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Technical Counselor Note #2
by Will Fox

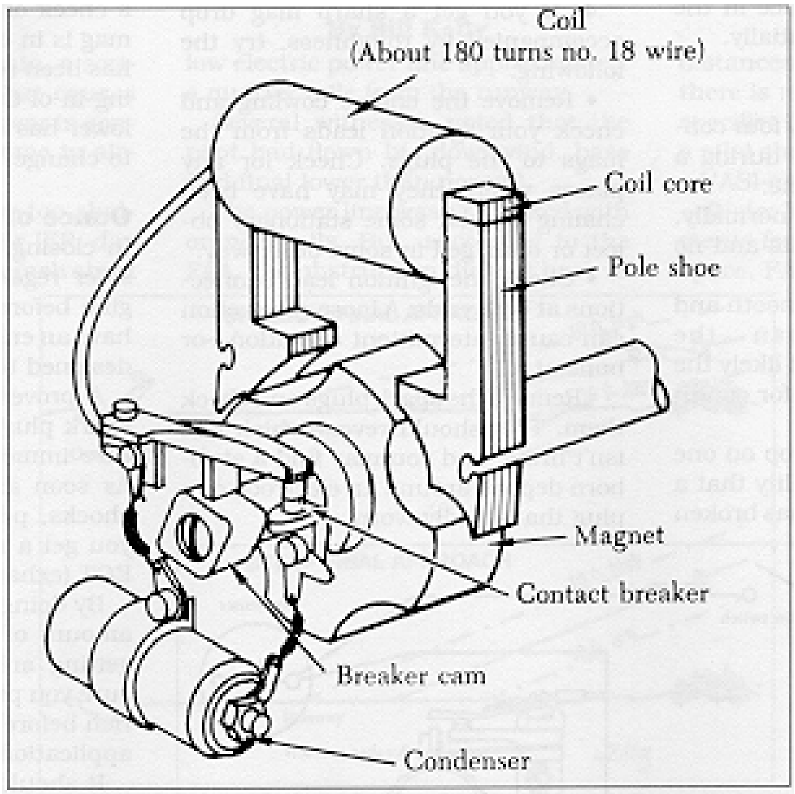
Magneto Ignition Systems

The technology for the modern airplane magneto ignition system is over fifty years old and yet still remains the principal ignition system used for general aviation aircraft. Why is this? It is really a marvelous little invention. It generates its own electrical energy completely independently from any other electrical source, provides thousands of perfectly timed sparks each minute to ignite the air/fuel mixture in the engine and is able to not only retard its timing to properly start the engine but also produces a hot energetic spark with virtually no crank speed so that the engine can be started by hand. Another reason is reliability. The failure rate of aircraft engine magneto ignition systems is once in every 5000 hours, but the failure rate that results in an engine shutdown is only once every 100,000 hours. This mean that while the average pilot may experience an ignition system failure during his flying career, the probability of an ignition failure leading to an engine failure is very remote.

Bendix S-1200 Magneto.

Slick 6300 Magneto.

The purpose of the magneto is fairly simple. It must generate an electrical spark of sufficient intensity to ignite the air/fuel mixture at the correct time during the cycle for maximum engine performance. So to start with, what sort of electrical spark is required to do this? Well, it looks like a big, fat blue spark that is readily visible even in daylight conditions. This spark packs a pretty good punch. The voltage is about 10kV initially and then drops to 1kV after the arc is established for normal firing. The coil in the magneto can produce up to a 20kV spark if necessary for very rich or lean conditions or for high pressure mixtures produced by high compression ratios or turbocharging. The normal aircraft sparkplug gap is 0.016” to 0.021”.   The greater the spark gap, the greater the voltage required to jump the gap. The greater the gap, the better the ignition of the air/fuel mixture, but the higher the stress on the high voltage components in the ignition system. Most experts recommend gapping your plugs often and on the smaller end of the range to reduce stress on the magneto and wear of the sparkplug.



Magneto illustration.

