Chapter 6

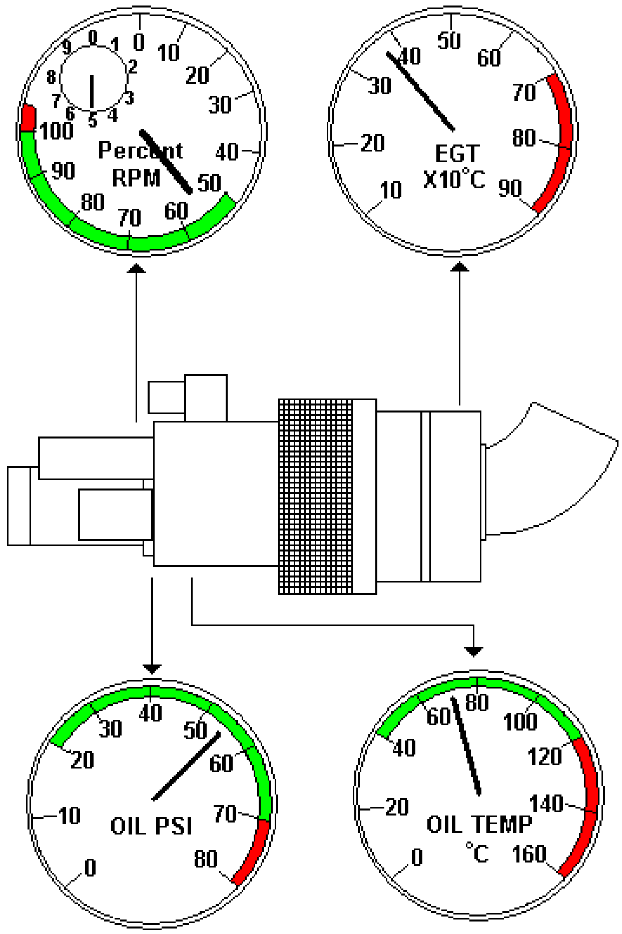
Instrumentation

When operating any gas turbine engine, instrumentation is useful and, in many cases, essential. The two most important operating parameters of a gas turbine are speed and temperature, that is, how fast is it going and how hot is it getting? The rotational speed of an engine must be considered during different stages of its operation, and a maximum speed should never be exceeded. The exhaust gas temperature or turbine inlet temperature indicates the health of an engine and when it has reached its maximum permitted load.

There are many other useful operating conditions that may be monitored such as lubricating oil pressure and temperature, compressor delivery pressure, fuel pressure, and air intake temperature. In the case of electrical generators, voltage output, current flow, alternating current frequency and power output or VA (volts x amps) may also be monitored.

Devices may also be fitted to gas turbines that measure cumulative and cyclic events, the most common are total running time and the number of starts.

Executive devices may also be fitted as part of an instrumentation system that will protect the engine by shutting it down in the event of a fault condition or if running parameters are exceeded.



Typical basic small gas turbine engine instrumentation

Engine speed measurement and indication

Many gas turbine engines are fitted with some sort of speed measuring or indicating device, normally this consists of either an electrically operated tachometer or a mechanically driven speed indicator.

Mechanical tachometer

Many stationary engines employ a mechanically driven tachometer to indicate the engine speed. A cable drive is used which is derived from the engine accessory gearbox like a mechanical automotive tachometer. The cable connects to a simple automotive type of indicator that works in the same way as a piston engine tachometer or a car speedometer. Inside the indicator a rotating magnet is driven by the connecting cable and spins inside an aluminum drum. Due to electrical current that are induced into the drum, the drum turns in the same direction as the rotating magnet, but it is restricted in movement by a spring. The faster the magnet turns the further around the drum turns which flexes the spring, the rotation of the drum is proportional to speed and so is used to move a pointer next to a calibrated scale.

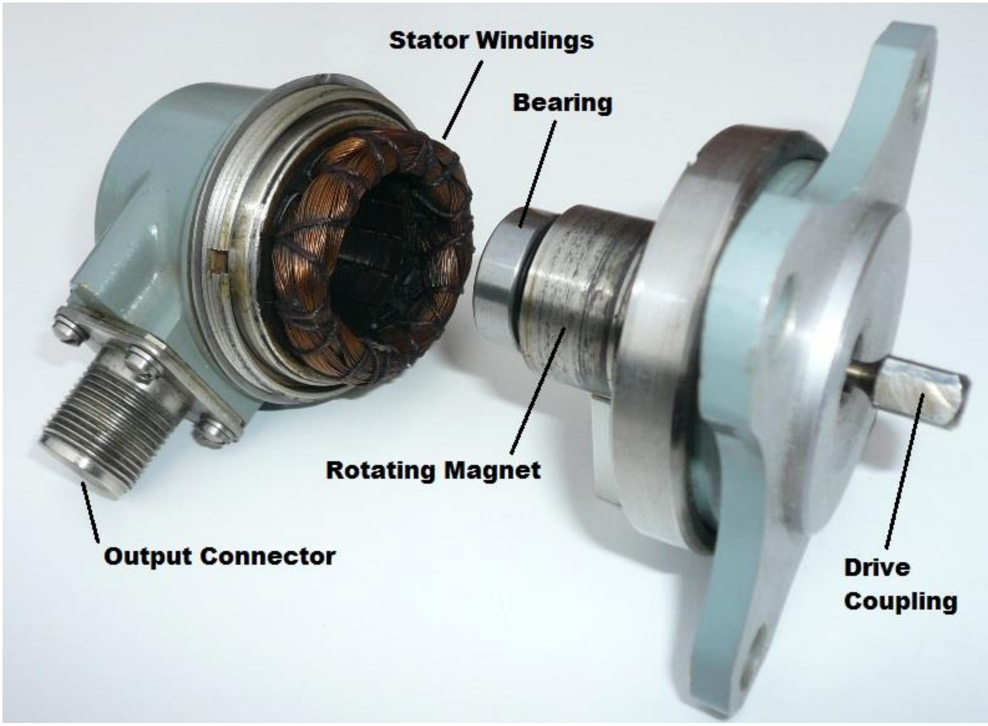
Mechanical RPM Indicator (Rover)

Certain versions of the Rover 1S60 engine use a mechanically driven tachometer. The tachometer is also fitted with an "Odometer" type counter which records engine running time. The correct governed speed is marked on the tachometer dial face, and it is calibrated from 0 to 50,000 rpm.

Electrical tachometers

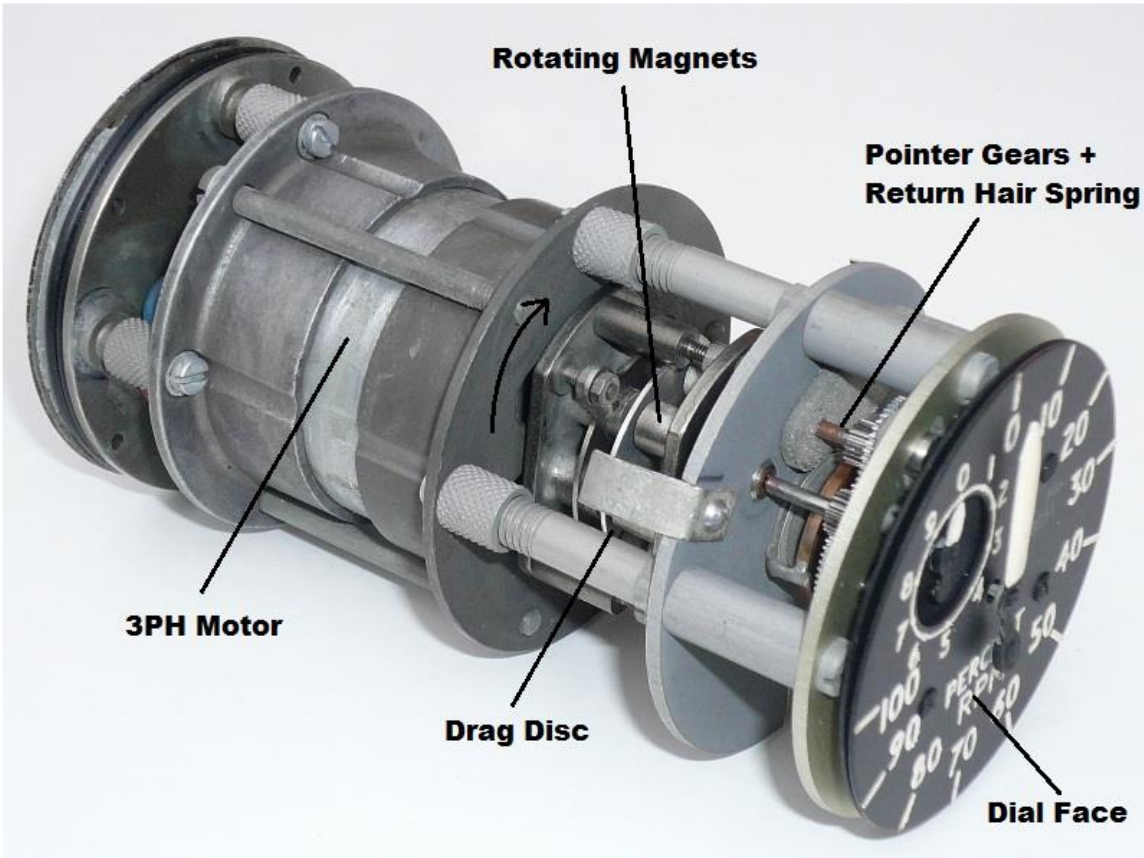
There are many electrical systems that are used to indicate engine speed, the most common system uses a tachometer-generator/indicator system. A small two-pole alternator is driven by the engine accessory gear train and normally mounted on a part of the accessory gearbox. The alternator provides a three-phase electrical signal; the frequency of the signal is proportional to the engine speed. A three-phase generator is chosen for this application as it provides a current that will rotate a small motor in a defined direction. A three-phase signal not only carries the frequency information but also the direction of rotation information also. The tachometer-generator (alternator) is connected to an indicator instrument that is calibrated in RPM. This arrangement is very common on older aircraft and can also be found on ground based stationary equipment.

A tachometer-generator consists of a magnet that rotates inside several stationary coils and pole-peices. Most tachometer generators are of the three-phase type and so there are three individual coil windings. The coils are wired together to from a three-wire live circuit with a common neutral. The three-wire output signal is brought out of the unit to a three-pin connector. Because the signal is a three-phase type, the order of the wiring determines the rotation of the motor connected to it. When installing and testing such a system the rotation and order of wiring should be checked. If incorrect (Which will result in the indicating device running backwards), two of the three phase wire connections must be reversed. Care should be exercised never to create an electrical short across the coils of the tachometer generator when it is turning, as this will damage the generator by reducing the strength of the magnet inside. A weakened magnet will result in less electrical output that will, lead to false or unreliable readings on the indicator instrument connected to it.



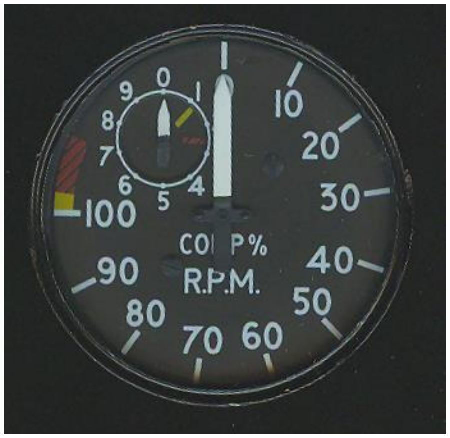
Tachometer-generator (Disassembled)

The three-phase electrical output from the tachometer-generator is used to drive a small electric motor, the motor is mounted inside the speed indicator instrument. The instrument is constructed in a similar way to the mechanical tachometer, the motor drives a "speedometer" type mechanism that moves a pointer to reveal engine speed. The combination of the electrical generator and the instrument-mounted motor replaces the mechanical cable drive.



Electro-mechanical percent RPM indicator

The instrument dial face is calibrated in RPM or in many cases %RPM. Gas turbine engines unlike piston engines vary enormously in operating speed, for instance a Rolls Royce Derwent engine idles at around 3500 rpm a Saurer GT15 APU idles at about 50,000 rpm! Percent is an easier way of quantifying engine speed for all sizes of gas turbine. A common %RPM indicator consists of two dials, a large one for x10% and a small dial for x1%. The small dial is sensitive to speed changes and rotates rapidly when an engine accelerates or decelerates.

