Aircraft Reciprocating Engine Ignition Systems

Fundamentals we need to understand:

Without going into any mathematical elaboration, we need to understand the base principles of electromagnetism, to further our understanding of the aircraft systems that use those principles to function and others that may be affected by it adversely.

Two basic concepts need to be understood and accepted for further understanding of electromagnetic systems. To discover the origins, refer to any number of online guides covering electromagnetism and electromagnetic induction.

For current to be induced using magnetism, we require;

- A conductor
- Magnetic lines of flux
- Relative motion between the conductor and the lines of flux. What this means is that we can either move the conductor through stationary lines of magnetic flux or move the magnetic lines of flux over the conductor, either way we will induce a current on said conductor.

Conversely if we have a conductor and there is current flowing through it, you will develop lines of magnetic flux around the conductor.

Reference to conductors implies a wire or other conductive material designed for the purpose of permitting current flow.

Reference to condensers or capacitors implies a device used to store energy in a direct current system.

Ignition, how and why?

Reciprocating engines operate on either the two stroke or four-stroke / cycle principle. The “Lycoming” engine that we commonly see is four stroke, the four strokes are; the intake, compression, power and exhaust. On the intake stroke, air and fuel are drawn into the cylinder. The fuel/air mixture is compressed on the compression stroke. Near the top of the compression stroke, the mixture is ignited forcing the piston down, forming the power stroke and finally the hot gases are expelled on the exhaust stroke, once completed, it all starts again and is repeated hundreds of times each minute.

Unlike automobile engines, aircraft reciprocating engines commonly have fixed ignition timing and use magnetos. Magnetos are reliable and fairly compact self contained units that require no battery or other source of external energy to produce a spark, every time they turn they produce an ignition event.

magneto-equipped aircraft engines typically have two spark plugs per cylinder, allowing each cylinder to be powered by both magnetos, providing both;

- Redundancy should one of the magnetos fail.
- Improved engine performance and efficiency (through enhanced combustion). Twin sparks provide two flame fronts within the cylinder, these two flame fronts decreasing the time needed for the fuel charge to burn, thereby burning more of the fuel at a lower temperature and pressure. As the pressure within a cylinder increases, the temperature rises and if there is only a single plug, the unburnt fuel away from the original flame front can self-ignite, producing a separate asynchronous or uneven flame front. This leads to a rapid rise in cylinder pressure, causing detonation and producing engine “knock”. Higher octane fuel delays the time required for auto-ignition at a given temperature and pressure, reducing knock; so by burning the fuel charge faster, two flame fronts can decrease an engine's octane requirement. As the size of the combustion chamber determines the time to burn the fuel charge, dual ignition was especially important for the large bore aircraft engines.

Ignition system component parts:

The ignition system is generally composed of an ignition switch, two magnetos with two sets of points installed in each, a vibrator switch or impulse coupling to aid in starting, the starter relay/solenoid with starter and the aircraft battery. On the R22 we utilize the left magneto (airframe right) for starting.

The left magneto has two sets of contact points. One set is adjusted to open 25 degrees before TDC used for normal operation. The other set; the "retard points" are adjusted to open 25 degrees later, at TDC, only used for starting. The right magneto also has two sets of contact points. One set is adjusted to open 25 degrees before TDC, just like the left magneto while the other set provides the signal for the engine Tach and governor systems in Robinson installation.

It all starts when I turn the key...

The ignition switch commonly used has 5 positions –

1. "Off" which internally grounds both magnetos primary windings and makes them both inoperative.
2. "Right" allows the right magneto to operate and makes the left magneto inoperative.
3. "Left" allows the left magneto to operate but makes the right magneto inoperative.
4. "Both" allows both left & right magnetos to operate.
5. "Start" detent position (spring loaded to return back to "Both") by turning the key into the detent position, just to the right of the "Both" position we accomplish four things;
    - We only use the left magneto for starting, so we ground the right magneto primary windings internally (through the "P" lead), to prevent kickback that would be caused by an ignition event at 25 degree BTDC.
    - We bypass the left magneto main breaker points and use the retard points by grounding the "P" lead on the left magneto, to allow the ignition event to be triggered at TDC as opposed to 25 degree BTDC.
    - We activate the shower of sparks vibrator.
    - We energize the engine starter relay/solenoid, that in turn powers the starter motor.

P-leads? Coils? Capacitors? What the hell???

