Use EGT to Analysise the Performance of Piston Engine

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Keywords: Exhaust Gas Temperature, Thermocouple, Peak EGT, Gas-oil Ratio, Poor or Rich Oil

Abstract: Exhaust Gas Temperature directly reflects one cylinder or whole engine gas and oil combustion status, through the study of EGT, can indirectly understand and master the engine performance parameters, and then targeted to improve the program, so that the engine work in the best performance status. This paper introduces the principle of engine EGT indication system and analyze the relationship between EGT value and engine performance is based on engine measurement parameters of Lycoming piston engine test bench.

1. Introduction

Most airplanes have a EGT (Exhaust Gas Temperature) sensor and an EGT indicator. EGT is one of the main performance parameters of aero-engine. An accurate analysis of EGT can not only help to identify the performance state of the engine, but also provide sufficient decision-making time for troubleshooting and maintenance scheme formulation.

2. EGT Measuring principle

EGT sensor is essentially an industry the most commonly used temperature measuring element, thermocouple, thermocouple principle is based on the Seeback effect, a thermocouple exists when any two wires made out of different metals are twisted together and heated, such as Copper-steel, aluminum-nickel, and gold-silver twisted wires all make thermocouples and generate a voltage when heated, However, some combinations are more useful than others because most combinations will only produce a very small voltage just barely detectable with sensitive instruments, some combinations of metals produce more pronounced voltages.

The main components of EGT detection system include thermocouple probe, conductor, conductor connection box and electronic control module (EEC). The thermocouple converts the induced EGT temperature into the potential difference of the thermocouple detection loop, calculates it through EEC and displays it on the display module, as shown in figure 1.A thermocouple generates a small voltage proportional to the temperature at the probe. The traditional EGT gauge, as shown in Figure 1A., is analog instruments, so it is impossible to measure small temperature changes. With the development of technology, digital EGT gauge, as shown in Figure 1.B becomes the normal state and the signal amplification circuit is introduced. Therefore, it read out the voltage directly with no calibration numbers. Typical EGT at cruise run about 1500 oF. At this temperature the probe produces about 36 mv (0.036 Volts). Digital EGT amplify this and display precise temperatures.

  DOI: 10.25236/eeems.2018.056

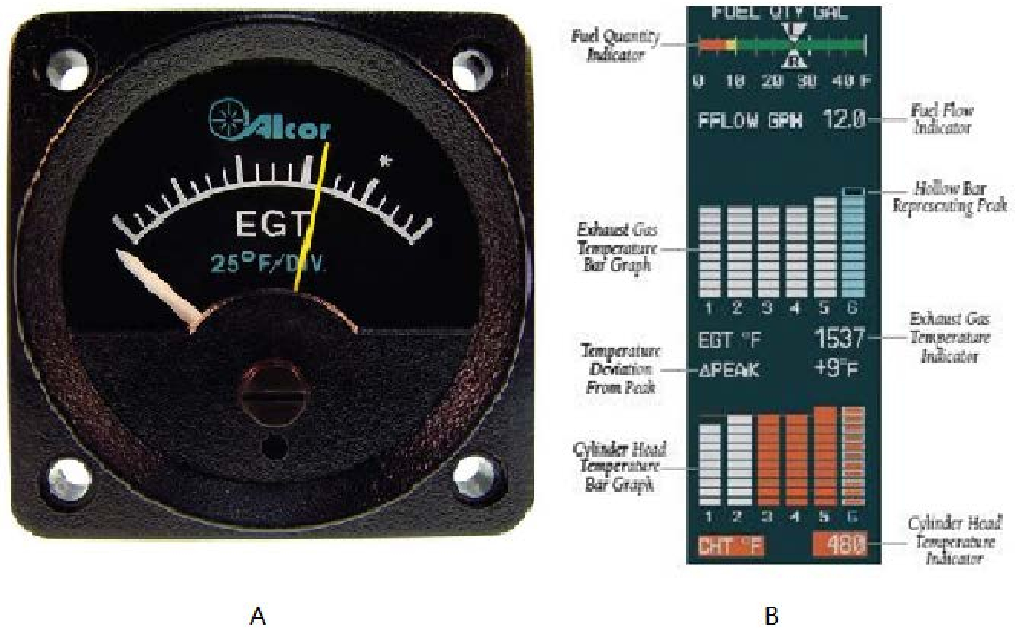

FIG. 1 Analog(A) & Digital(B) EGT Gauge

3. How to use EGT in air

Most aircraft have a single point EGT system installed in the exhaust port of the cylinder that the factory has determined that is normally expected to have the hottest EGT. What we mean by single point is that a single thermocouple temperature sensor is mounting intruding into the exhaust stream just outside the exhaust valve in the exhaust manifold of the cylinder being monitored. Multi-point systems have a thermocouple in the exhaust manifold for each cylinder.

The Figure 2. shows how the EGT varies with the ratio of fuel to air. This ratio is controlled directly by the aircrafts mixture control, usually the red knob. The first thing you should notice is that EGT reaches a peak value when the fuel to air ratio is 0.067. This means that for each pound of fuel consumed the engine is consuming 15 pounds of air. This magic mixture ratio is called Stoichemetric mixture. In a Stoichemetric mixture the mass of combustible fuel just matches the amount of oxidizer (oxygen) present.