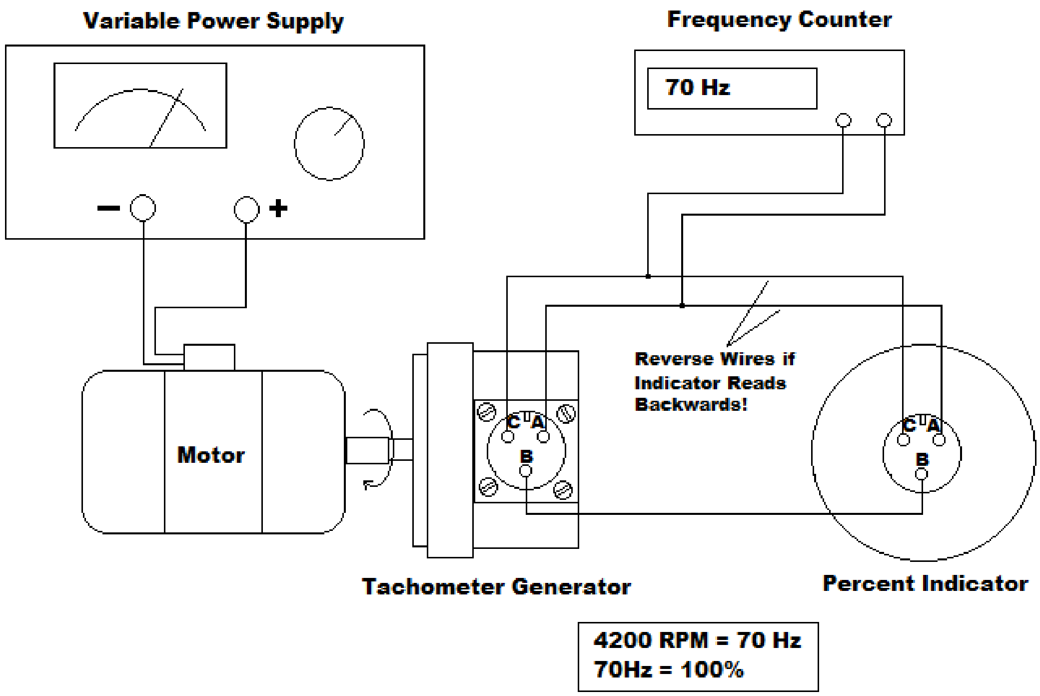


Percent indicator dial

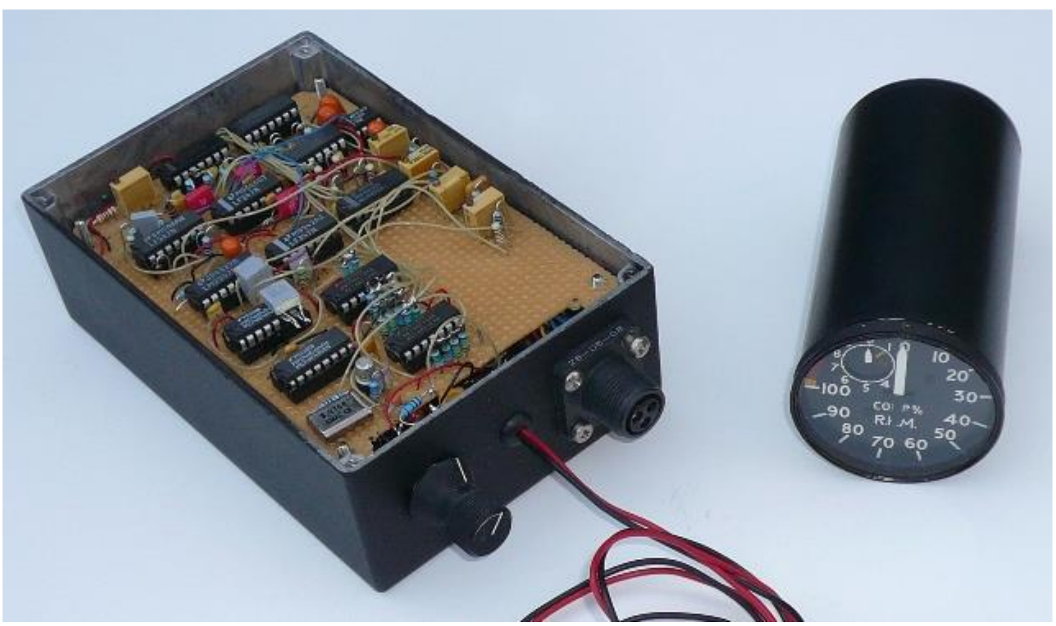
Many %RPM indicator instruments conform to a common standard. The instrument indicates 100% when fed with an AC signal measuring 70 Hz in frequency. A two-pole tachometer-generator turning at 4,200 rpm will produce this signal. It is normally arranged inside the engine gearbox so that the tachometer-generator is driven at 4,200 rpm when the engine is operating at maximum speed i.e., 100%.

Older (circa 1950s) engines may use other gear ratios and instrument calibrations, it is important to always be clear about the actual and indicated speeds of any running gas turbine. It is useful if possible, to check a tachometer-generator and indicator instrument combination when removed from the engine. An electric motor is used to rotate the tachometer-generator at a particular know speed and the indicator reading noted. The tachometer-generator unit may be removed from the engine, and the drive rotation examined so that the exact speed ratio may then be determined, this is achieved by rotating the main engine shaft slowly and watching for movement of the tachometer-generator drive.

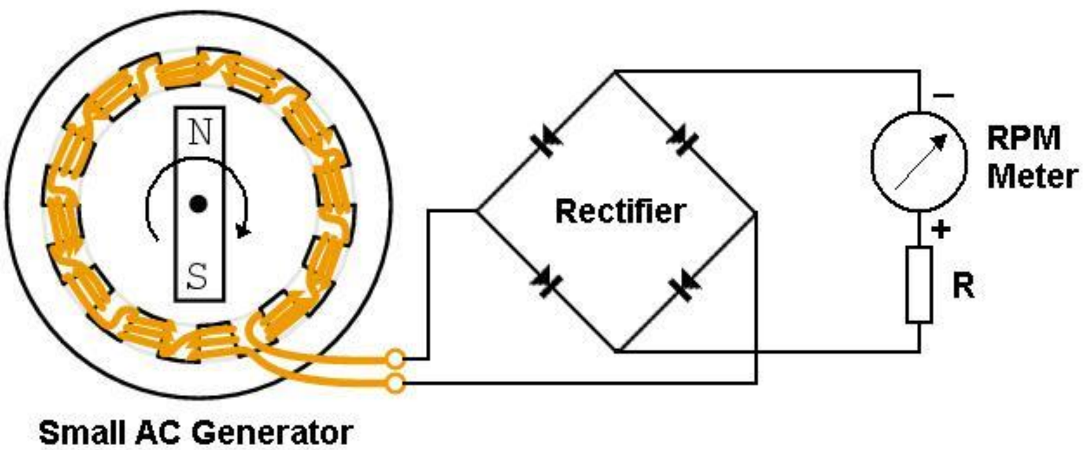
Bench testing percent indicator



Electronic 3-phase test generator for operating percent indicators



There are many electrical tachometer systems, one simple system consists of a single-phase engine driven AC generator and a low current voltmeter. The EMF (electro motive force) produced by the generator is found to be directly proportional to the rotational speed of the generator, as the speed doubles the voltage doubles. This is because the EMF driving the induced electrical current in the generator windings is dependent on the rate of change of magnetic flux through them. In any moving magnet generator this is the case. The generator output voltage is measured with a simple low current moving coil meter and rectifier; the meter is calibrated in RPM. A resistor is placed in series with the meter coil to calibrate the circuit and protect the meter against excessive current flow.



Simple RPM indicating system using small AC generator

Electronic circuits may be used to provide a speed indicating system when an engine was not originally fitted with such a system. A rotating shaft or gear wheel is used provide a point where a sensor can detect the rotation and provide a train of electrical pulses proportional to speed. Magnetic reluctance probes are useful devices that may be used as engine speed pick-ups. A reluctance probe consists of a small magnet and a coil mounted on a common magnetic pole piece. The probe is placed near rotating objects such as gear teeth that are made of a magnetic (ferrous) material; the magnetic coupling is found to vary as the gear teeth pass by. The varying magnetic field leads to an induced electrical signal in the coil, the signal is amplified and processed to provide a speed indication.

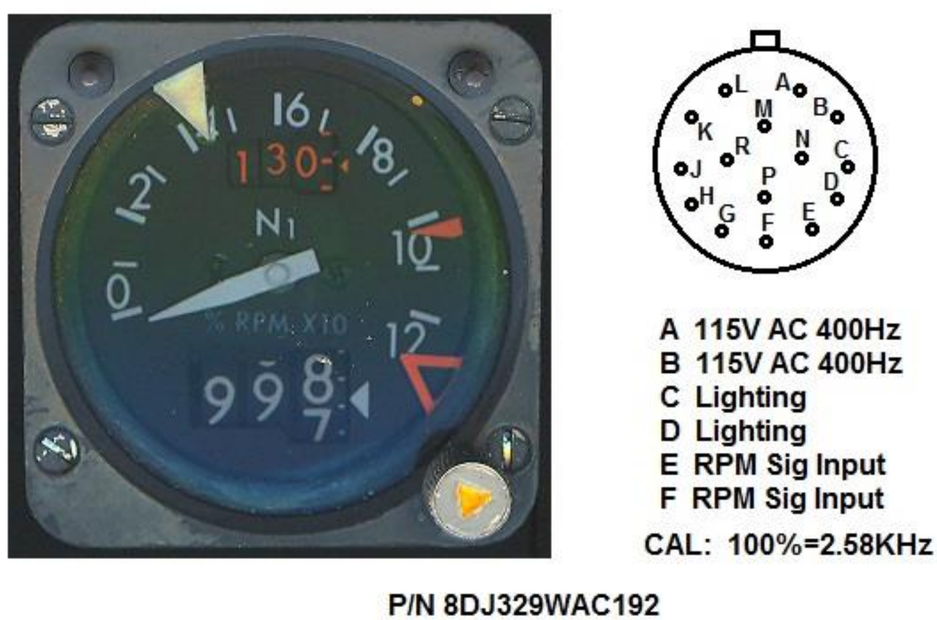
Electronic percent engine speed indicators

Electronic servo-driven percent indicator

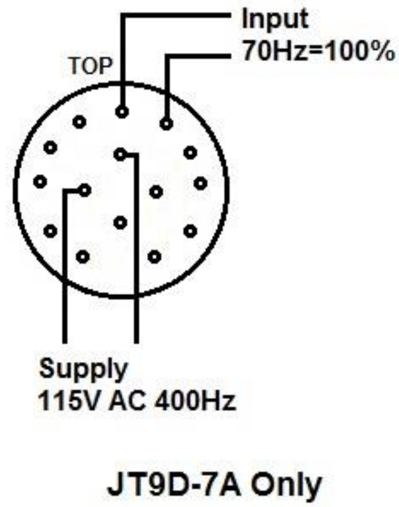
Analogue indicator with integral digital readout

Example electronic indicators (Warning: Test carefully)

Airliner N2 indicator pin outs

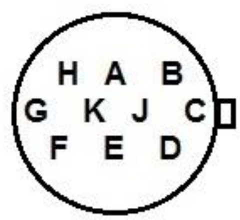


Airliner N1 indicator pin outs



JT9D indicator N1 pin outs

A GND
B +28V DC
C GND
D +Lighting 28V
E -Lighting 28V
F
G Input 70Hz=100%
H
K GND
J

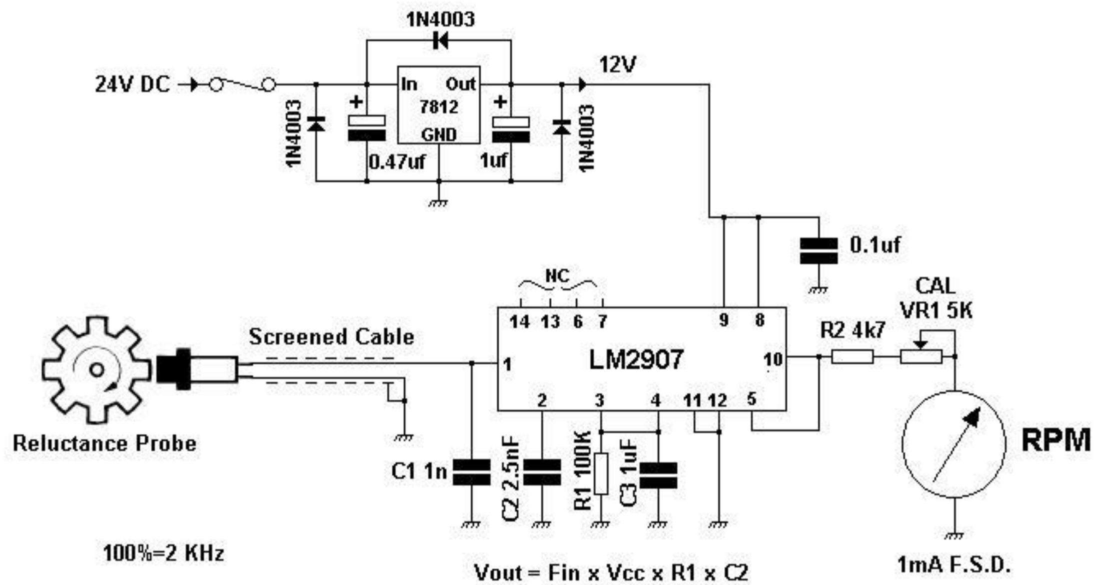


Gull Indicator NH 0-110%

Helicopter NH indicator analogue + digital

LM2907 tachometer circuits

An integrated circuit manufactured by National Semiconductors is designed to function as electronic tachometer or frequency to voltage converter. The IC with only a few external components may be used for a variety of applications, including automotive tachometers, piston engine tachometers, and industrial process control. It is suitable for gas turbine speed indication. The IC is a member of a family of similar devices with varying package styles, pinouts and supply voltages. The LM2907 chosen here is suitable for 24V supplies when used with an external 12V regulator.



LM2907 simple gas turbine engine tachometer (Frequency to voltage converter) circuit.

The above diagram shows a simple circuit that may be used to measure the speed of a gas turbine engine model suitably equipped with a speed sensor. A magnetic reluctance probe placed inside the engine feeds a speed signal to the tachometer IC via a screened interconnecting cable. C1 suppresses any RF noise and interference that may be present on the probe signal. The speed signal is fed into the IC internal charge pump tachometer circuit. The IC output voltage is equal to frequency input (f) x Vcc x R1 x C2. In this case for a typical signal of 2 KHz (Solar T62T32 engine probe, other engine types will require appropriate calibration) the value is 6V. Capacitor C2 in conjunction with R1 sets the basic frequency to voltage conversion factor. C3 provides a smoothing time constant for the internal IC charge pump circuit. The IC incorporates an internal buffer amplifier that in this circuit is set to be a unity gain buffer by strapping pins 5 and 10 together. The IC output signal is suitable for driving many types of moving coil and moving iron meter. R2 and the potentiometer VR1 set the drive current to a typical 1mA FSD meter movement.

