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Revision A, October 17, 2010

What’s all this Spike Catcher Stuff, Anyhow?

From time to time, the AeroElectric List is visited with a question about the selection of components for inductive spike-suppression on relay and contactor coils. In this instance, we’re dealing with a potential for the inductive energy storage phenomenon to have a deleterious effect. The inductive energy storage phenomenon has been well understeood for over 100 years. In the case of electrically powered ignition systems for gasoline engines, the phenomenon was exploited as a beneficial effect.

Induction Stored Energy by Design

Both the Ford Model-T and Kettering ignition systems illustrated in the adjacent figures show techniques for closing a set of contacts and applying DC power to a coil causing a magnetic field to be generated within the coil’s core. As contacts open, the circuit is broken and the magnetic field is allowed to rapidly collapse. “Rapid” is the operative word. It’s the magnetic field’s unrestrained rate-of-collapse that induces a large and useful voltage in a second winding wound about the common core.

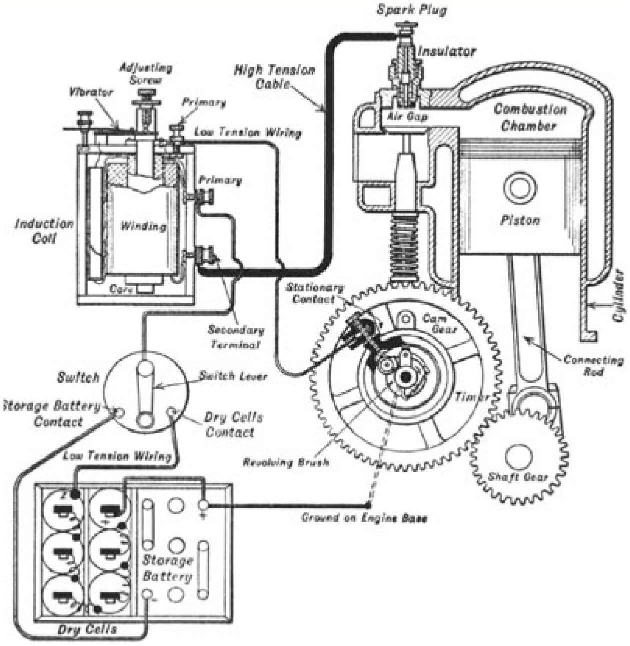

Figure 1. Model-T Ford Ignition System

In the Model-T system, the contacts or “points” are part of a repetitive “buzzer” style current interruption system. The buzzing causes a continuous stream of sparks to be generated at the spark plug as long as power is applied to the coil assembly.. Each spark plug had its own coil. Power to each coil was timed by an optimally positioned set of contacts on the flywheel. Figure 1 comes from a nicely authored paper on the Ford ignition system at:

http://tinyurl.com/2bf7amm

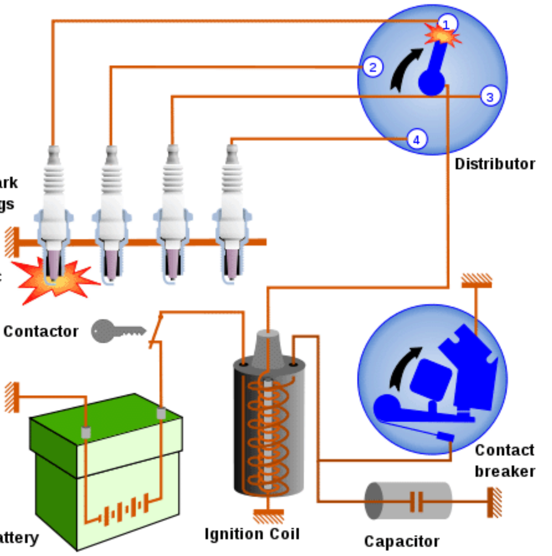

Figure 2. Kettering Ignition System

The Kettering system required only one coil for all cylinders because the high voltage spike was routed to the appropriate spark plug with a distributor. Timing of the spark was controlled by cam operated breaker points within the distributor. This image came from the Wikipedia dissertation on ignition systems at:

http://tinyurl.com/rxxd3

Note the capacitor (or ‘condenser’) connected across the points in the Kettering system. The relatively slow contact spreading velocity of the cam operated ‘points’ made this necessary. The capacitor slows the rate of magnetic field collapse just a little bit . . . enough to reduce arcing at the points to an acceptable level , , , but not so much as to degrade quality of energy stored on the coil. When it comes to lighting fires, a faster rate-of-change produces a higher induced voltage at the spark plug.