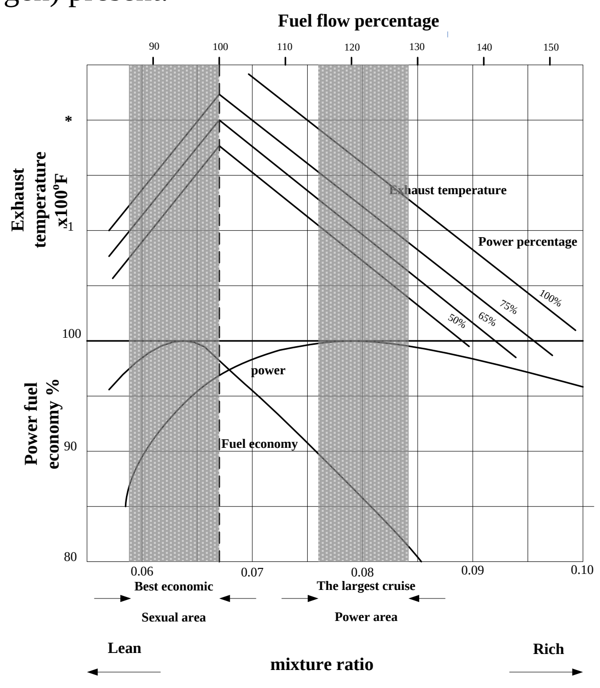

FIG. 2 Schematic Diagram of EGT and Related Parameters Curve of Piston Aero-engine

When excess fuel is present the mixture is determined to be rich. When there is excess air the mixture is called lean. Fuel (avgas) weights 6 lb/gal and air weights 0.0763 lb/ft3 under standard sea level conditions. This translates to 0.0102 lb/gal. This means the engine needs to use 8764 gal of sea level air for each gal of fuel.

To put that in perspective the Cessna 172R has a displacement of 360 in3. When it turns at 2500 RPM it draws in 1950 gal of air per minute (the engine type is 4 stroke, so only half of the revolutions bring in air). Ideally this is 19.8 lb/minute of air. But the air pumping efficiency of the engine is 75% so only about 14.8 lbs of air are actually going through the engine. For a stoichemetric mixture you need 0.99 lb/m of fuel to match up with the air. This translates to 9.9 gal/hr, which is about right for what we know from the POH.

When you are operating on the rich side of peak EGT there is excess unburned fuel in the engine due to the fact that there is insufficient air to match up with the mass of fuel. In this case the unburned fuel carries heat away from the engine resulting in lower EGTs. When operating on the lean side of peak EGT there is insufficient fuel to match up with the air so there is less energy developed, therefore cooler temperatures.

Also notice on the Figure 2. that the peak EGT increases with increasing power up to the maximum power output for the engine. For most engines this will be around 1570 oF. So referencing your leaning point from the maximum (or peak) temperature has become the standard practice. Most often this is given be the manufacturers to be Peak -100 oF .

The engine power is also a function of EGT. Experimental results show that the maximum power is developed when the mixture is set to an EGT reading of Peak EGT -100 oF at this temperature the fuel to air ratio is 0.083. At this setting you are consuming 26% more fuel per minute than at peak EGT. But, for that RPM/throttle setting the engine is producing the maximum possible power.

In the case of a single probe system this is the temperate of the exhaust gases at only that cylinder. What about the other cylinders? For carbureted engines the air and fuel is mixed as it passes through the carburetor and intake manifold. The fuel/air charge in each cylinder may be a little different, but the mixture will be pretty consistent. In fuel injected engines the fuel is injected directly into each cylinder through a small nozzle and mixed with the intake air during the compression stoke. For fuel injected engines the fuel/air ratio in each cylinder depends on how closely each injector nozzle is matched.

You usually find each cylinder peaks at a slight different fuel flow as you adjust the mixture control from rich to lean settings. Here is a picture from the Lean Engine page in a Garmin G1000 system. Just as in Figure 1.(B), cylinder #6 has the hottest EGT. Adjusting the fuel flow so that the first cylinder to peak is running 100 oF lean of assures that all the remaining cylinders are running on the rich side of peak.

There is an on-going argument about running general aviation piston engines at peak or even on the lean side of peak to conserve fuel. The old school argument is that you will burn the engine up. But does that make sense? The engine is operation at all the same temperatures as on the rich side of peak. The problem comes about with only a single probe you have no visibility as to what the temperatures are on the unmonitored cylinders.

But, carefully leaning the engine so that the hottest EGT is on the lean side of peak EGT and 50 oF below that peak EGT assures all cylinders are well below peak EGT. In this circumstance the engine is running at nearly the same temperatures as it was when running 100 oF below peak EGT on the rich side.

Continue analyzing the Figure 2.,the EGT Chart tells us the fuel air ratio will be about 0.055,that’s only 1 lb of fuel for 18 lbs of air, a 31% improvement over running at 100oF rich of peak EGT on the rich side. The result will be a reduction in power of about 6% and a corresponding reduction in speed of 8 kts for a 130 kt airplane.

4. Conclusion

Excessive EGT, if prolonged, will damage the piston. This damage can include piston deformation, melting, burning, perforation, cracks, etc., and this damage is cumulative. If there is a slight ablation on the top of the piston, the engine can continue to run without any problem, but next time the EGT is too high, there may be greater damage, and so on, until the failure occurs. Failure is catastrophic for aircraft piston when the piston suffer damage, because the aluminum than steel or cast iron has low hardness and melting temperature, the damage of the piston and connecting rod will destroy the engine internal parts made of aluminum or aluminum alloy, it will seriously damage the flight safety, the influence of the minimum is required engine overhaul, this would mean that the expensive maintenance cost.High levels of EGT can also result in the exhaust manifold and the cylinder head cracks, and the exhaust valve is inoperative.

In summary, EGT is a direct product of the combustion process. Understanding how it relates to fuel consumption and engine power for fuel management, aircraft range and endurance, and power plant management is essential for your safety and successful flight operations. If you are paying for the fuel and maintenance you will find out right away how well you understand EGT implications.

Acknowledgment

This work was supported by CAAC Technology Innovation Guide Fund (20150215); CAFUC Scientific and Technological Innovation Project (J2015-10).

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