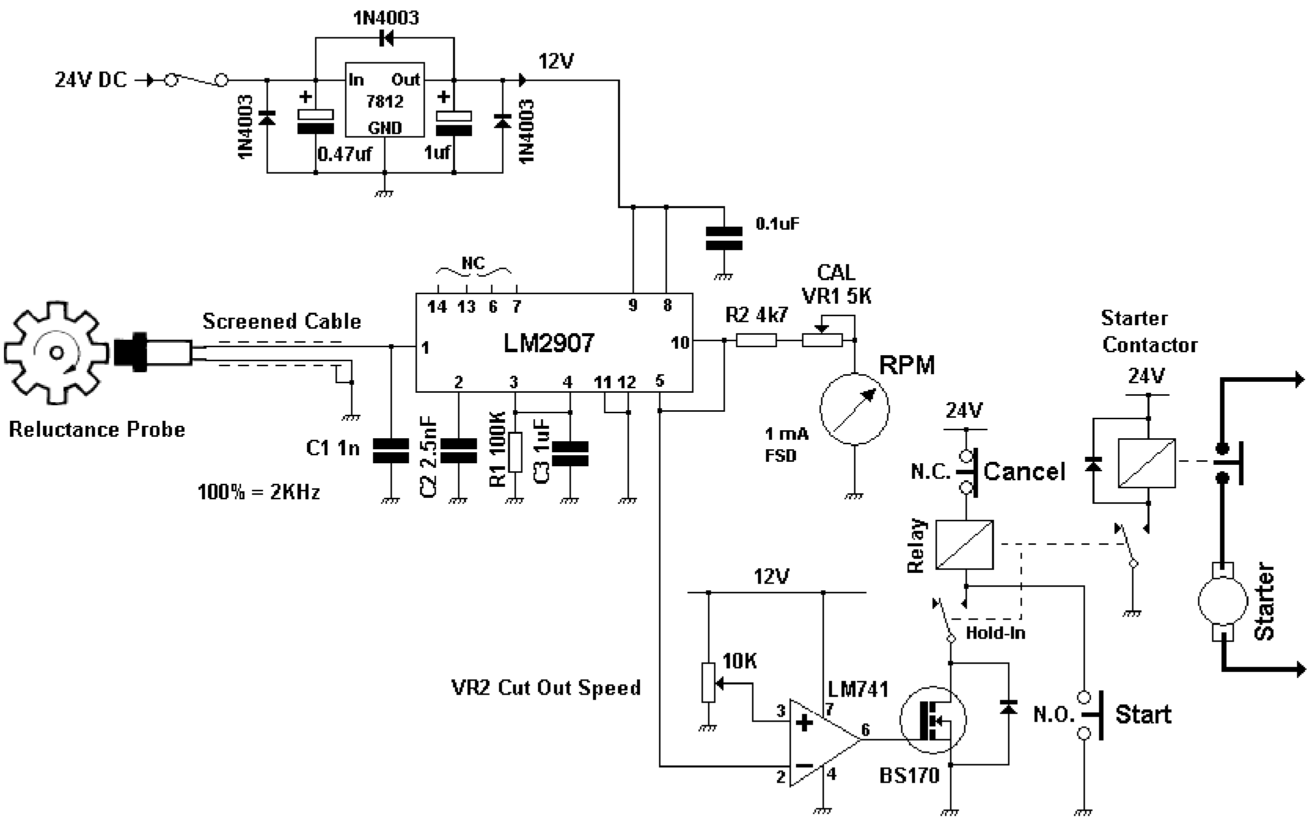
The exact calibration of the circuit should be set up before use. A 2KHz AC signal supplied from a signal generator or oscillator should be applied to the tachometer IC and VR1 adjusted for full-scale deflection of 100%, or the required RPM figure, if the meter is to be calibrated directly in RPM. It is common practice with gas turbine installations to calibrate the RPM indicators in 0-100 percent. Alternatively, if it's safe to do so (i.e. the engine speed is known or trusted) the engine may be run up and an electronic frequency counter placed across the speed signal and the calibration adjusted according to the counter read-out. A frequency counter may also be found useful to verify the output of a signal generator or oscillator. Many modern hand-held multi-meters often incorporate a frequency counter.

The circuit is powered from a 24V supply via a conventional three terminal voltage regulator. The regulator is decoupled with small capacitors to prevent oscillation. Added to the regulator circuit are three diodes, these are to protect the device from any Back- EMF switching spikes which may be present on the supply. The 24V supply may be used to start and control the gas turbine in which case it's likely a number of electromagnetic devices such as solenoids, motors and ignition systems may put spikes on to the supply.

During the engine starting phase a 24V supply may "Dip" significantly due to the large starting load placed on the supply, the 12V DC regulator will ensure the tachometer circuit remains properly calibrated during the starting cycle, it will not miss-read and is unaffected by a temporary reduction is supply voltage.

Starter cut-out circuit

The LM2907 tachometer may be used as a speed detection circuit. This circuit monitors engine speed and a relay switch operates when the speed exceeds self-sustaining speed, and the starting system may be cut off.



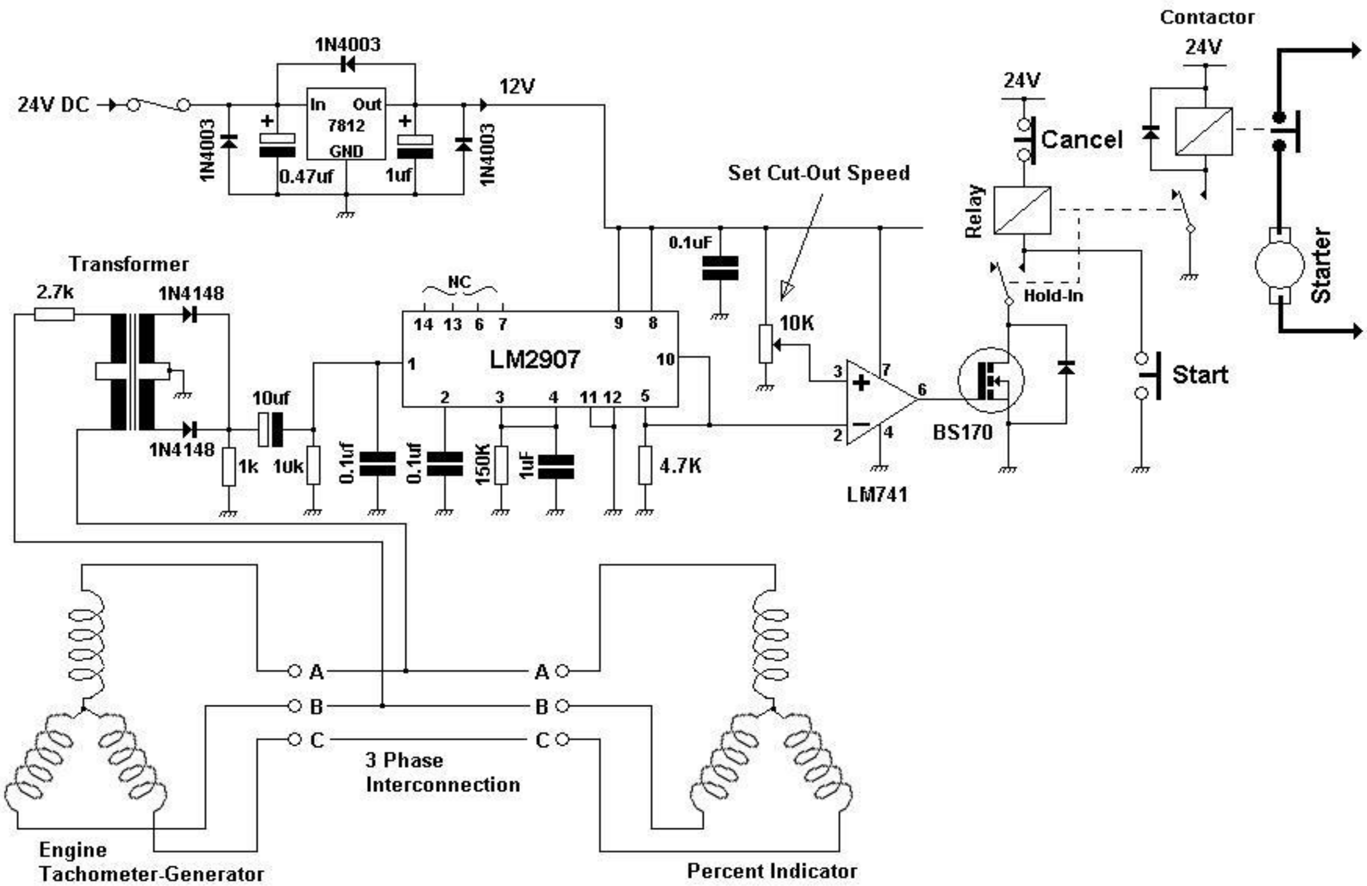
The above circuit uses the LM2907 IC as a speed detector as well as an RPM indicator. An OP-Amp comparator circuit is set to switch over when the rpm value exceeds the value set by VR2. To initiate the engine start cycle, the start button is pressed, this closes a relay, and a hold-in contact keeps it energized. An FET wired in series with the relay is held switched on by the comparator as the engine speed is below the cut-out speed. The relay supplies current to a main starter contactor that operates the engine starter motor and ignition. When the engine speed exceeds the cut-out speed (set just beyond self-sustaining speed) the comparator switches off the FET, the circuit drops out and the starting equipment is de-energized. Should the engine fail to start or not reach self-sustaining speed, the start cycle may be manually cancelled by de-pressing the cancel button, this breaks the hold-in current and the circuit drops out as before.

The circuit cut out speed may be set up on the bench by the adjustment of VR2. A speed signal is applied to the circuit from a signal generator or similar oscillator device. A typical cut-out speed lies between 30% and 40% and so with the circuit initially held in, VR2 is adjusted until the circuit drops out. The circuit is repeatedly tested until a satisfactory cut out speed is reliably verified.

It is recommended that an indicator lamp is wired into the start system so that it can be seen during the start cycle. The lamp will be seen to extinguish when the engine passes self-sustaining speed thus confirming the correct operation of this automatic circuit. Should the starter motor continue to be energized as the engine accelerates beyond self sustaining speed may result in overheating and damage to it. A typical gas turbine engine starter motor will only carry an intermittent rating in this role.

Picture switch with hold-in coil

Many gas turbine engines are fitted with a three-phase tachometer generator system. A small permanent-magnet three-phase generator is driven from the engine accessory gearbox. The generator supplies an AC signal that is used to drive a remote percent indicator device. The system is devised so that a two-pole generator turning at 4200 rpm supplies a signal of frequency 70Hz to the indicator, this corresponds to a measured engine RPM of 100%. This electrical rpm signal may be used to supply a tachometer speed detector circuit that is used to cancel the engine start cycle automatically.



Starter cut-out circuit for an engine type fitted with percent reading three-phase tachometer system.

This circuit uses a signal derived from the tachometer generator to cut off the starter motor at 40%.

The AC tachometer generator signal is fed to a small transformer and two diodes form a full wave rectifier. The rectifier affectively doubles the frequency of the speed signal; this improves the precision of the circuit. Even at maximum speed the signal frequency is at a relatively low 70Hz value leading to ripple at the tachometer IC output. Doubling the frequency helps reduce this ripple.

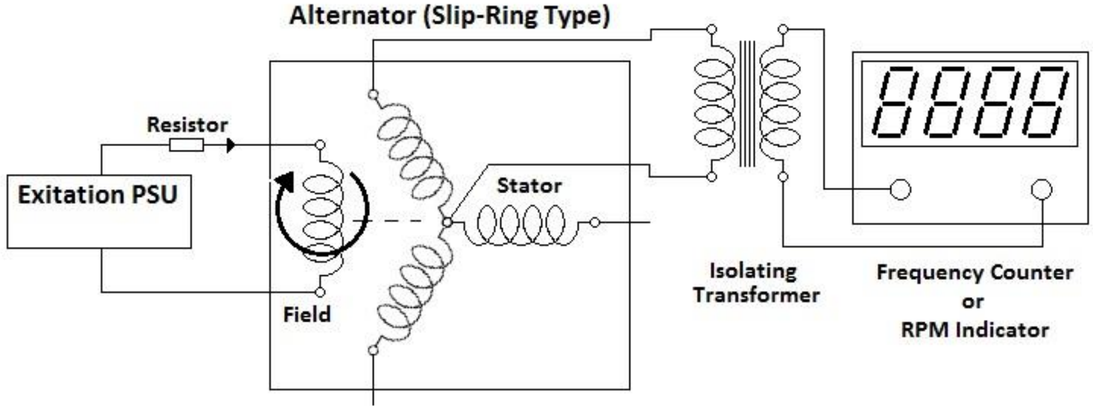
The LM2907 IC functions as a normal charge-pump frequency to voltage converter calibrated for a maximum signal of 140 Hz (100% RPM). The IC output feeds an op-amp comparator detector which switches the output to a relay when the speed signal exceeds the value set by the potentiometer. Below cut off speed the relay will hold-in as the FET is driven-on by the comparator. As the engine speed passes the cut-off speed the comparator switches off, the FET switches off, and the relay drops out canceling the start cycle and engine starting equipment. Should the engine fail to start or not reach self - sustaining speed, the start cycle should be cancelled manually by de-pressing the cancel button, this interrupts the hold-in current and the start relay drops out.

This circuit should be calibrated and adjusted on test using a variable low frequency oscillator to inject a 60-80Hz signal (approx.40-55%) at the tachometer IC input. Alternatively, the unit may be adjusted by using an actual tachometer generator unit driven by a variable speed motor on a suitable test rig. The potentiometer is adjusted so that the circuit switches at the required speed of between 35 and 40% rpm. Some relay chatter may be present as the circuit approaches switching speed, the comparator may detect the residual ripple present at the tachometer IC output. This should not be a problem as an accelerating engine will normally pass this point only once during the start cycle and the relay drops out beyond the cut-out speed.