The Model-T system in Figure 1 includes a switch to change from the storage battery to an array of dry cells. Seems that designers of this system perceived some reliability risk for the normal vehicle power and provided a “get home” back up power in the form of dry cells.

What do automotive ignition systems have tod do with relay life? Indulge me a little here. The point to be made is that ALL inductive circuits will store energy on their magnetic fields. This energy is sometimes good. Design goals strive to store and utilize the largest practical bundle of stored energy. Other times, the phenomenon is problematic and the designer wishes it could be made much smaller or eliminate it without compromising functionality. The phenomenon is always present and demands an understanding of the simple-ideas before the designer can make a seamless integration of the device into the elegant system solution.

Contact Science

Another important feature of this study is that which I call “Contact Science”. Every relay, contactor, switch, and set of distributor points is fitted with metallic contacts tasked with controlling a flow of current. Bring them together and the circuit is closed. Separate them and the flow of current stops. Simple enough.

But then it gets complicated. Depending on load current, supply voltage, switching rates, and reactivity of the load, the choices for contact composition, size, mechanical mounting dynamics, and reactivity mitigation components become a big study in simple-ideas and recipes for success in crafting the elegant solution.

There have been encyclopedic volumes of work produced on the physics and practical considerations for design and applications of mechanical switching devices. It’s of no special concern that the contacts are part of a relay, manually operated switch or some component of a complex mechanism. Occasionally, inattention to detail can produce challenging failure modes that force the designer to put down the manufacturer’s catalogs and rating charts and dig deeper into the physics books.

Fortunately, the majority of applications calling for the use of a switch or relay do not demand optimized solutions for reliability or service life. Some switching devices are so lightly loaded or infrequently operated that stresses to the device’s moving parts and contacts are not likely to produce a failure over the lifetime of the system. Even when a particular set of contacts are loaded such that performance to rated service-life is improbable, doing something about it may have no return on investment. Such is the case with the way most of switches and relays are used in OBAM aircraft.

Let us consider one second in the life of a set of contacts. I’ll ask your indulgence in imagining yourself to be about 25 millimeters tall. You’re standing at the edge of a set of contacts on a toggle switch . . . or a relay . . . it doesn’t matter. The contacts is 2mm thick and 5mm across. So looking across the edge of the stationary contact is about like looking across the top of a large pizza.

The moving contact is supported perhaps 5 millimeters above the stationary contact . . . if you were to stand up it would be about the same height as your belt buckle. The contacts are made of some alloy of metal . . . certainly their mass is a significant value . . . how much would a pizza sized chunk of brass, silver cadmium, or tungsten 6" thick weigh? Considerably more than you’d want to drop on your foot.

Now, let’s accelerate that mass of material downward toward the stationary contact such that it closes the distance in say 3 milliseconds. What velocity do you suppose it would achieve to traverse the gap in so short a time? How would you imagine the two masses would behave when they came into contact with each other? Stick and stay stuck? Bounce? How many times and how high? Obviously we can only guess at the numbers but it’s a pretty safe bet that none of the values are zero.