Lets take a look at how the aircraft magneto works. A magnet attached to the rotor of the magneto is driven by the engine and rotates such that alternating lines of magnet flux pass through an electric coil known as the primary winding. These alternating lines of magnetic force produce a wave like flow of electrical current in the primary winding. The faster the magnetic field moves through the coil, the higher the crest of the wave. The voltage produced in the primary winding can exceed 200 volts. While this can give you a pretty good jolt, it is not nearly enough voltage to produce a spark large enough to fire a high pressure air/fuel mixture. So a second coil with a 100 times the number of windings as the primary coil is inductively coupled to the primary coil. The secondary coil is capable of much higher voltages than the primary coil, in fact a 100 fold higher, or over 20,000 volts in some magnetos. In order to produce this kind of voltage, the energy in the primary coil must be transferred to the secondary coil at just the right time. The transfer is accomplished by interrupting the circuit in the primary coil just as the wave of electrical current reaches its peak. This interruption of electrical current in the primary coil forces the energy into the secondary coil via the inductive coupling. The interruption of current is accomplished by opening a set of breaker points that are driven by a cam on the rotor. You might ask why doesn't an arc form across the breaker points as they begin to open rather than across the spark plug gap? Well, it would, were it not for a capacitor connected to the points in parallel that absorbs the energy from the coil just long enough to allow the points gap to reach a spacing that is too great for the primary coil to spark across. You can see that without this capacitor, the magneto would not work properly because the sparking would be taking place at the points rather than the sparkplug. To maximize the voltage potential in the secondary coil, the rapidly changing magnetic flux in the primary coil needs to be interrupted at the point in time when the flux is changing most rapidly, so the points need to open at just the right position during the rotation of the rotor.

Slick coil x-section showing the primary coil (thicker wire) and secondary coil (thinner wire) wrapped around the laminated iron core.

There are two internal adjustments that must be set correctly for a magneto to operate properly: point gap and "E-gap". The point gap should be set first. To do this, the drive shaft of the magneto is rotated to the position at which the cam has opened the breaker points to the maximum extent. Then the point gap is measured with an ordinary wire-type feeler gauge. The points are then adjusted for the specified gap (normally about .018 inch for Bendix mags). Once the point gap is correct, the "E-gap" can be set. First, rotate the rotor slowly until you can feel a "magnetic detent." This is known as the "neutral position" of the rotor. Now, with a timing light ("buzz box") attached across the breaker points, rotate the magneto until the points just start to open. The number of degrees of rotation from neutral to point opening is called the "E-gap" (Electrical gap or Efficiency gap) and needs to be set to a specified value (e.g., 10 degrees +/- 2) so that the points open exactly when magnetic field induced in the coil by the rotor is at its maximum. On the big Bendix S-1200 and dual Bendix D-2000/3000 mags, this adjustment is made by loosening the screw that attaches the cam to the rotor shaft, and rotating the cam until the "E-gap" is correct. Other magneto models have non-adjustable cams, so the "E-gap" adjustment is made by adjusting the breaker points. The correct adjustment of the E-gap is crucial to producing an energetic spark. If the E-gap is not set properly a poor spark or no spark at all may result. Also as the points erode and the actuator arm wears the gap changes and needs to be readjusted to produce the best possible spark.

Slick magneto showing the timing pin inserted.

Now that the E-gap is properly set, we need to set the engine timing properly for best operation. Normal engine timing is set to ignite the air/fuel mixture 20-25 degrees before top dead center (BTDC) as specified by the engine manufacturer. The air/fuel mixture is ignited while the piston is still on the compression stroke. This is because, at high (2700) rpm it takes a while for the mixture to fully ignite and as a result, maximum pressure on the piston does not occur until the piston passes top dead center on the compression stroke and begins the expansion stroke. The magneto needs to be timed such that the spark plug fires early enough to accomplish this. The magneto rotor is positioned using timing marks typically located on the gears in the magneto, so that the points are just beginning to open. Most magnetos allow a pin to be inserted through the housing and gears to lock the rotor in the proper position. The engine is then set to the proper position of 20-25 degrees BTDC by timing marks located on the engine. The magneto is then inserted into the accessory case on the engine and this engages the drive gear on the rotor. At this point, the timing is pretty close to being perfect. It may be slightly off though due to play in the gears. This can be checked by using a timing light or timing buzzer, and a fine adjustment can be made by removing the locking pin in the magneto and rotating the magneto housing very slightly in one direction or the other to get the timing right on. Over time the points and cam follower wear resulting in a change in the E-gap as well as in the timing of the engine. “Bumping the mag” is a term used to describe setting the timing by rotating the magneto in the accessory case to compensate for wear of the magneto. While this can correct timing errors, it changes the E-gap and reduces the energy in the spark. Slick allows up to a 5 degree correction in timing by “Bumping the mag’ but recommends resetting the E-gap if more correction than this is required.