The circuit is powered from a regulated 12V supply that is derived from a nominal 24V supply. This will ensure moderate variations in 24V supply should not affect the 12V supply used to power the calibrated electronic circuit

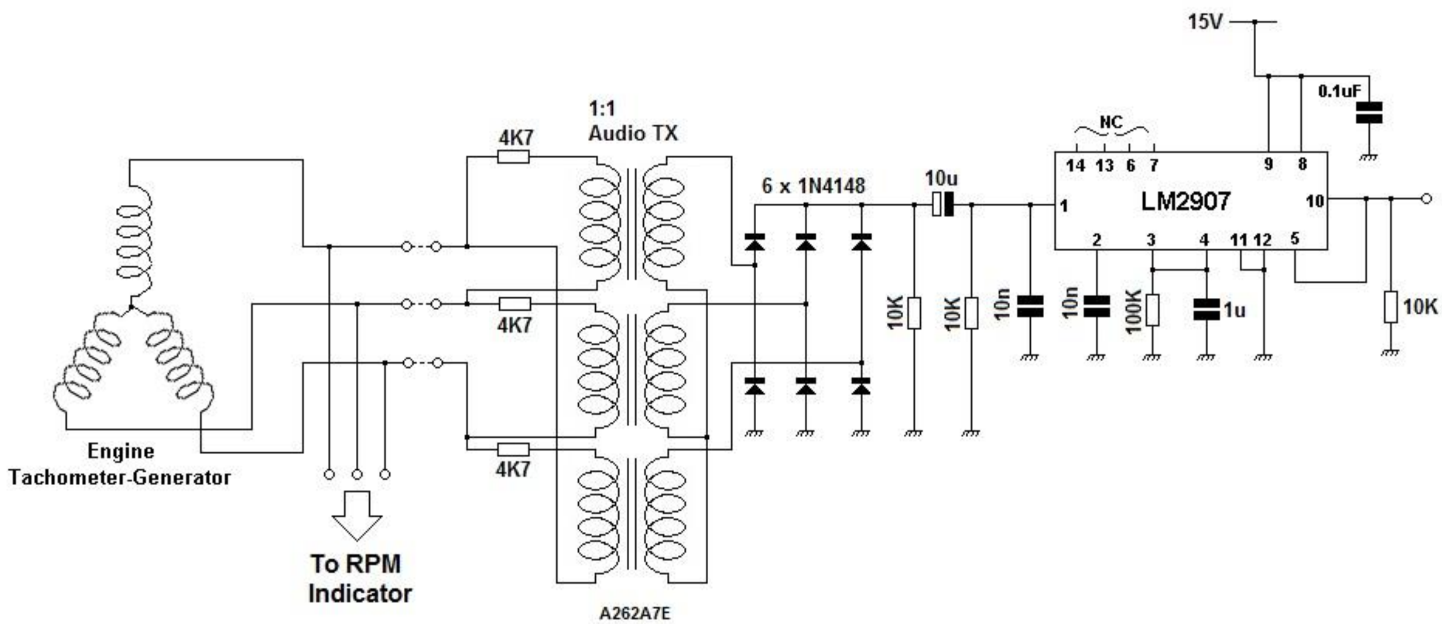
Alternator speed -sensor

An alternator or AC generator may be used to provide a speed signal for use with a tachometer indicating system. As with the small tachometer-generator units, a larger generator output frequency is available as a signal from which the engine rpm may be determined. A typical gas turbine equipped alternator will produce AC power at a frequency of 400Hz, 400Hz is a common power supply frequency in the aerospace industry. The alternator supply output is rated at 110V so a small transformer must be used to step down the voltage so it may be safely supplied to an electronic tachometer circuit.



Derivation of speed signal from engine-driven alternator

Increased precision tachometer-generator derived tachometer circuit



Increased precision tachometer circuit

The above circuit shows how an increased precision tachometer frequency to voltage converter may be achieved. The three-phase signal derived from a normal engine mounted tachometer generator is passed through a 3-phase bridge rectifier. The resultant rectified DC voltage exhibits an AC ripple frequency equal to 6 x the original frequency. A normal tachometer generator unit operating at 100% will provide a 70Hz frequency signal, the resulting rectified signal will be 420Hz. An electrolytic capacitor is used to AC couple the rectifier ripple frequency into the input to the tachometer IC.

A conventional LM2907 tachometer frequency to voltage converter IC may be used to detect the 420Hz signal and convert it to a calibrated known value. In the case of the circuit illustrated this value is approximately 5V. Because the circuit is operating at a substantially higher frequency the response and time constant of the circuit is faster, the charge-pump circuit is updating faster than before.

Transformer coupling is used to provide an isolated circuit that does not interact with the original indicating instrument connections. Series ballast resistors are used in each phase to prevent overload and saturation of the small transformers. A small 1:1 balanced audio transformer is suitable for this purpose as the actual signal energy to operate the circuit is very small.

This circuit functions well, it was built to supply a tachometer signal to an electronic governor circuit. Due to small differences in the phase amplitudes emerging from the tachometer generator the ripple frequency may contain lower frequency components, this will result in some jitter when converted to a square wave within the LM2907 IC. Whilst observing the ripple signal on an oscilloscope the phase amplitudes may be trimmed in value (by altering the ballast resistors) to obtain a better more consistent ripple waveform.

Hand held laser rpm meters

During bench running and rig testing small gas turbine engines a hand-held optical laser type tachometer unit may be used to indicate engine speed. A visible rotating part of the engine may be carefully marked, and the optical tachometer instrument aimed at it. In some cases, the tachometer may be aimed at the compressor rotor itself for speed measurement. Care should always be exercised to ensure false or inaccurate readings are not obtained which could compromise safety!

Automotive RPM indicators

After-market automotive style tachometers are widely available that in some cases are suitable for gas turbine speed indication. Often these devices are calibrated 0-6000 rpm or higher, some modification may be necessary to achieve the correct calibration for the engine in use.

Exhaust gas temperature (EGT)

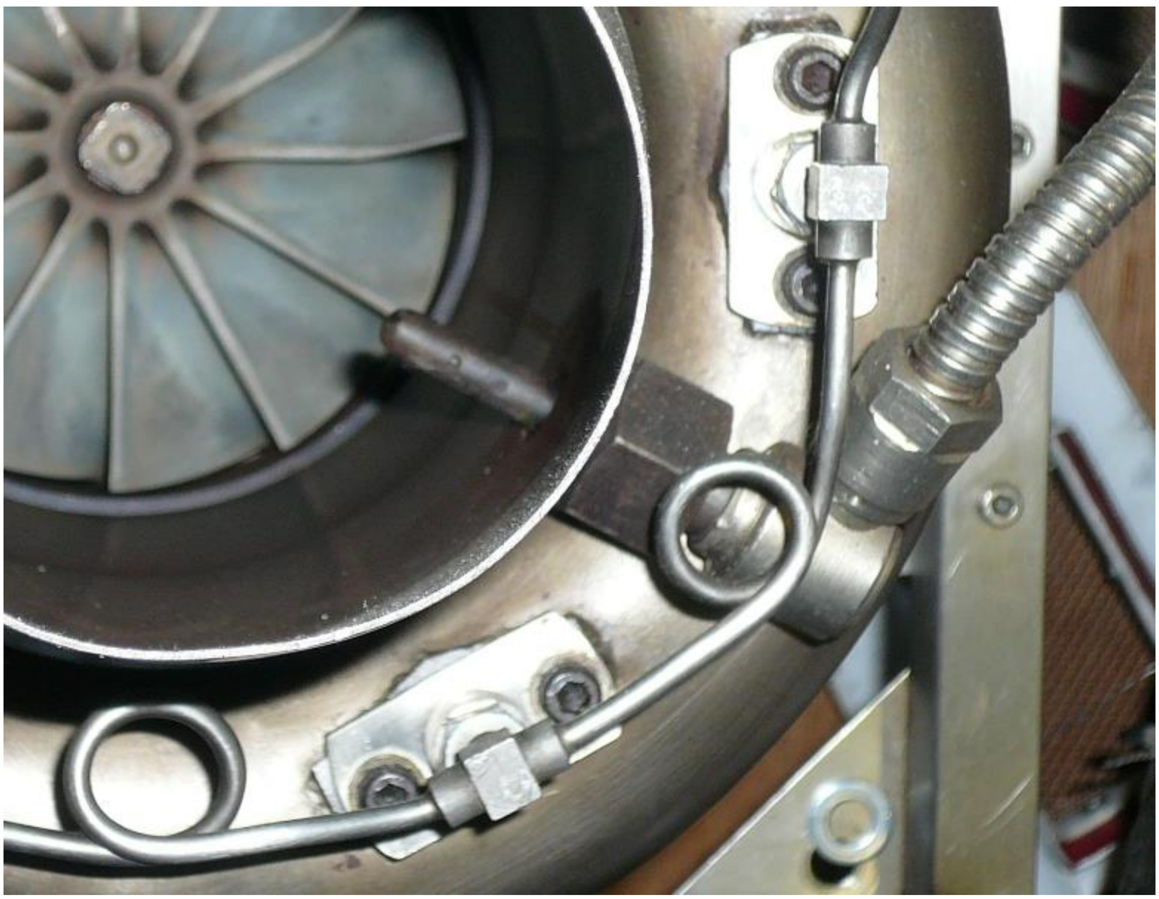
Exhaust gas temperature or jet pipe temperature is the basic measurement of how hot a gas turbine is running. Exhaust temperature is one of the simplest parameters to measure and can be measured accurately. Exhaust temperatures are relatively high and may reach 750 degrees centigrade, changes are also quite large and so detecting this with simple electronics is straightforward.

Gas turbine engines are sometimes fitted with turbine inlet temperature probes. Instead of sighting the probes in the exhaust stream, they are placed in the gas stream feeding into a turbine stage, usually a free or power turbine. The measurement obtained from the probes is abbreviated to Turbine Inlet Temperature TIT or Turbine Gas Temperature TGT. In these cases, the principal remains the same, TGT is a strong indicator of the performance, load and health of the engine.

The universal way of measuring exhaust temperature in a gas turbine is to place one or more thermocouple probe devices into the exhaust gas stream. A thermocouple consists of a junction of two dissimilar metals, when the junction is heated a small electro motive force (EMF) is created, this EMF is proportional to the temperature of the junction. The EMF leads to electric current generated by the thermocouple and is sufficient to directly drive an indicating device such as a moving coil meter or a digital readout.

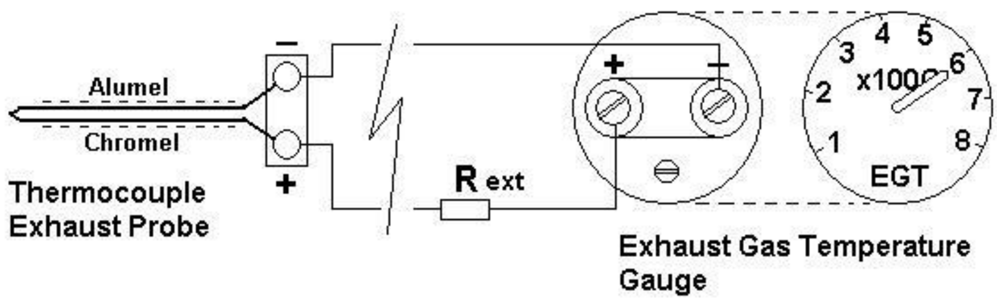
The metals usually used for gas turbine thermocouples are chromium aluminum and nickel chromium alloys, these are often abbreviated to Cr and Al, a thermocouple of this type is also known as a "K" type device. When placed together the metals form a junction that develops a precise electrical signal proportional to temperature. Normally two junctions exist, a hot junction and a cold junction, the actual voltage potential generated is proportional to the temperature difference of the two junctions. The hot junction is obviously placed in the exhaust of the engine, the cold junction exists in an area of relatively stable temperature, in the case of a simple aircraft indicator instrument, the cold junction is placed inside it.

Exhaust gas temperature indicator



Single engine mounted EGT thermocouple stagnation-type probe.

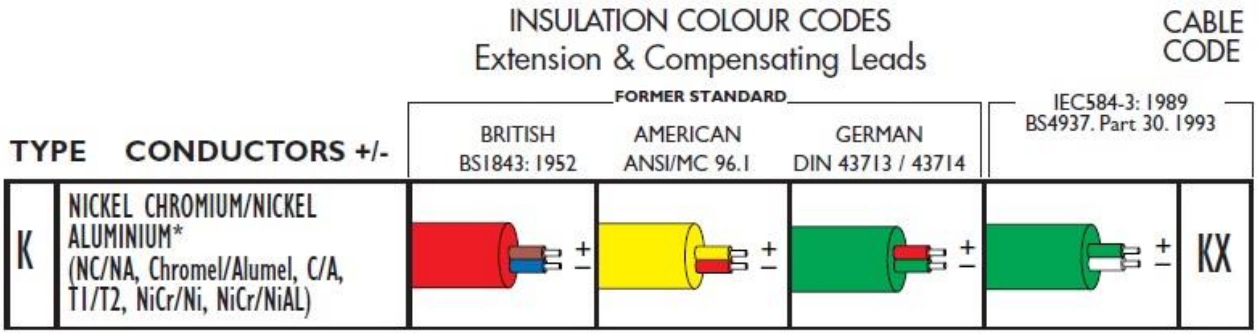
A thermocouple that is placed in the exhaust gas stream may consist of a simple bonded junction or the junction may be placed inside a small tubular housing or shroud. The housing may have small holes and orifices placed in it to allow the exhaust gases to reach the thermocouple junction. The fast-moving hot gases pass through the holes and into the tube, they flow over the thermocouple junction and then passes out through additional holes. This type of thermocouple system is referred to as a "stagnation thermocouple" and it exhibits a more accurate measurement as it measures the temperature at a much slower gas flow velocity.



Analogue exhaust gas temperature indicator circuit

There two basic ways of indicating exhaust temperature, an analogue meter may be used, or an electronic digital meter may be used. Simple analogue indicators consist of a sensitive moving coil meter, the cold compensating junction and a network of calibration resistors. These cold components are mounted inside the instrument. This type of simple analogue instrument is commonplace in older gas turbine powered aircraft and also useful for stationary or ground applications. The beauty of the analogue meter is that it requires no source of external electrical power, the energy to drive it comes from the thermocouple signal itself!

Exhaust temperature indicators should be connected in a particular way. Special cable is used to connect the thermocouple junction placed in the engine exhaust to the exhaust gas temperature indicator. The cable employed is known as thermocouple compensating cable or extension cable. The cable is made of similar metals to that of the thermocouple junctions, this prevents unwanted electrical signals from being generated at the electrical junctions and disturbing the accuracy of the indicator reading.