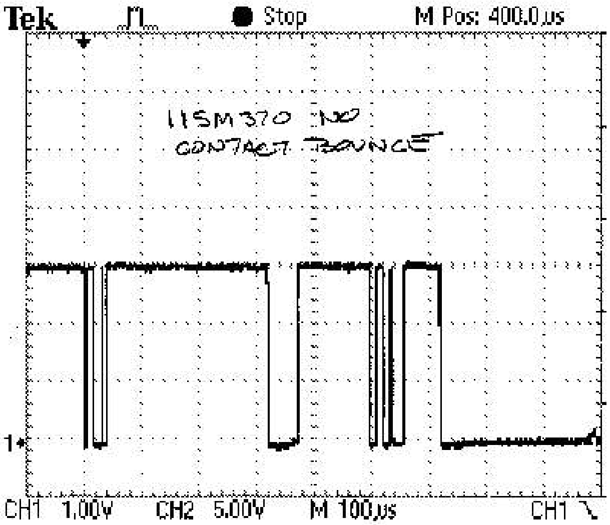

Figure 3. Contact Bounce in SM Series Microswitch

In Figure 3 you see some conduction traces recorded for a contact transition on one of those itty-bitty SM series Microswitches. Note it takes about 600 microseconds and 9 tries for the contacts to stop bouncing. I can tell you that some switches and relays are better . . . some are much worse. Variables that control contact bounce in frequency and severity are many.

The trace in Figure 3 was taken at a current flow of perhaps a few milliamps. Let us imagine again that you're peering across your pizza-sized contact rated for 40 amps and it's switching a 200 watt, incandescent landing light. When the moving contact comes down to touch the first time it undoubtedly rebounds. How much current flows when the contacts first touch? A 200W landing light in a 14 volt system can have a cold current approaching 100 amps.

Okay, how much will the lamp warm up during the first 5 microsecond contact? Not much. When the contact comes down again, how much current flows? About the same as before. And so it would be with other high-inrush currents like motors and appliances with large capacitors across their power input terminals.

Air has a dielectric strength on the order of 700 volts per 1/1000th of an inch of gap. How far apart are the bouncing contacts when they first separate? Damned small inches. How many volts does it take to start an arc across damned small inches? Damned small volts.

The Microswitch shown here was one of the devices I studied during some investigation of switch field failures. I put this particular switch in a loop with a 1.5v D-cell and a 1.0 ohm resistor. Current draw, about 1.3 amps. While watching the contacts under a microscope in a dark room, I could readily see an arc form between the contacts both on opening from a static condition and during contact bouncing. What's more, the color of the arc was blue. What's the temperature of a blue fire? Suffice it to say, HOT.

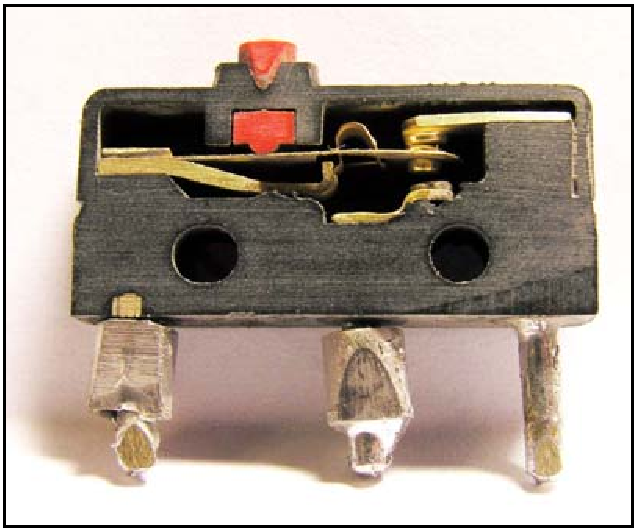

Figure 4. SM Microswitch Cutaway

The point of this experiment was to show that even for small voltages and relatively benign current levels, some degree of HOT arcing occurs. At these temperatures and particularly in DC systems, each arc event melts molecules of contact material and transports the ionized metals as a gas from one contact to the other. Of course, some molecules are lost to surrounding environment to be deposited elsewhere. Contact arcing causes distortion and loss of material.

Getting back to our pizza-sized, contact-crash closing the loop on 100 Amps. Without a doubt, the Liliputian observer would be impressed with the storm of blue fire over mozzarella mountains. Event the standard sized human would have no problem observing the arc event without the aid of a microscope.