Starting an engine with the timing advanced 25 degrees can be very exciting. It usually results in a backfire and is not only hard on the engine but can actually break engine components like starters. To properly start, the normal engine timing needs to be retarded by 25-35 degrees. The magneto uses what is known as an impulse coupling to accomplish this task. When the starter cranks the engine, a spring-loaded flyweight in the magneto drive hub catches on a stationary stop pin mounted on the magneto case. This stops the magneto shaft from turning further. As the engine continues to turn, an impulse spring in the hub is wound up for 25° to 35° of engine rotation (the "lag angle") until a drive lug on the coupling body trips the flyweight, disengaging it from the stop pin. At this point, the wound-up impulse spring "snaps" the magneto through its firing position at a speed much faster than cranking speed. This results in retarded spark timing for good starting. The spring driven, high rotational speed of the magneto produces a very good energetic spark. This is why very little propeller rotation speed is needed to start even very large engines. It is also why an ungrounded magneto can be very dangerous, because any propeller movement that trips the impulse coupling can produce a powerful enough spark to start the engine.

Let me make a couple of other comments on the design of the magneto. The lag angle is different for different engines and different magnetos. For Slick magnetos on Lycoming engines it is 5-20 degrees and with Slick magnetos on Continental engines it is 25-35 degrees. Lag angles on Bendix magnetos range from 10-45 degrees. Why the variation in lag angles? The amount the timing is retarded depends not only on the lag angle but also on the starter speed. It takes a finite time for the points to break after the impulse coupling is tripped. During this time the engine is being turned over by the starter. The faster the starter turns, the more the engine rotates before the magneto can produce a spark. So different engines with different magnetos with different starters need different lag angles. Think about this next time you put one of those high speed starters on your engine or find a “good” replacement mag for your engine at an fly-in swap mart. If the engine doesn’t start or it backfires during starting, you may have the wrong lag angle on the impulse coupling.

The impulse coupling incorporates a pair of flyweights to decouple the retard feature after the engine starts. The flyweights rotate around a pivot that is can wear over time. In some impulse coupling designs, severe wear between the flyweight and the pivot pin can result in catastrophic failure of the engine. The wear is initially apparent as scuff marks on the flyweight arm as the wear allows the heal of the flyweight to graze the stop pin. Periodic inspection of the flyweights will detect this wear before it becomes a problem. If it is not detected and the wear continues, it can become so severe that the contact with the stop pin can cause the flyweight to fly outward and engage the next stop pin. If this occurs at cruise rpm, the impulse coupling will disintegrate in the accessory housing resulting in an engine stoppage. If you ever wondered about the periodic inspection requirement on some impulse coupling, now you know why.


Sheared flyweight pivot pin.

The permanent magnet attached to the rotor is not permanent. It loses strength over time due to vibration and heat, and needs to be periodically remagnetized to produce an energetic spark. This should be done when the magneto is overhauled.

The magneto incorporates high voltage rotary switch to direct the spark to the correct cylinder. This switch is driven by the rotor and is called the distributor. It needs to be kept clean. Contaminants such as oil and water can lead to electrical breakdown and carbon tracking of the distributor. This results in misfiring of the engine and typically occurs at higher altitudes where lower air pressure results in less electrical insulation.

The capacitor connected in parallel with the points is a very important part of the magneto operation. It prevents the points from arcing which makes for a hotter spark as well a reducing points wear. If the capacitor shorts to ground, it is the same as turning the ignition off, the magneto just doesn't produce a spark across the secondary. If the capacitor fails open, the points will arc until they separate far enough to extinguish the 200-300 volt arc produced by the primary coil. This arc will absorb quite a bit of energy resulting in a much reduced spark at the spark plug. It also retards the timing, resulting in a loss of engine power at higher rpms.


Badly neglected Bendix coil

The reliability of the magneto is quite high. It would be even higher if it were properly maintained. The general maintenance approach on mags seems to be that "if it ain't broke don't fix it" and "you've got two of them in case one fails, so don't worry about it". Those with this approach to magneto maintenance should remember Murphy's Law, "When it breaks it won't be on the ground". The problem with this approach to magneto maintenance is that you are giving up engine performance along with reliability. The timing drifts with magneto wear and this results in poorer performance as well as poorer gas mileage. You are also likely to see more failures in expensive components such as coils, distributors and high voltage leads then would not normally occur if normal maintenance was performed. It is therefore recommended that the timing and sparkplugs be checked and adjusted every 100 hours. The magneto should be removed from the aircraft and disassembled, inspected, and maintained every 500 hours.

Well, that is it for magnetos. In the next installment we will talk about retard breaker points (Shower of Sparks) and some of the new CDI systems and their pros and cons. In the mean time, keep those plugs sparking.

Will

Some good reference Web Sites
http://www.sacskyranch.com/aircraft_magneto_troubleshooting.htm
http://selair.selkirk.bc.ca/systems1/Engines/Aircraft%20Magneto%20systems.html
http://www.avweb.com/news/maint/182843-1.html