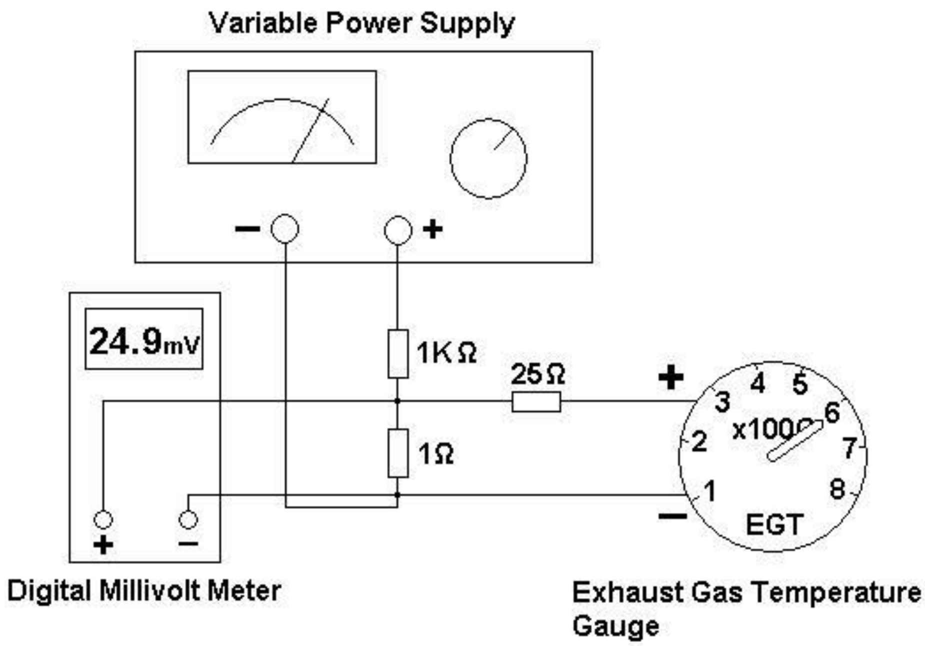
Colour codes for K-Type thermocouple cables

A consequence of using compensating cable is an electrical loss. The compensating cable unlike ordinary copper cable exhibits a significant electrical resistance; this resistance is compensated for in the calibration of the indicator instrument. The required resistance of the external cabling between an indicator instrument and thermocouple is referred to as the "External Resistance". The value of the external resistance is often written on the instrument dial face or on a specification plate attached to it. Common values are 8, 25 or 30 ohms, the external resistance refers to the total resistance or loop resistance i.e., both conductors in the cable. When setting up an exhaust gas temperature indicator the connecting cable should be chosen to provide the required external resistance. Compensating cable is sold in various gauges, if a long run between the thermocouple and the instrument is required a heavier gauge cable should be selected.

Typical resistance values for compensating/extension cables are-

Thermocouple cable size	**Looped ohms per combined meter length**
1/0.2	31.8
1/.315	12.8
1/0508	4.9
7/0.2	4.5
13/0.2	2.4
14/0.2	2.2
23/0.2	1.4

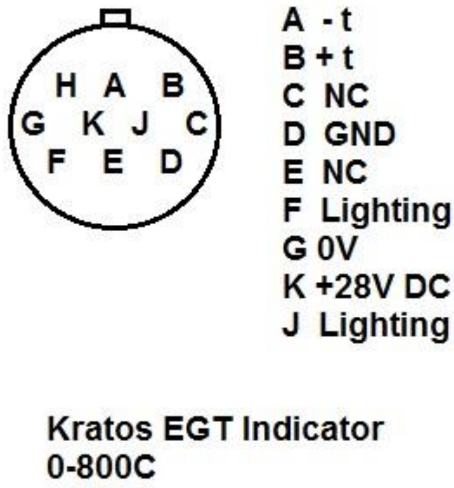
Checking EGT indicators



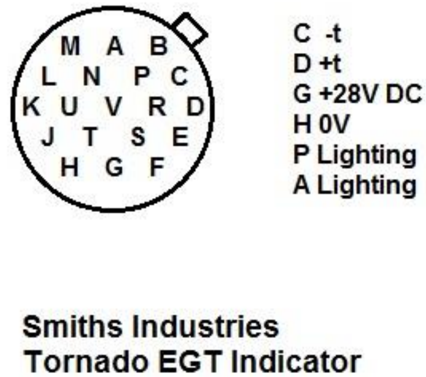
Test arrangement for EGT indicators

An analogue EGT indicator may be tested by generating an artificial temperature signal from a bench-top power supply and applying it to the instrument. Thermocouples exhibit a precise temperature/voltage characteristic; it is found that an EMF of 24.9mV is equivalent to a thermocouple temperature of 600 degrees centigrade. A power supply is used to supply current to a voltage divider made from resistors. The resistors are arranging to produce the very small EMF, and this is applied to the indicator via the “external” resistance value. Checking the indicator at 600 degrees will ensure that the indicator reads correctly at the most significant temperature range i.e., when the engine is starting or placed under high load.

Example electronic EGT indicators-



Kratos indicator pin outs (K-Type Thermocouple)



Smiths servo indicator pin outs (K-Type thermocouple)

A +t
B -t
C 0V
D Lighting (5V)
E NC
F +28V DC
G Lighting (5V)
H 0-5V O/P +ve
J 0-5V O/P -ve
K Case GND

Gull PTIT Indicator with digital readout pin outs (K-Type Thermocouple)

A Lighting
B Lighting
C +28V DC
D 0V
E Thermocouple
F Thermocouple

Jaeger Sextant EGT Indicator

Digital indicators

The electrical signal produced by a thermocouple is suitable for amplification by electronic devices and may be displayed on a digital meter. Digital meters are sophisticated devices that are capable of precise and accurate measurements; these devices are produced in various forms. Handheld meters may be purchased that are battery powered, or panel mounted modular industrial style units may be employed in more permanent situations.

Digital meters consist of a digital voltmeter which has had the calibration altered to make it indicate temperature e.g. a 24.9mV thermocouple signal reads as 600 degrees C. Digital meters employ a “Analogue to Digital” converter or A to D, this converts the small analogue signal developed by the thermocouple to a digital one that feeds a numerical readout circuit. One of the simplest forms of A to D consists of a counter device and a capacitor. The counter is incremented by a clock and at the same time the capacitor begins to charge up. The voltage across the capacitor is compared to an amplified version of the voltage signal that is to be measured and when the capacitor voltage equals that of the amplified voltage the counter is stopped. The reading on the counter is read off and directly relates to the time taken to charge the capacitor, it can be seen if a higher voltage to be measured, the capacitor will take a longer time to charge up and so the counter reading will be higher. The reverse is true for a lower voltage, it will take less time to charge, and the indication will be lower and so the any measured voltage is converted to an equivalent numerical value.

Digital meters measure the precise voltage developed by the thermocouple junction, cold junction compensation is also built in to maintain good accuracy. Digital meters normally exhibit a high input resistance and so do not require a specific external circuit resistance to be maintained. It is important to use the correct compensating cable when connecting a digital thermometer.

Panel Mount

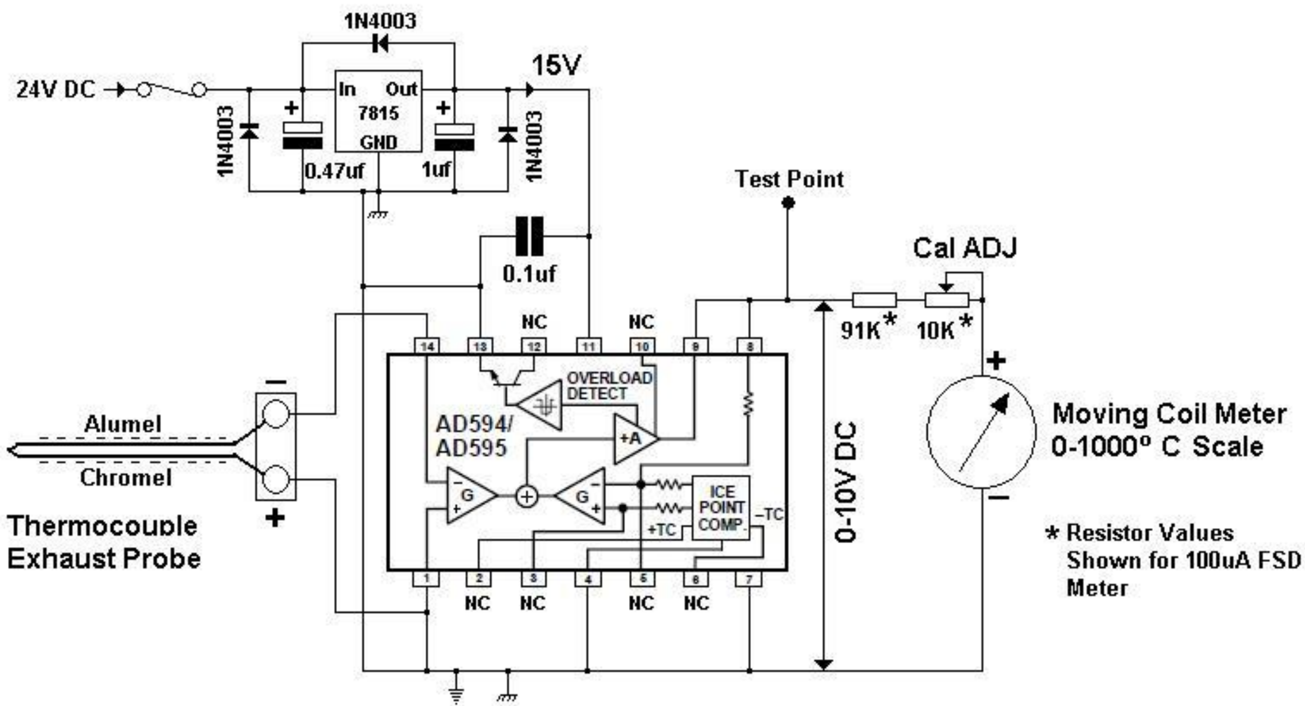
Hand Held

Digital meters suitable for measuring exhaust gas temperature

Digital meters are useful for checking the calibration of analogue indicators. Analogue meters are useful and sometimes clearer to view in certain situations, but accuracy of the reading is also important. Many models of digital meter have a maximum reading hold facility, this is useful for recording high temperatures during starting or the application of a high loads to the engine.

There are other methods and sophisticated systems for measuring exhaust temperature. More complicated aircraft instruments exist which incorporate an electronic amplifier and may also employ an analogue dial and a digital readout all in one instrument. There are also electronic amplifier integrated circuits which may be used to convert the small thermocouple signal into a direct DC voltage calibrated in volts/per hundred degrees, such a chip is the AD595. The built AD595 IC built by Analogue Devices is useful if proper aircraft analogue indicator instruments are not available and the user prefers not to use a digital readout and use an analogue dial voltmeter instead. The AD595 is also useful for interfacing computer-based data logging equipment that may expect or be calibrated for relatively large voltage changes. A temperature signal developed by a AD595 chip may be applied to a fuel control system and used to provide over-temperature protection.

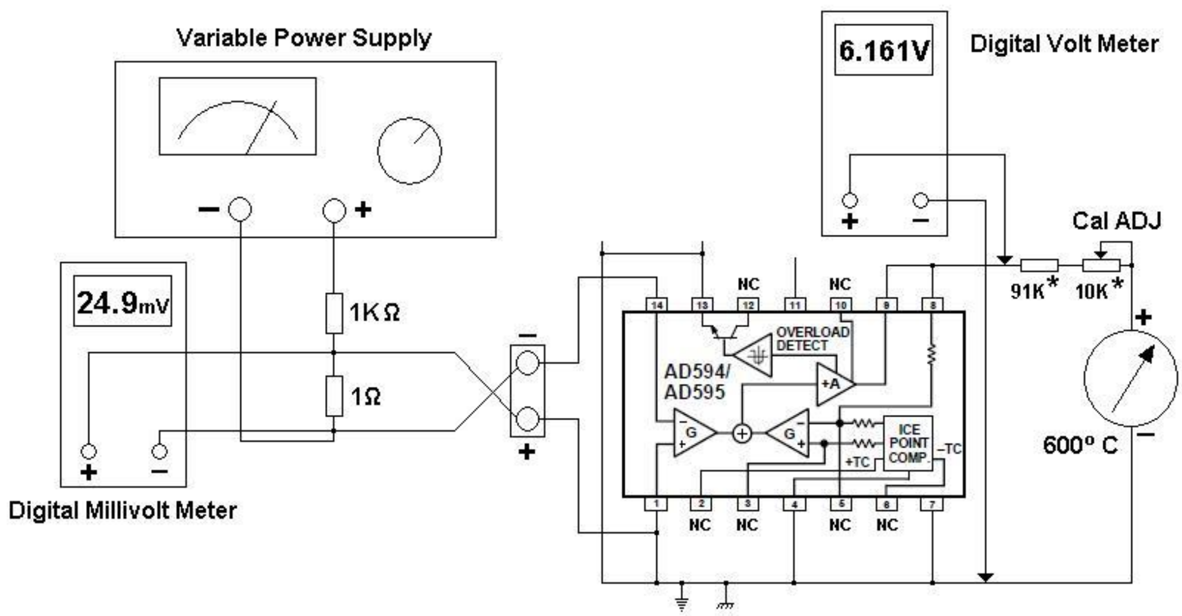
AD595 electronic thermocouple circuit



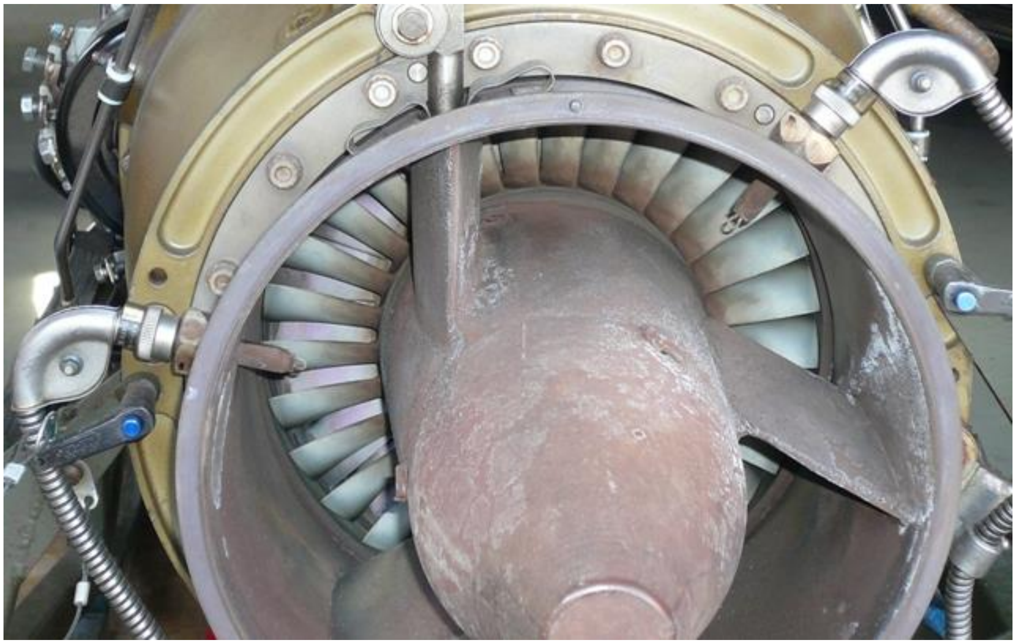
Simple analogue EGT indicator circuit employing AD595 integrated circuit

The above circuit shows how the AD595 integrated circuit may be used to accurately measure exhaust gas temperature. With few external components the IC is simply operated from a DC supply, it amplifies a thermocouple signal according to an in-built calibration table and outputs it as a DC potential. An equivalent input signal range of 0- 1000 degrees results in an output range of 0-10V. The exact calibration of the IC is published in the manufacturers data sheet, a signal of 24.9mV corresponding to 600 degrees results in an output of 6.161V. The output signal developed by the AD595 chip is suitable for driving a range of devices including a simple moving coil meter. A calibration resistor is included so that the circuit may be set up to drive a particular meter. The moving coil meter may then be calibrated in several ways-

1. By applying a 24.9mV signal to the circuit input and adjust the calibration resistor for an indicated reading of 600 degrees C on the meter.
2. By applying a variable signal to the IC and adjusting it for an output potential of 6.161V (Measured with an external digital multi-meter or similar at the output test point) and then adjusting the calibration to bring the meter in to read 600 degrees.