The point of this cerebral exercise is to secure the notion that just because you flipped a switch on but one time, the number of contact closures and the stresses placed on those contacts during the closure bounce-a-thon has a profound effect on contact wear.

So much for the closure event, how about opening? As it turns out, the same dielectric limits for air are still in operation and depending on how reactive the loads are, the inevitable fire that forms in the spreading contacts can be prolonged and severe. This is why switches are DERATED both for inrush events during closure and what one might call the "Kettering effect". An inductively driven rate-of-voltage-rise during contact opening. (The citation of 'Kettering effect' is a tip-of-the-hat to one of my personal heros and should not be mis-construed to be an industry wide attribution.)

Whether or not the fire goes out between spreading contacts has to do with contact spreading velocity, heat sinking of arc energy into the contact mass, pressure of the atmosphere, and rate-of-rise for voltage delivered to the spreading gap from the collapsing magnetic field in the load being switched.

It has been suggested that some forms of relay coil suppression (plain diodes) contribute to reduced service life because the contact spreading velocity is decreased thus allowing more time for a Kettering effect to erode the contacts.

Keeping the Dragons at Bay

Some coil suppression techniques cause obvious and measurable delay in relay opening time. Some writers have erroneously suggested a proportional impact on contact spreading velocity. Let's explore this assertion.

Figure 5 shows the time from first control switch opening until the contacts break for a 30A rated, plastic relay. In this case, the coil is fitted with no suppression of any kind. Here we see an OPENING DELAY on the order of 2.5 mSeconds. Note the second trace displaying a significant inductive field collapse spike from the disconnected coil.

Figure 6 shows how the plain coil suppression diode extends the drop out delay to 12.5 mSeconds. Further, the coil spike is effectively suppressed. Hmmm . . . the opening delay goes