As stated above; to induce a current we can either move the conductor through lines of flux, or move lines of flux over a conductor. In the type known as a shuttle magneto, the engine rotates a coil of wire between the poles of a magnet. In the inductor magneto, the engine rotates the magnet and the coil remains stationary, this is what we have in aircraft magnetos. On each revolution, a cam opens the contact breaker points one or more times, interrupting the current, which causes the electromagnetic field in the primary coil to collapse over the secondary coil. As the field collapses there is a voltage induced (as described by Faraday's Law) across the secondary coil.

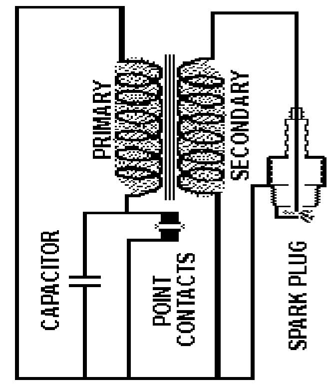
The secondary coil, with many more windings than the primary coil, is wound on the same iron core as the primary coil, but is insulated from said coil, forming an electrical transformer. The ratio of turns in the secondary winding to the number of turns in the primary winding is called the turns ratio. Voltage across the primary coil results in a voltage across the secondary coil directly proportional to the turns ratio. The turns ratio between the primary and secondary coil is selected so that the voltage across the secondary coil reaches a very high value, enough to arc across the gap of the spark plug.

Parts of the magneto

<u>The rotor</u>

The term "magneto" comes from the permanent magnet rotor which is spun by the engine's accessory gearing. In a four-cylinder engine, the rotor turns at engine RPM — in a six-cylinder engine, it turns 1.5 times crankshaft speed. This magnetized rotor, together with the primary winding of the magneto's coil, function as a specialized alternator which generates alternating current flow in the primary as the rotor turns. Each full rotation of the rotor induces two waves of electric current in the primary coil, of opposite polarity.

The amount of energy generated in the primary coil winding is a function of how rapidly the magnetic field across the primary changes. This varies with two things: how strong the rotor's magnet is, and how fast it turns. Big mags (like the Bendix S-1200) generate more energy than do little ones (like the Slick 6300 or the Bendix D-3000 dual-mag) because their rotors have bigger, more powerful magnets. As a mag gets older, its rotor gradually loses magnetism, so its ability to generate energy weakens. Fortunately, the rotor can be re-magnetized and this is typically done at major overhaul of the mag. Equally important as the strength of the rotor's magnetism is its rotation speed. Like any alternator, mags generate their maximum energy when turning at full operating speed, and put out a lot less energy at slow RPM. Hence the need for the starter vibrator, as the starter cranks the engine quite slowly.



The coil and breaker points

As stated above, the turning magnet induces magnetic lines of flux in the magnetic core, as the flux lines develop, they spread over the primary winding (which is wrapped around the core), inducing a voltage in the primary winding, the induced current is alternating due to the poles of the permanent magnet rotating between fixed pole shoes, where one minute we have magnetic north on one pole, 180° later the magnetic south pole reaches the same point, the reversal of magnetic polarity, in turn reverses the induced current. So a rapidly rotating magnet pair causes a rapid collapse of the core's magnetic field, this in turn induces a large voltage spike in the primary winding, which may be as high as 200 or 300 volts.

The primary winding of the coil consists of 200 turns or so of heavy-gauge copper wire wound around the magnetic permeable core mounted between two pole shoes. One end of the coil is permanently grounded to the case of the magneto, while the other end is connected to a set of cam-operated breaker points similar to those used in automotive distributors in the pre electronic-ignition era. Normally, the breaker points are closed, grounding both ends of the primary coil closing the circuit and allowing current induced by the rotor magnet to flow continuously through the coil. This current flow produces a powerful magnetic field in the primary winding, which blooms over the secondary winding (that is wrapped around the primary). At the moment of ignition, the magneto's cam opens the breaker points, interrupting the flow of current in the primary coil winding and causing the magnetic field in the primary winding to collapse quite abruptly. The abrupt collapse of magnetic lines of flux originating from the primary winding and radiating over the secondary winding now induces a current on the secondary winding.

The secondary winding of the coil consists of a very large number of turns of very fine magnet wire — perhaps 20,000 or so vs the 200 of the primary— wound around the same core as the primary. Just like the primary winding, one end of the secondary winding is grounded. The other end of the secondary winding is hooked to the high-tension terminal of the coil (the one that goes to the plugs).The lines of flux from the rotor create a 200- to 300-volt spike in the primary winding when the breaker points open. As the secondary winding has something like 100 times as many turns as the primary winding, and the voltage ratio is directly proportional to the turns ratio ,the lines of flux from the primary winding induce a voltage 100 times as large in the secondary winding: 20,000 to 30,000 volts.