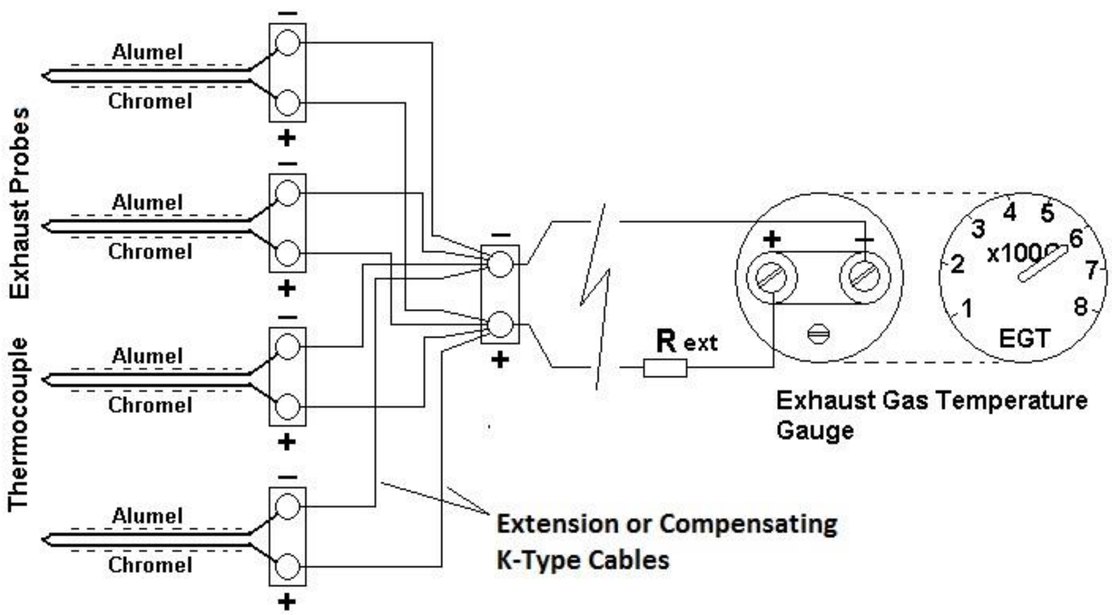


Setting up an electronic circuit to measure EGT



Multiple EGT probes placed in exhaust flow (Turbomeca Astazou)

Multiple thermocouple probes are often placed in the exhaust flow from a gas turbine engine. Several probes may be sited around the circumference of the exhaust and the E.M.F. outputs connected together in parallel. This set up will enable the average total exhaust temperature to be measured and will negate the effects of localized increased temperature and hot spots. Engines fitted will non-axi-symmetric combustor layouts may naturally not produce an even exhaust temperature around the exhaust circumference.



Wiring of multiple exhaust gas temperature probes

Oil temperature

Thermocouple type probes are useful for measuring the temperatures of all kinds of systems within a gas turbine engine such as oil temperature and air intake temperature. Research or test rig engines may employ many thermocouples placed at each stage of the working cycle to closely monitor performance and changes in operating parameters.

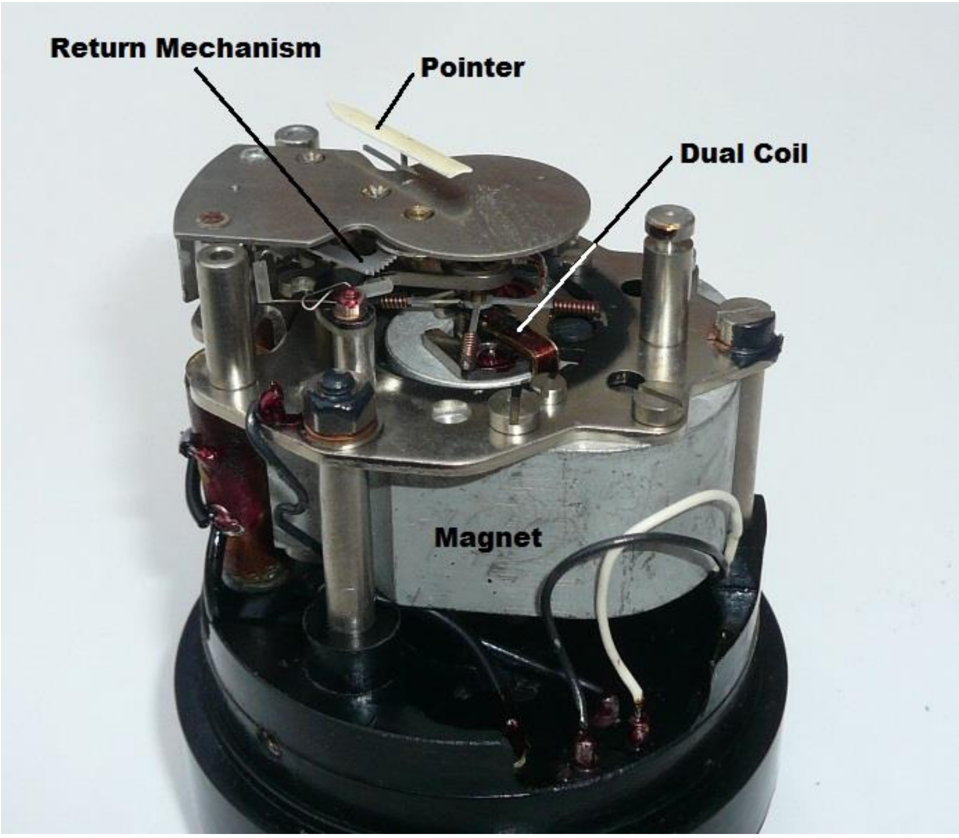
There are alternatives to thermocouples for sensing moderate temperature ranges (-50 to + 150 degrees C) particularly oil temperature. Oil temperature is often measured on engines originating from aircraft, these often use a thermistor resistance probe which is placed in a suitable part of the engine oil system. A thermistor probe consists of a special resistor that varies in resistance according to its temperature. A thermistor probe is normally wired to an indicator mounted on a control panel or in the aircraft cockpit.

Weston "Ratiometer" oil temperature indicator

Thermistor oil temperature sensor probes

Ratiometer temperature indicator

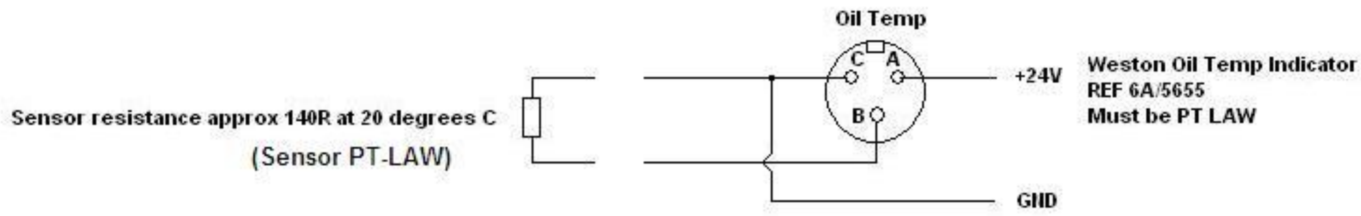
A typical temperature indicator consists of a moving coil type meter mechanism operated with two electromagnet coils wound together on the same former. This type of indicating system is referred to as a ratiometer system, as the meter indicates the ratio of the relative currents flowing in the two coils. The two coils form one half of an electrical bridge circuit, the thermistor temperature probe and a fixed resistor (inside the instrument) form the other half of the bridge. The whole system is powered from 24V, the use of a bridge circuit enables the system to be insensitive to power supply voltage changes and is less susceptible to temperature drift. As the thermistor DC resistance varies with its temperature, this results in the balance of the bridge circuit being altered as does the ratio of the currents in the coils, this results in the indicator pointer moving around a scale.



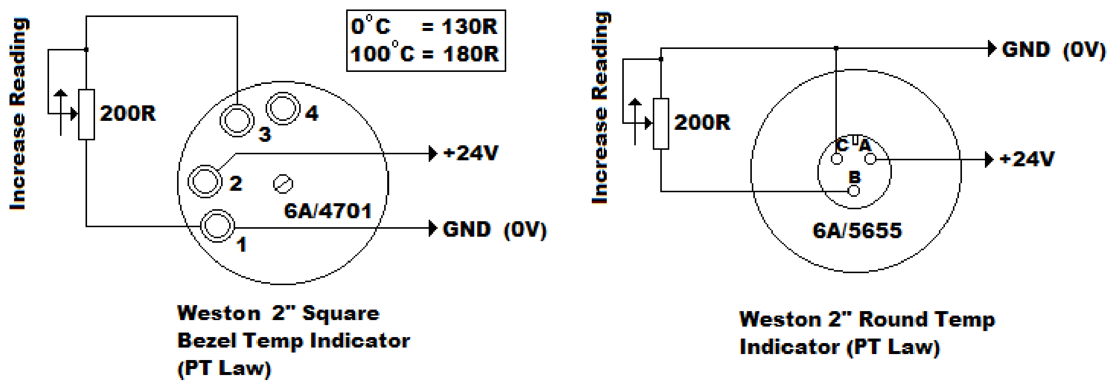
Weston DC ratiometer type indicator (Dial face removed)

There are two types of thermistors, the devices operate in two ways; they are found to have a positive temperature coefficient law or a negative temperature coefficient law A positive law is such that the resistance of the thermistor increases with temperature and a negative law is the opposite where resistance decreases with temperature. The thermistor law required may be marked on the indicator instrument.

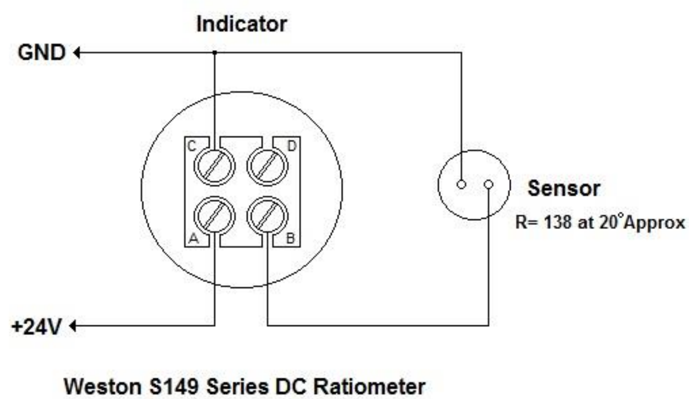
The indicator instrument circuitry will be matched to a particular thermistor probe law so the correct matched types of indicator and probe should be obtained.



Wiring of Weston thermistor temperature indicator

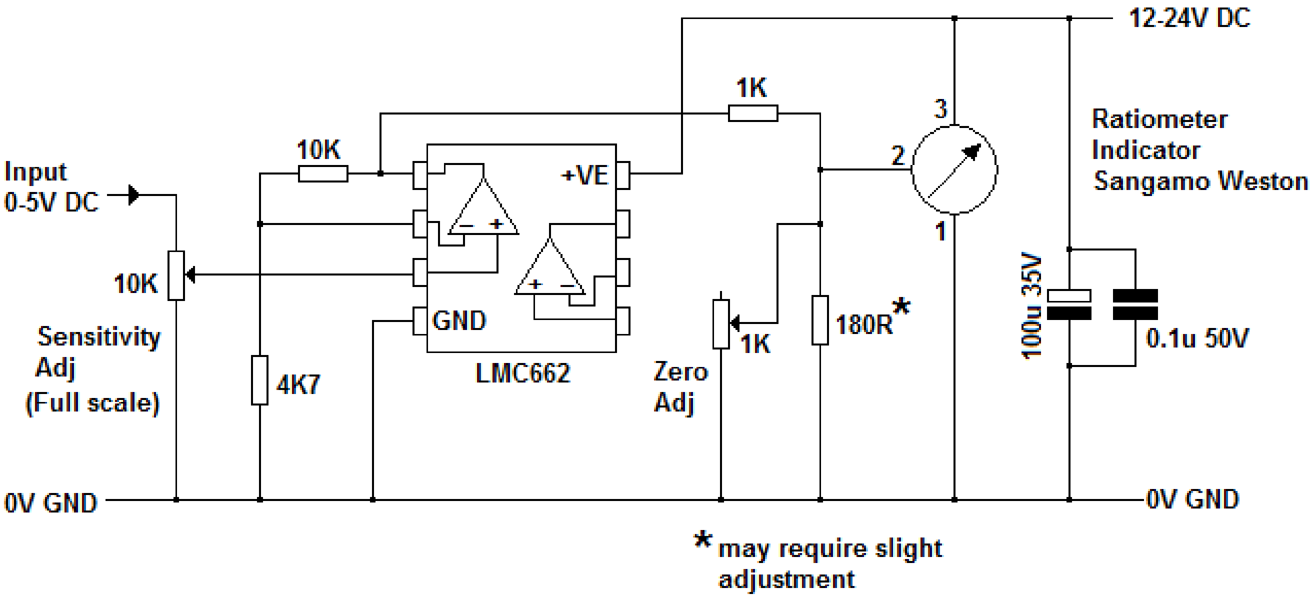


Test circuit for Weston temperature indicators



Indicator fitted with screw terminals

Western temperature indicator driver circuit



Temperature indicator driver circuit

A simple op-amp circuit may be constructed to drive Weston DC ratiometer type indicators from a 0-5V signal. This may be useful for interfacing with modern pressure transducers or for constructing classic aircraft cockpit simulators and restoring cockpits for working static display. A 0-5V DC drive signal may be derived from a computer I.O. interface card such as an Arduino or Phidget type USB interface cards.