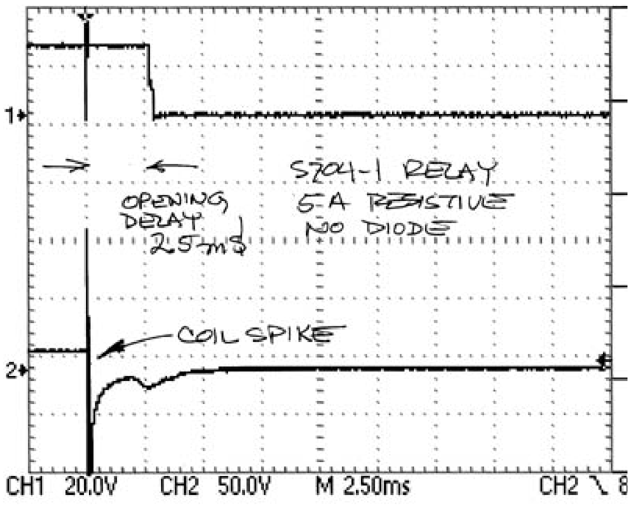

Figure 5. Exemplar Opening Delay No Diode

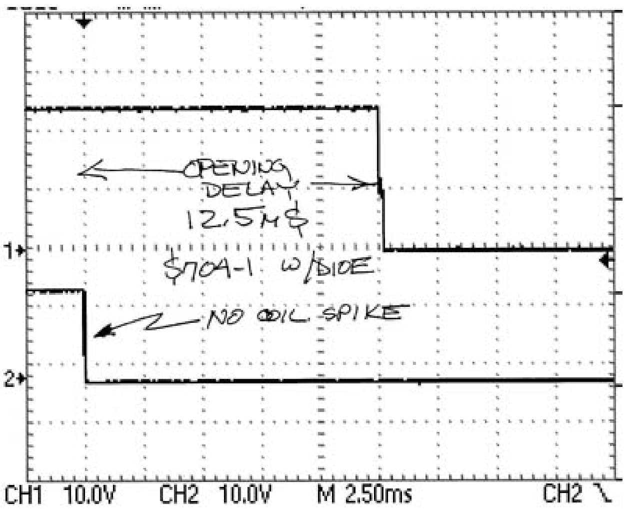

Figure 6. Exemplar Opening Delay with Diode

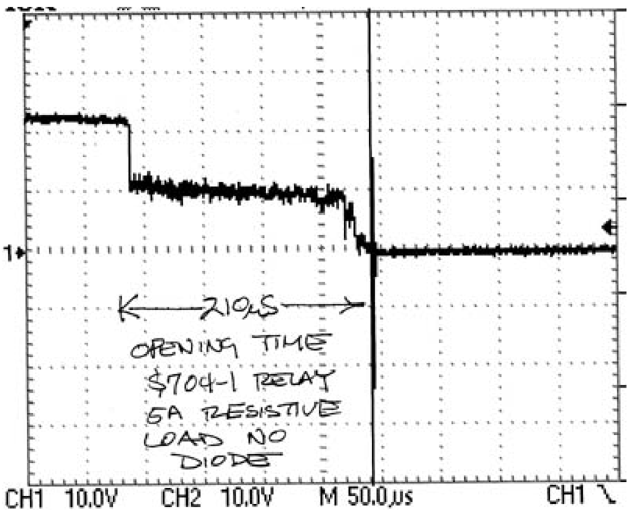

Figure 7. Exemplar Arc Duration No Diode

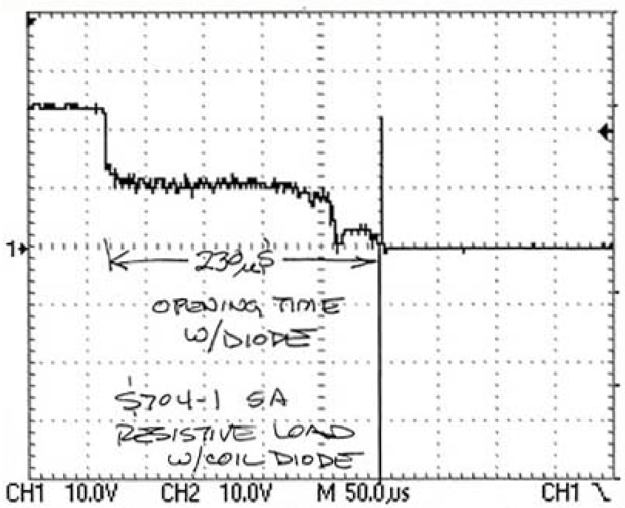

Figure 8. Exemplar Arc Duration with Diode

up by a factor of 5 when the plain diode is installed. No doubt it would be much shorter with a supper-suppressor but these traces illustrate the extremes for range of performance. Traces in Figure 7 plot the delayed break in current flow across spreading contacts due to arc formation. Here we see that from the time the contacts first open until the current drops to zero is on the order of 210 micro-Seconds.

Figure 8 shows delayed break in current flow with a plain vanilla diode installed. Here the time was measured at 230 micro-Seconds . . . not a 500% increase but only a 10% increase in arc maintenance time for having added the "less-than-ideal" coil spike suppression diode.

Assuming a rated service life for this relay is 50K cycles, these experiments demonstrate that the worst case, plain diode coil suppression technique probably decreases the service life due to opening arcs to something on the order of 45K cycles. How old will your airplane be by the time you put 45K cycles on any relay? Keep in mind that coil suppression has no effect on contact erosion due to arcing during closure.

The prudent designer makes component selections based upon the big picture that includes design goals and a working knowledge of wear-out stresses and the source of those stresses. For example: we don't put arc suppressors on starter motors to protect starter contactors. Starter contactors specifically designed for that task. Some manufacturers install catch diodes on the coil of their starter contactors. This improves on the life of the starter push-button and has virtually nothing to do with contactor life. Erosion during contact bounce cannot be strongly mitigated by any form of arc suppression because the gaps in which arcing takes place are so small.