The capacitor

One little fly in this ointment has to do with what happens at the breaker points at the moment they're opened by the cam. Since the points are being opened by mechanical action of the cam, it's obvious that the process of point opening isn't exactly instantaneous. During the first microseconds that the cam is opening the points, they're still so close together that the 200-volt spike in the primary coil winding can arc across them. Such arcing at the breaker points is a bad thing for two reasons. First, arcing causes a tiny amount of metal transfer from one breaker point to the other, and if left unchecked would cause the points to erode and pit quite quickly. Second, arcing causes the magnetic field in the coil to collapse more slowly, resulting in a lower voltage induced in the secondary winding, and therefore a weaker spark at the plugs.

To solve these two problems, mags are equipped with a capacitor connected across the breaker points. Here's how it works. At the moment of point opening, the initial voltage spike charges the capacitor for 50 microseconds or so instead of arcing across barely-separated breaker points. By the time the capacitor is charged, the cam has separated the points far enough that the 200- or 300-volt spike in the primary coil cannot jump the gap. The result is a nice, predictable pulse current (waveform) and much longer-lasting points. The size of the capacitor is critical, if it's too small, arcing won't be effectively suppressed. On the other hand, if it's too large, the coil's field will collapse so slowly that the magneto's voltage output will be seriously reduced, again resulting in a weaker spark. The capacitor and the coil together form a resonant circuit which allows the energy to oscillate from the capacitor to the coil and back again. Due to the inevitable losses in the system, this oscillation decays fairly rapidly.

The distributor

The high-voltage pulses produced by the secondary winding of the coil must be directed to the spark plug of each cylinder in sequence. The magneto accomplishes this by means of a mechanical distributor. The high-tension lead of the coil is connected to a rotating wiper electrode on a large distributor gear that turns at half crankshaft speed inside the mag's distributor block, passing in close proximity to individual electrodes connected to the four or six or eight spark plug lead wires.

The distributor block is made of insulating (dielectric) material capable of withstanding tens of thousands of volts. It is essential that the inside of the distributor block remain scrupulously clean and dry. The slightest bit of contamination — moisture, oil, or dirt — can impair the dielectric properties of the block and allow internal arc-over between distributor block terminals, causing engine misfire, particularly at high altitudes. Once such arc-over occurs, it tends to leave a carbonized track in its wake, facilitating subsequent arc-over events.

The P-lead

The "P-lead" is a wire that runs from the ungrounded end of the magneto coil's primary winding to the cockpit ignition switch (The "P" stands for "primary"). Its purpose is to allow the ignition switch to disable the magneto by grounding the hot side of the primary. As long as the P-lead is grounded through the ignition switch, the breaker points are unable to interrupt the primary current flow, making the mag incapable of generating a spark, thus preventing an inadvertent engine start or kickback.

The P-lead is normally a 16-gauge shielded wire, with the shield grounded to the magneto case. Shielding of the P-lead is essential, because an unshielded P-lead acts as an antenna that radiates the ignition pulses generated by the magneto and creates interference with aircraft radios. Broken P-leads are a frequent problem, since the lead is exposed to engine heat and vibration and air blast. A broken P-lead center conductor results in a dangerous "hot mag" condition in which the ignition switch is unable to shut off the magneto. A broken P-lead shield usually causes radio interference which disappears when the particular mag is shut off with the ignition switch.

Need help getting started!

There are two major obstacles to starting a magneto-ignition engine; RPM and ignition timing. For one thing, our electric starters crank the engine at very low speed — typically 10 to 20 RPM. But, a magneto is not capable of generating enough energy to fire a spark plug at less than, 150 RPM (The RPM necessary to create a spark over the resistance of the spark plug and air gap on the plug is called the "coming in speed"), and even at that speed, the spark would be marginal at best.

Then there's the problem of timing. Magneto-ignition aircraft engines have fixed ignition timing, typically at something like 25° BTDC (before top-dead-center). On fixed wing, it could be 20° BTDC, this setting is a compromise between takeoff and cruise (where we'd really like the ignition timing to be advanced even more) and idle (which would be a lot smoother if the timing was retarded). But there's no way that an engine is going to start with ignition timing like this. If you crank an engine at 20 RPM and a spark plug fires 20° before the corresponding piston reaches the top of its compression stroke, the engine will kick back (try to spin the wrong direction). So, to get the engine running in the right direction, we must delay or "retard" the time of ignition. The best time for ignition to occur in starting is just as the piston is at the top of the compression stroke, at TDC, or just a little past it. In this case we must delay the spark for 25° of rotation, this is where the retard breaker points in the left magneto come into play.