An amplifier circuit supplies current to a resistor placed in the temperature circuit of the indicator. The amplifier adds current to the resistor raising its potential that in turn causes the indicator to increase reading. To zero the indicator (scale zero not temperature zero) a parallel adjustable resistor is used vary the resistance and hence potential across it.

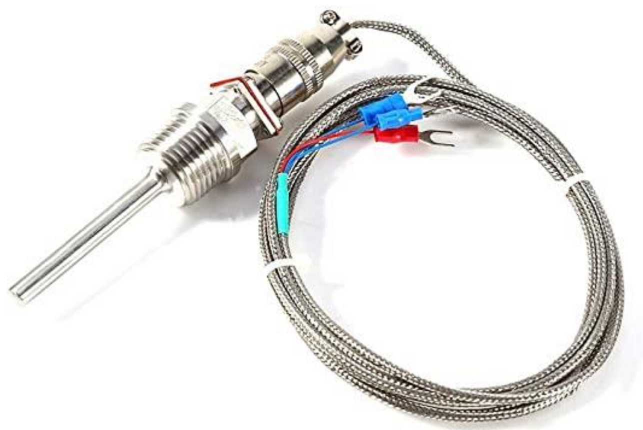
The amplifier provides sufficient current to operate the indicator to full scale, the input potentiometer provides a means of adjusting the gain to enable a 5V DC signal to produce full scale deflection.

The circuit will run on 12 or 24V from a regulated supply to prevent drift. Some indicators may not function properly on 12V and will require 24V. Some experimentation may be necessary to find the best set up for individual indicators.

It is possible with additional circuitry to operate the indicator from a calibrated temperature source such as a PT100 type probe. This will enable the aircraft indicator to be used with standard non-aircraft sensors.

PT100 Platinum sensors

A common industrial temperature sensor device is known as the PT100 platinum resistance temperature probe. This type of probe is suitable for the measurement and indication of gas turbine engine oil temperature. A specially manufactured probe exhibits a varying resistance characteristic with temperature. It’s found that at 0 degrees centigrade a PT100 probe resistance is equal to 100 ohms, at 100 degrees C the resistance is equal to 138 ohms. The probe may be used to feed an electrical circuit and an indicating device such as a moving coil meter. The probe may be used to form part of a bridge circuit and a small op-amp amplifier used to drive the meter. A calibration potentiometer is included to set the unit up and mach the probe to the indicator reading. The circuit is powered from a regulated DC supply in order to prevent voltage variations from disturbing the indicator reading.



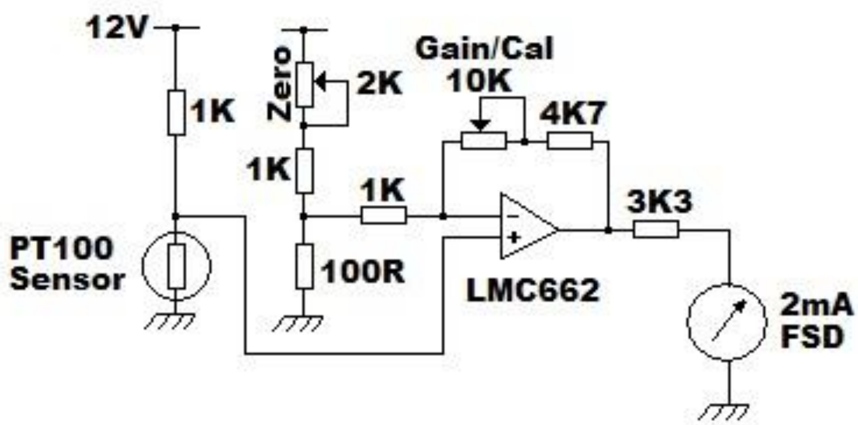
Picture PT100 probe

Skeleton PT100 indicating circuit using operational amplifier

An electronic operational amplifier may be used to interface an indicator meter to a PT100 temperature sensor probe. The PT100 sensor wired in series with a resistor forms one half of a electrical resistance bridge. The other half of the bridge is made up of a resistor chain with an adjustable resistor placed in it. The op-amp amplifier is feed by the centre of the bridge and forms a differential amplifier. The difference or imbalance in the bridge is used to drive the indicator. The indicator may be zeroed by balancing the bridge (Note: the indicator Zero readings may be below 0 degrees i.e., -50 C) by adjusting the series resistance. The gain or sensitivity of the amplifier determines the maximum reading available. The circuit may be set up and aligned by substituting the PT100 sensor for values of resistance which correspond to temperatures and readings on the indicator.

Pt100 Temperature–Resistance Table

°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90
-200	18.49	–	–	–	–	–	–	–	–	–
-100	60.25	56.12	52.11	48.00	43.87	39.71	35.53	31.32	27.08	22.80
0	100.00	96.09	92.16	88.22	84.27	80.31	76.33	72.33	68.33	64.30
°C	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
0	100.00	103.90	107.79	111.67	115.54	119.40	123.24	127.07	130.89	134.70
100	138.50	142.29	146.06	149.82	153.58	157.31	161.04	164.76	168.46	172.16
200	175.84	179.51	183.17	186.82	190.45	194.07	197.69	201.29	204.88	208.45



A simple PT100 indicator circuit.

Mechanical temp

Certain Rover gas turbine engines are fitted with a mechanical automotive style oil temperature indicator. Here a sealed, fluid-filled sensing bulb is connected to a pressure type gauge via a capillary tube. The fluid in the bulb one end of the capillary is placed in the engine oil and heated by it, the fluid expands exerting increased pressure in the sealed system thus moving the pointer on the pressure gauge which is calibrated for temperature.

A typical oil temperature for a running gas turbine may be around 80-100 degrees C. In some cases an oil cooler system may be automatically controlled from the oil temperature using a thermostat device.

Pressures

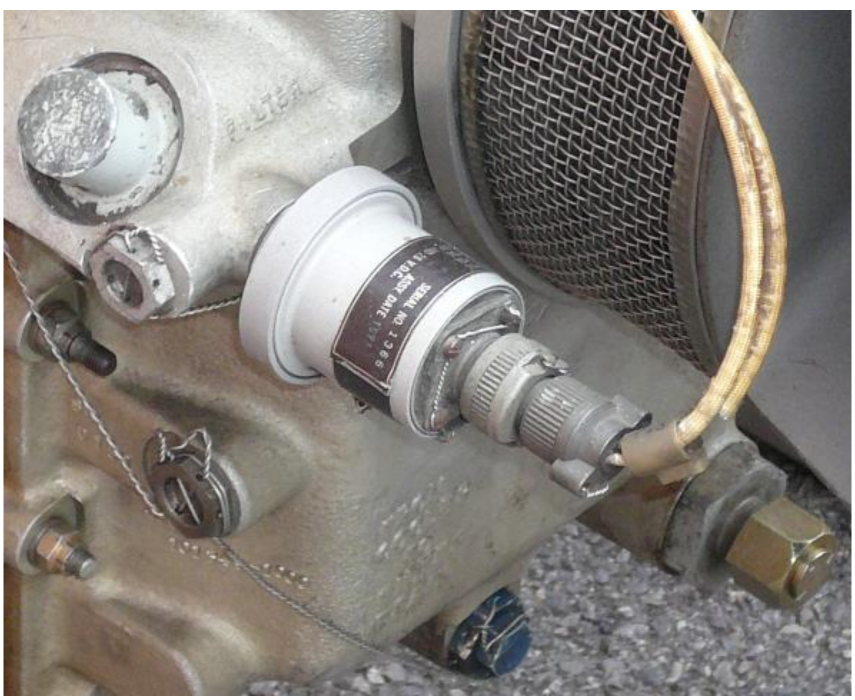
Throughout the gas turbine operating cycle there are many points where it is useful to monitor gas pressure. Lubricating oil pressure is also important and must be maintained within defined limits and a complete loss of oil pressure will necessitate an engine shut down.

Mechanical oil pressure gauges

The simplest means of measuring and indicating oil pressure is to fit a bourdon type conventional pressure gauge. A small hydraulic style hose is used to “tee” into the flowing oil system and indicate system pressure. The gauge will have to be placed relatively close to the engine. Suitable quality fittings should be employed to prevent leaks. Typical oil pressures range from 10-50 PSI and are generally lower than that which are found in piston engines. The reason for this is that gas turbine engines employ jet and splash lubricated ball races and not automotive crank-shaft style plain bearings.

Oil pressure switches

Sensitive electrical pressure switches are sometimes placed in the oil system to detect and warn of low or failing oil pressure. These switches may form part of an interlock system that will shut the engine down automatically if oil pressure failure occurs. During the engine-starting phase, oil pressure may be low or initially intermittent in which case some systems will inhibit the interlock operation until the engine has reached self-sustaining speed.



Lubricating oil pressure switch

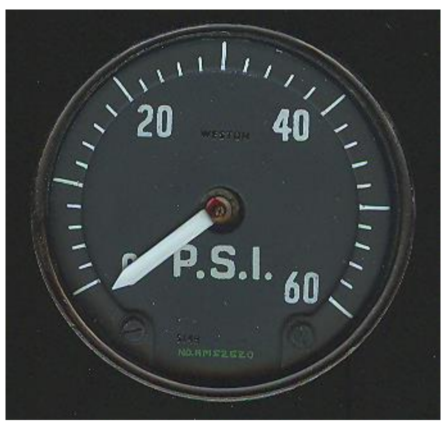
Electrical oil pressure indicators

Electrical sensors or transducers may be fitted to a gas turbine engine oil system to aid in the indication of oil pressure. There are several old-fashioned aircraft style remote sensor and indicating systems which may be found on many small gas turbine models. -

1. **Weston DC ratiometer system**

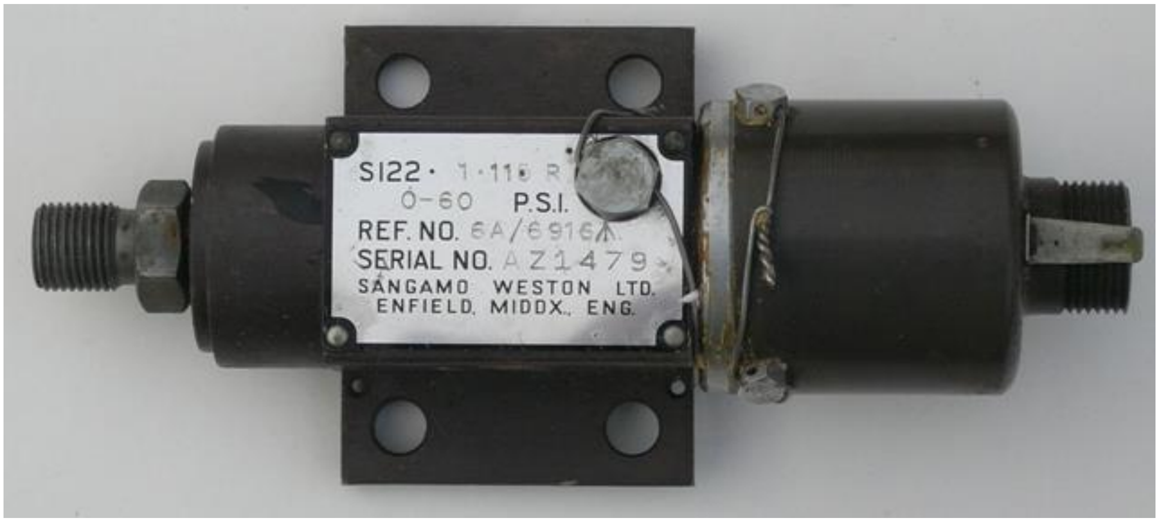
Here an expanding pressure capsule is pressurized by the engine oil system and mechanically linked to a variable resistance to form a pressure sender unit. The variable resistance in the sender is wired into one half electrical bridge circuit, the other bridge half is formed by the two coils in a ratiometer type indicator. The ratiometer indicator consists of a small permanent magnet armature that is allowed to rotate between two coils mounted at 90 degrees. The whole circuit is powered from a 24V DC supply. Changing oil pressure will cause the capsule to expand and contract altering the balance of the circuit and hence the indicator reading.

The Weston system may accommodate differing pressure ranges, electrically all the indicating systems are the same. Different mechanical capsules are manufactured for different ranges and the indicator scale calibrated accordingly.

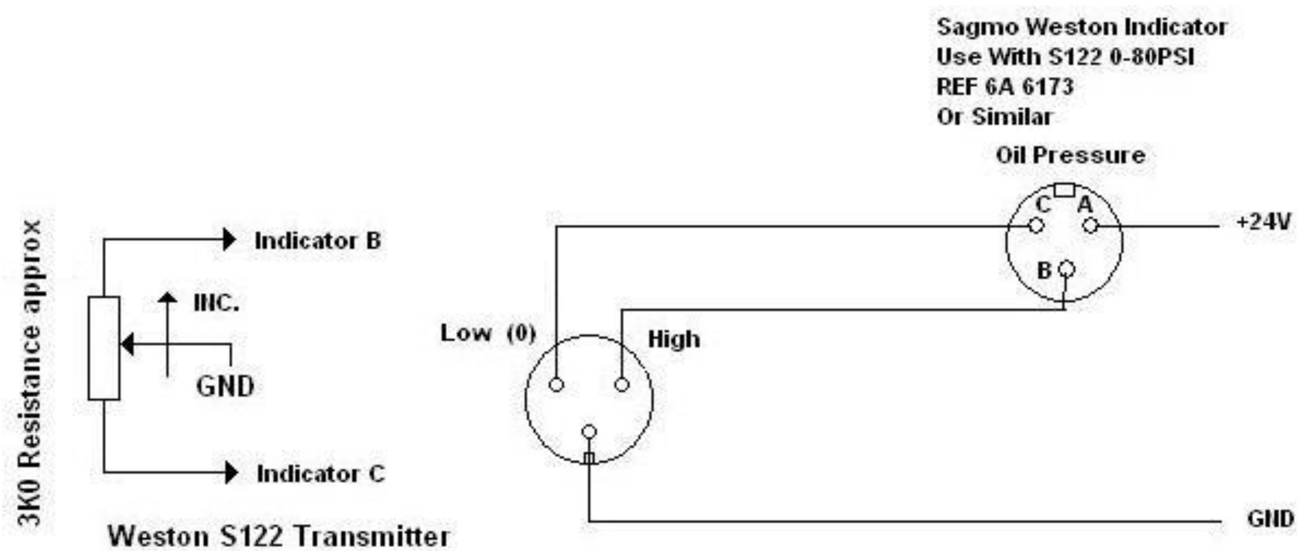


Weston "ratiometer" oil pressure indicator

The Weston pressure indicating system is a common type and is found on several British manufactured helicopter engines and APUs including the RR Nimbus, RR Artouste, RR Palouste, RR Gnome H1000, H1200 and Rover AAPP MK10301.