Some years ago, I had occasion to investigate some switch failures where the only loads were a couple of light bulbs on the panel. These switches were first-class, gold-plated critters that simply went open-circuit after some hours of service on the nose gear down lock annunciator. You can read a report on the failure analysis and suggested fix at:

http://tinyurl.com/2g6ufz2

The Microswitch documents cited in the report are at:

http://tinyurl.com/2car9bz

http://tinyurl.com/264ojmc

While these papers address small switches, the physics that drive contact performance in relays is the same.

Finally, I'll offer for your consideration another field failure where mil-spec relays with built-in, latest and greatest coil suppression technology were sticking and causing trim system runaways. These relays were loaded to a small fraction of their design values yet they failed after a few thousands cycles at most.

The problem was identified and duplicated on the bench. It turned out to be a combination of three decisions for materials selected by three designers over a period of 30 years that combination to generate contact stresses never anticipated by the design literature from any manufacturer or researcher.

Risks to Service Life

Limits to service life on switches, relays and contactors fall into four categories. Listed in order of probability:

- Environmental effects of moisture, vibration, corrosive gasses and liquids, and time.
- Installation error
- Wear out
- Mis-application of the device chosen for the task

I've personally replaced more switches for root causes related to environment and old-age than for end-of-service-life.

We've discussed several switch failures on the AeroElectric List where improper election of components, tools or application process contributed to a failure. We deduced that breaking a single current pathway (wire) to install a particular style of switch added a total of 10 new fabricated metal to metal joints. All were in series with the current path. Each new joint contributed additively to voltage drop. Each new joint added risk for installation-induced loosening followed by failure.

Relays and contactors probably don't have as many interfaces but they're potentially more vulnerable due to the relatively higher currents they're intended to carry.

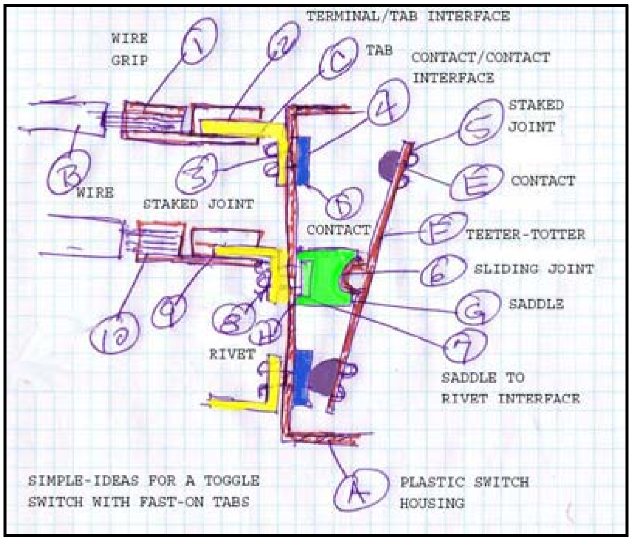

Figure 5. Parts-Count for Electron Flow Through Switch

The purpose of this essay is to place the coil spike suppression techniques into perspective. The prudent system designer will consider the value of adding some form of arc suppression or inductive spike mitigation depending on system design goals, variables described above along with the nature of the device being "protected." Kettering had to add the capacitor across the points for tailoring characteristics of a magnetic field collapse he DIDN'T wish to attenuate. In his case, the switch (cam operated points) operated 2 to 3 thousand times per vehicle traveled mile. An optimization of all components in the chain of wear-out stresses was and essential feature of his design goals.

I've seen pre-mature failures on switches and relays with super spike-mitigation where failure was due to causes unrelated to class of spike mitigation. Relays and contactors with more mundane or even no coil spike-mitigation have also delivered good service (although some of them may have been hard on their controlling switches!).

In Conclusion . . .

I wouldn't suggest for a minute that the more exotic coil suppression techniques do not perform as advertised. I do suggest that compared to more destructive forces, the style of coil suppression is insignificant for how relays and contactors are used in OBAM aircraft.

If the builder wishes to apply the-best-we-know-how-to-do in every product purchase decision, so be it. But citation of an article that asserts "this is a good thing to do" is not a well reasoned driver for spending more $time$ on a particular component. This is especially true if the designer is ignorant of the return on investment for having accomplished the "good thing."