In order to start a reciprocating engine, we need to do two things:

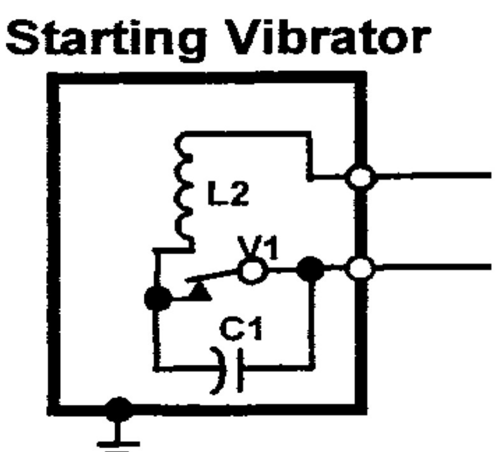
- Figure out a way to coax the magneto into generating enough energy to fire the spark plugs at slow cranking speeds and delay the timing to prevent kickback.

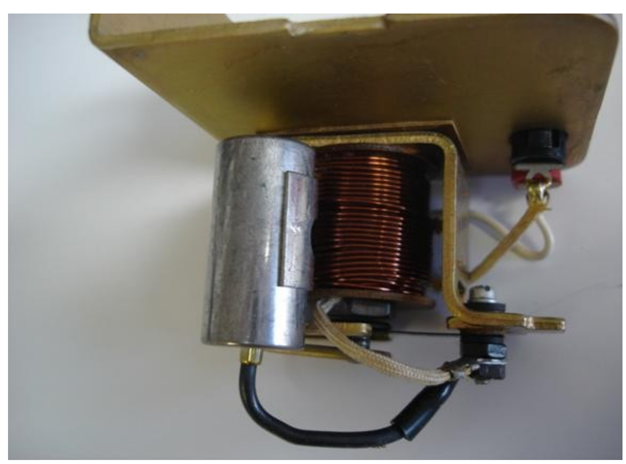
    - Because the magneto has low voltage output at low speed, starting an engine is more difficult. We commonly see two solutions to this problem in aviation reciprocating engines, one mechanical, the other electrical;

      Mechanical - Some magnetos have an impulse coupling, a springlike mechanical linkage between the engine and magneto drive shaft which "winds up" and "lets go" at the proper moment for spinning the magneto shaft. The impulse coupling uses a spring, a hub cam with flyweights, and a shell. The hub of the magneto rotates while the drive shaft is held stationary, and the spring tension builds up. When the magneto is supposed to fire, the flyweights are released by the action of the body contacting the trigger ramp. This allows the spring to unwind giving the rotating magnet a rapid rotation and letting the magneto spin at such a speed as to produce a spark. The impulse coupling mechanically delays the ignition event while it is being “wound up”, as opposed to the shower of sparks system which employs a set of retard breaker points added to the starting magneto.

      Electrical – Alternatively we can use a starter vibrator. The starter vibrator, also commonly referred to as the shower of sparks system uses battery voltage to operate an electromechanical switch that very rapidly opens and closes a circuit, feeding pulsating direct current to the primary winding in the magneto, bypassing the effect of the permanent magnets in the rotor. This rapidly pulsating current produces strong pulsating flux lines in the primary winding. The secondary winding (in its capacity as a transformer) steps up this current, creating a very strong and continuous spark current and directs that high voltage pulse to the spark plugs via the high tension terminal through the distributor, each plug fires at its predefined time (TDC), but with a continuous series of sparks,to ensure ignition, as long as the breaker points are open (almost like a welder).

- Figure out a way to retard the spark enough to ensure that the engine won't kickback during cranking. The impulse coupling mechanically delays the ignition event while it is being “wound up”. The shower of sparks system employs a set of retard breaker points added to the starting magneto.





References and useful links

References without links relate to documents contained in the relevant subject folder on the shared drive.

Wikipedia (http://en.wikipedia.org/) – Good for everything from a detailed treatise on neural-chemistry to growing Cannabis. Keywords search “magnetos” and “ignition magnetos”

Don Maxwell – “Shower of Sparks” article located @ http://www.donmaxwell.com/publications/MAPA_TEXT/Shower%20of%20Sparks/Shower%20of%20Sparks.htm

University North Dakota – fantastic animation and layered construction of magneto, located @ http://media.avit.und.edu/f7_Virtual%20Engine/f1_Magneto/Virtual%20Engine.php

AVWEB - http://www.avweb.com/news/maint/182843-1.html

TCM Ignition Vibrator Manual

The magneto ignition system – John Schwaner (Sacramento Sky Ranch)