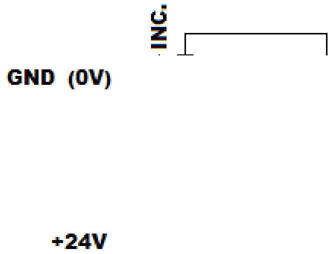


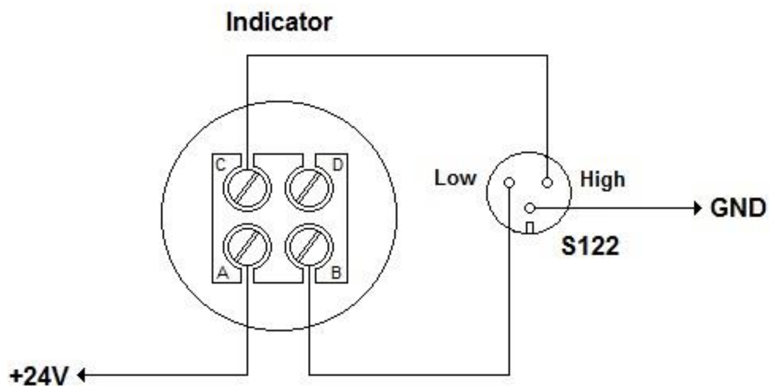
Weston oil pressure DC ratiometer type sender unit



Weston pressure indicator circuit

Test circuit Weston oil pressure indicators

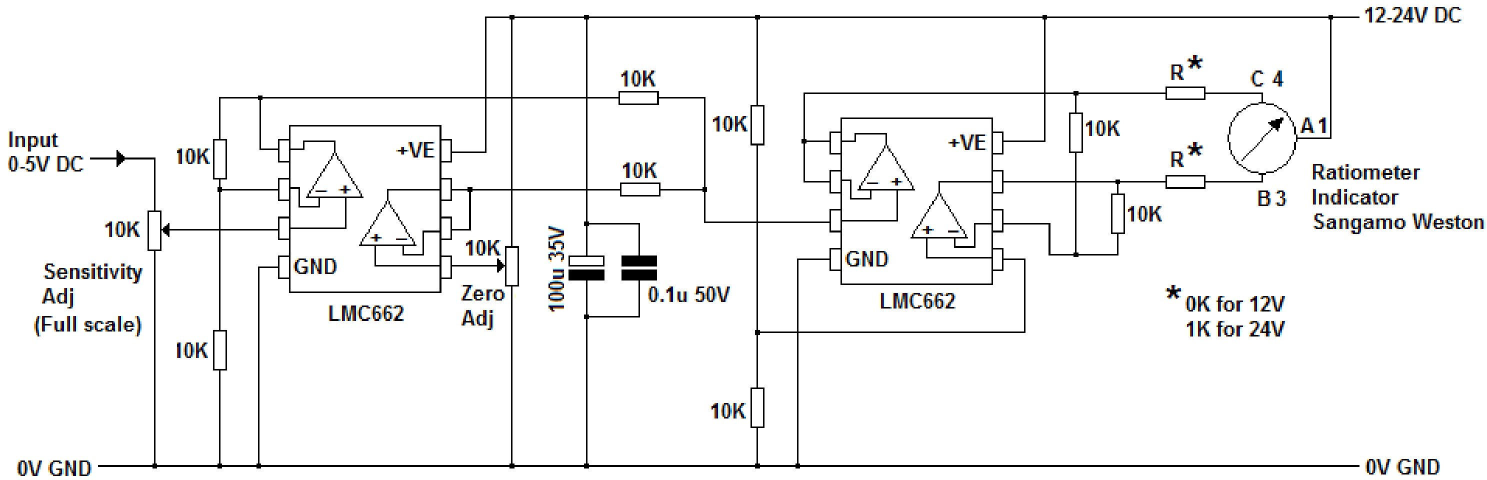




Weston S149 Series DC Ratiometer

Weston indicator with screw terminals

Driver circuit for Weston ratiometer indicators



Pressure ratiometer indicator driver circuit

A simple op-amp circuit may be constructed to drive Weston DC ratiometer type pressure indicators from a 0-5V signal. This may be useful for interfacing with modern pressure transducers or for constructing classic aircraft cockpit simulators and restoring cockpits for working static display. A 0-5V DC drive signal may be derived from a computer I.O. interface card such as an Arduino or Phidget type USB interface cards.

The circuit is simply a balanced amplifier feeding the indicator coils. For the circuit to operate on a single 12-24V supply a half rail reference is provided. A second input amplifier circuit increases the sensitivity and a variable DC offset is introduced to zero the meter.

The circuit will function on a 12V supply and will provide reasonable linearity with 2" round and square bezel indicators. For 24V operation it is recommended to fit series resistors of 1K value to reduce the dissipation in the indicator coils. In the original aircraft circuit, the coils would be fed by the resistance of the sender unit, when directly driven form an op-amp there is no voltage lost in the sender increasing the potential across the coils.

A regulated DC supply is required to operate the above circuit to prevent drift and maintain accuracy.

2. Smiths Desyn system

An alternative remote pressure indicating system offered by Smiths Industries makes use of a three phase DC bridge circuit. The sender consists of an expanding capsule pressurized from the engine oil system. The capsule is mechanically linked to a pair of contacts that rotate around a circular resistance. A 24V DC supply is connected to the pair of contacts that energize the resistance and create an electrical potential around it. Tapped off around the resistance at fixed 120-degree points are three signal wires. The signals wires carry a DC three phase signal to the indicating device. The indicator consists of three static coils arranged around a moving magnet connected to the pointer. The pointer is free to rotate to any point and is NOT restrained by any kind of hair-spring as is common practice in moving coil meters. It can be seen that as the bellows expand and contract, the contacts move, the potential around the resistance varies at the three points, hence the current in the three coils varies also and so the pointer connected magnet aligns itself with the resulting flux from the three coils. Indicator will hence follow the position of the contacts in the sender providing an accurate and precise remote indicating system.

As with the Weston system, the Smiths system employs differing pressure capsules to provide appropriate calibrations for differing applications. The scale on the indicator will be printed to match the mechanical capsule.

The advantage of the three-phase bridge circuit is that it is insensitive to supply voltage changes over a relatively wide range.

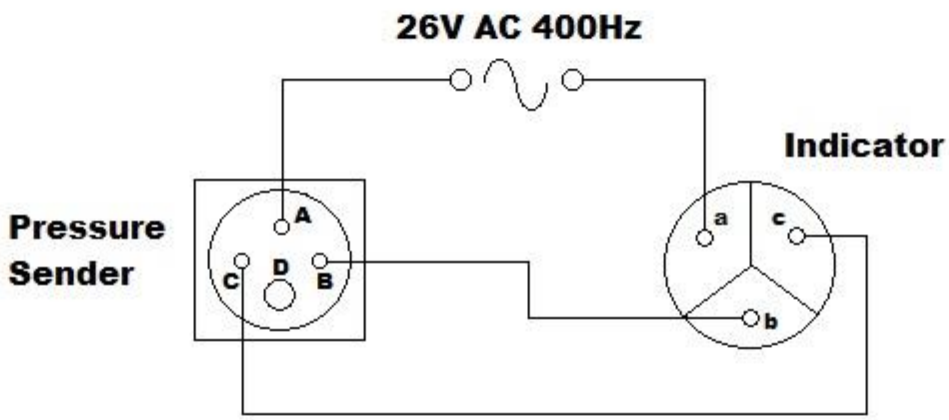
A disadvantage of this and similar DC indicating systems is that they employ wiping contacts that are subject to deterioration and wear that can lead to inconsistencies in readings.

3. Smiths AC bridge system

An alternative to the DC bridge remote indicating systems is to use a system powered by an AC supply. Here a 400Hz 26V AC supply is used to operate indicators that employ a variable coupling transformer to create changes that will move an indicator pointer.

Smiths AC ratiometer indicator and sender

Wiring diagram for Smiths AC ratiometer indicating system



Automotive indicators and senders

Electronic

Modern electronic transducers may be used to accurately and precisely monitor oil pressure within a gas turbine engine. A suitably specified sensor unit with the appropriate pressure operating range may be used to drive a moving coil indicator via an electronic amplifier.

P2 Air

Air pressure from a gas turbine engine compressor may be monitored during engine operation. Compressor delivery pressure is often referred to as P2 pressure (P1 being atmospheric at the engine intake). P2 is not commonly recorded in aircraft installations as it normally falls within close limits when an engine is running normally at a governed speed. P2 is recorded as part of engine test or research rigs and is a useful indicator when operating an engine of unknown characteristics. All gas turbine engines when started begin to self-sustain when the P2 pressure starts to build up, during the first 20% P2 will hardly register, beyond 30% a rapid rise in P2 is experienced. Once the engine is running with significant P2 (beyond 2 PSI) it can be considered as self sustaining, this is useful when testing an unknown engine, the engine may be safely operated below governed speed but at a speed sufficient to maintain acceptably low temperatures. Operating the engine at too slower a speed may cause it to overheat due to a lack of cooling air-flow.

P2 is measured by simply tapping off a fraction of the air delivered from the compressor. Many engines will have some sort of tapping on the main air casing and P2 air may be fed to the fuel control unit. Air bled from the compressor is connected to a standard pressure gauge, in some cases fluctuations may be seen on the gauge in which case a restriction should be placed in the line feeding the gauge to dampen them out.

Picture P2 tapping

Typical values for P2 pressures experienced with small gas turbines range from between 15 and 45 PSI.

Air pressure switches are employed in some engine installations. Some versions of the Rover 1S60 engine use a group of air pressure switches to control various functions during starting. As the engine speed rises so does the air pressure, these switches can be used to cancel such devices as the starter motor and ignition system.

Manometers

Other air pressures are sometimes measured particularly in research or educational stationary engines. Low pressures i.e., fractions of a PSI are measured with liquid filled manometers, the slight pressure losses in air intake ducting may be recorded using this apparatus. The air intake mass flow if passed through a suitably calibrated venturi and bell-mouth can also be calculated by using a manometer.

Fuel pressure is sometimes useful to know, these exhibit pressures up to 500 PSI depending upon the engine type. An indication of fuel pressure at the pump inlet (LP Fuel) is useful in some installations; a pressure switch may be placed in the fuel line and will indicate satisfactory operation of any preceding priming pump or booster pump.

Events counters

Engine mounted hour meter

Gas turbines are often fitted with events counters, the two most common are hours run and number of starts. Normally an electric hours run meter is connected so that it is energized when the main engine fuel valve (HP Cock) is open, it will then increment all the time the engine is running. The meter effectively records the life of the engine and is used to indicate when servicing and inspections are necessary. When obtaining scrap or surplus gas turbine engines, the hours run is very useful to know. Many gas turbine engines have an hour meter mounted on them.

A common practice is to fit gas turbine engines with a starts counter. A starts counter simply records each time the engine is started or in some cases an attempt to start it has taken place. When an engine is started it experiences relatively high temperatures that may influence the overall life of the unit. A starts counter is normally connected into the starting circuit of a particular engine installation. It may be operated whenever the starter motor is energized or when a combination of events takes place. A useful combination is the operation of the ignition and the starter motor simultaneously, this condition usually signifies a start attempt. It is often required that the engine is rotated on the starter motor without actually being started, also the ignition may need to be tested. Recording a combination of events ensures that the starts counter is not falsely incremented and only records "Real" starts.

Other events can be recorded, certain test rigs may record trip conditions such as over speed or over temperature. Lucas gas turbine starter units are fitted with a counter which records transitions from one mode of operation to another.

Instrument panels

A comprehensive instrument panel puts a nice touch to any stationary small gas turbine engine. Instruments should always be closely monitored during engine operation and normal running values should be noted. Ideally indicators should be arranged so that normal operation is indicated by pointers and needles that reside halfway around there respective dials. One exception to this is RPM, normally if an engine is running at governed speed it will be operating at 100%.

In addition to instruments, clearly marked controls are important and appropriate warning lights are also useful. A means of stopping an engine in an emergency is good practice, a clear "Stop" or "Abort" button should be placed where it can easily be reached. Consideration should be given to any electrical fault conditions, engines fitted with solenoid valves will normally shut down if electrical power is lost in a failsafe condition. Engines are sometimes fitted with motorized actuators and may continue to run in the event of a control power supply failure.

An instrument panel should be placed away from the hazard areas of an engine i.e., the rotation plane of the rotor, the air intakes and exhaust outlet.

Simple instrument panel incorporating starting controls and indicators

Electronic instrument panels-

Modern computer graphical displays may be used to present a multiple array of instruments to the user. Modern aircraft utilizing such displays may be referred to as employing a “glass cockpit”. The AS350 B3 series helicopter built by Eurocopter is powered by a FEDEC (Full Authority Digital Engine Control) equipped Turbomeca Arrius engine. During start up a colour graphic display indicates all major engine running parameters and even switches to an appropriate “flight mode display” of alternative indicators once the engine start cycle is complete.

Eurocopter AS350 B3 helicopter instrument display

Graphical computer displays may be built for ground use by utilizing sophisticated code running on a Windoze operating system platform. Here interface devices are required to transform engine derived signals into converted USB type signals for interpretation by the

software code. Interface devices made by companies such as Phidget and Ardweeno are suitable for the task.

Bespoke made MGF Windoze GUI panel