the starting effort to be supplied by two people.

Hydraulic starters

It is possible to use a hydraulic motor to rotate a gas turbine engine for starting. Hydraulic pressure is supplied from a reservoir and pump, a hydraulic motor mounted on the engine rotates it to self-sustaining feed. The Williams APU make use of this arrangement. For independent starting a hydraulic “power pack” will be required to supply the motor. A hydraulic power pack will normally consist on a motor driven pump, reservoir and control valve.

Air impingement starting

Air Impingement is a simple way to rotate a gas turbine. A number of small propulsion engines make use of air impingement starting. Compressed air from a high-pressure bottle is rapidly discharged onto the compressor rotating inlet guide vanes via a small nozzle. The compressor rotates as a simple impulse turbine and accelerates up to light up speed. The air pressure continues to accelerate the engine to self-sustaining speed. As compressed air is entering the engine intake this helps to provide the engine with additional air to "breathe" during start up.



Turbojet engine fitted air impingement starting

To start a small gas turbine a relatively large quantity of compressed air stored at over 1500 PSI is required so that sufficient energy is available to accelerate the engine. A compressor unit is required to charge a reservoir for each start attempt this is sometimes inconvenient and time consuming. Rapidly discharging compressed air also creates frost and condensation on the pipes and connections.

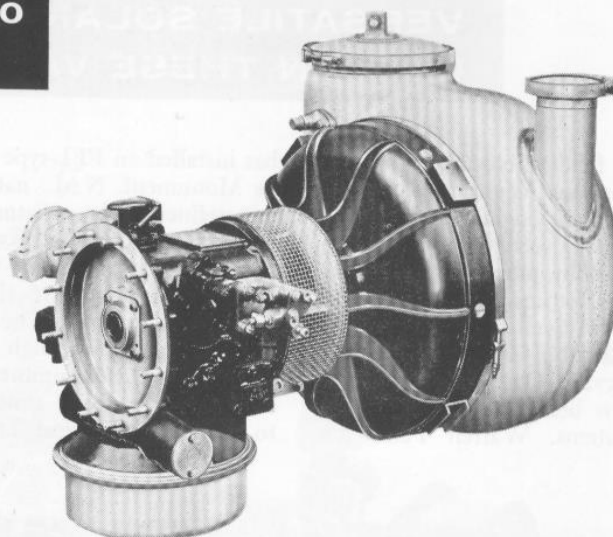
A pressure regulator unit may be placed between the engine and the storage reservoir to reduce the pressure to a relatively constant level for engine cranking.

Air impingement starting exhibits the advantage that the engine carries very little weight actually mounted on the engine itself. A simple nozzle is inserted in the region of the compressor impellor.

THE 350 HP SOLAR T-350 GAS TURBINE ENGINE

Solar's T-350 gas turbine is available for industrial applications, including EFL Energy Systems. In a typical EFL system, the T-350 engine drives a generator, pump or compressor, while its exhaust heat is recovered in a boiler to produce steam for heating, air conditioning or processes. Single or multiple EFL units can supply power needs for industrial plants, schools, office buildings, hospitals and shopping centers. System efficiencies are 80 per cent or better.

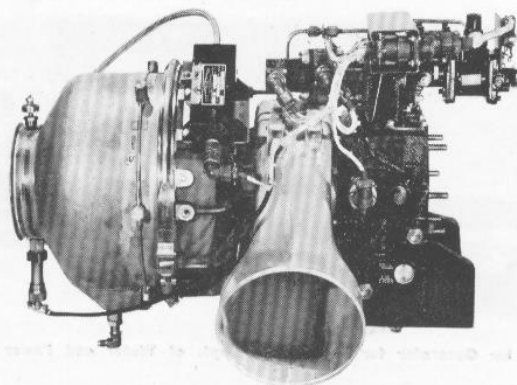
The T-350 is a simple cycle engine which operates at a conservative turbine inlet temperature of 1450°F. Constant speed shaft power and air bleed versions of the T-350 are available for a variety of aircraft starting and other auxiliary power applications. A typical package is a self contained 100 kw generator set for advanced field radar systems.



SPECIFICATIONS SOLAR T-350

hp	Length	Height	Width	Weight
350	38.00"	25.62"	26.35"	220 lb

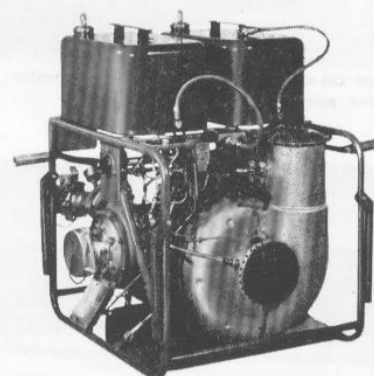
LIGHT COMPACT 80 HP SOLAR TITAN



Only 21 inches long and less than 13 inches in diameter, Solar's Titan gas turbine weighs 61 lb and develops up to 80 hp.

The Solar Titan gas turbine is a lightweight, simple cycle, single-shaft, constant speed engine. It is used in a number of auxiliary power applications. A Titan turbine powered APU aboard the Army's Vertol Chinook helicopter provides electric and hydraulic power and allows systems checkout without using main engines or rotors. Titan

engine units are also used aboard the deHavilland AC-1 Caribou STOL transport, Grumman AO-1 Mohawk reconnaissance aircraft and Sikorsky HSS-2 helicopter. A light, compact ground power unit designed by Consolidated Diesel for aircraft checkout uses Titan engine prime mover.



Above: The Solar Mars gas turbine engine develops 50 hp and weighs less than 100 lbs.

Below: Solar's 600 hp T-600 engine currently being developed will be fully competitive with reciprocating engines of similar horsepower.

