



Switching, Thermals and Other Topics

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Purpose:

To show how something as seemingly simple as a reed switch can give you clues to many real-life design issues and tradeoffs such as thermal voltages, thermal expansion, printed circuit layout, induced voltages, physical stress, and more.

Equipment:

- Agilent 33120A Synthesized Function/Arbitrary Waveform Generator
- Agilent 54600B 100 MHz Digital Oscilloscope
- Agilent E3631A Power Supply
- Agilent 34401A 6 1/2 Digit DMM
- Simple form A reed switch with magnet or magnetic coil to activate the reed switch

Introduction:

We often see labs designed around a complex device-under-test, but there are many things we can learn and extrapolate from a very simple electronic device. One such device is the reed relay, composed of a reed switch and a driving coil.

A “form A” (single pole, single throw) reed switch is a simple device, consisting of a glass vial that encases two ferrous switching elements:



“Kovar” (ferrous) metal leads; glass frit seal between metal and glass body.

FIG 1: Reed Switch

When the ferrous elements are driven by a magnetic field, the two elements are drawn together, thus closing the circuit. Obviously, the magnetic field can be generated either by a permanent magnet or by an electromagnet. When the electromagnet is used, the combination is called a “reed relay”. The reed relay’s small physical size enables it to respond within milliseconds... fast for a mechanical device.

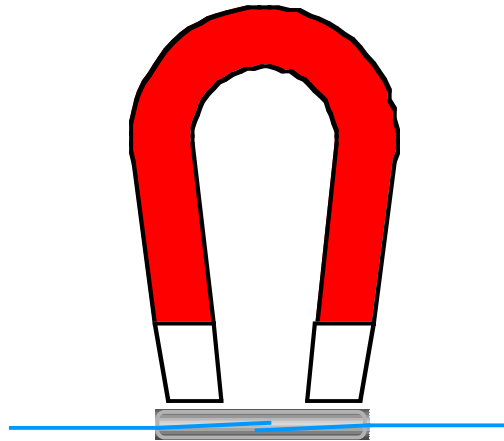


FIG 2: Actuating the switch

Metal Migration

While reed relays are relatively fast, they do have a small contact area, so contact ratings tend to be minimal.

Question: The dc rating of a reed switch is much less than its ac rating. Why do you think this is so?

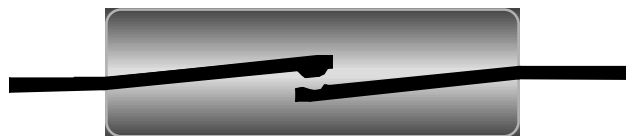


FIG 3: Pitted contacts due to dc switching

When switching dc current, the contact material migrates from one contact to the other, creating a pit on one side and a “hill” on the other. With ac current, the migration tends to take place in both directions, giving longer switch life.

This contact pitting increases the “on” resistance and shortens relay life. If you’re switching large currents with any relay, it’s best to use a “snubber” network--- a series RC network placed in parallel with the contacts. Of course, the snubber network won’t work in all cases. Sometimes the circuit parameters prohibit any kind of impedance from being placed around the switch.

“Why do I care? After all, I don’t use reed relays much.”

Well, maybe you do. They’re found in portable phones, VCR’s, TV sets, remote control toys, instruments, video games, PC’s, motors, cars and just about anywhere electronics are used.

Experiment:

Let’s hook up a relay and look at some design constraints. You can use any reed switch for this experiment, but it’s more fun if you can find an open coil and a separate switch, so you can see the reed switch itself.

First, let’s just turn on the switch and measure its resistance. For that you need a permanent magnet or a coil and a power supply.

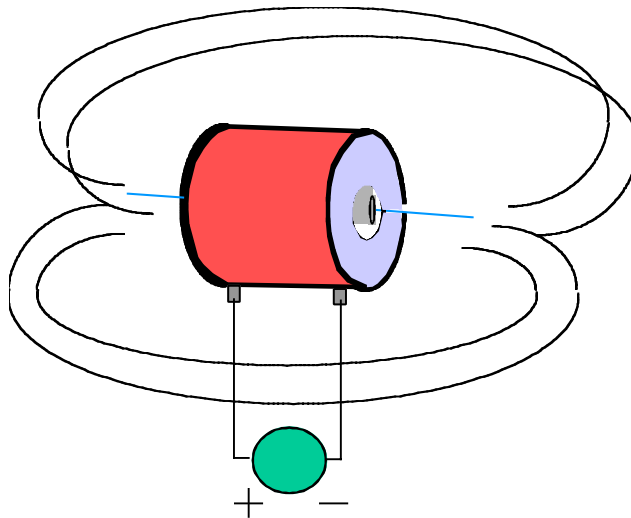


Fig 4: Reed Relay activated by dc supply such as Agilent E3630A or E3631A.

Here's another way to look at it:

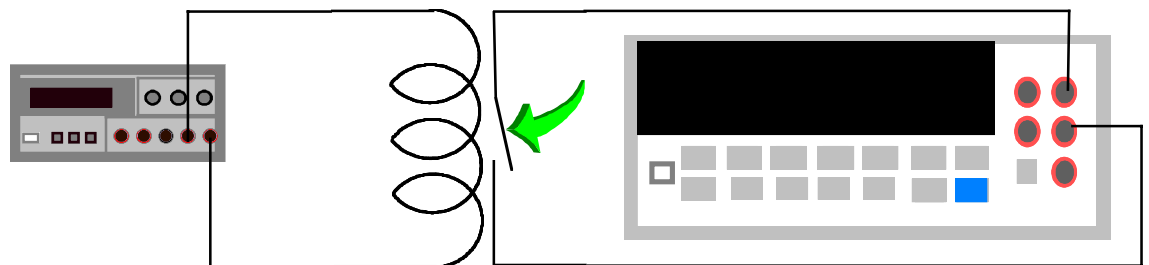


Fig. 5: Measuring Contact Resistance.

Contact Resistance Experiment

Exercise:

Set the power supply output to zero. This is important! [You don't want to burn out the coil before you begin the experiment.] Connect the switch contacts to the dmm, and set the dmm to read OHMS on the lowest range and with the most digits of resolution. For the Agilent 34401A, use Autorange, 6 digits.

The DMM should show Overload (open circuit). Now SLOWLY increase the power supply voltage until the DMM suddenly shows a reading, typically below 1 ohm. Record the resistance.

Without exceeding the maximum voltage specification on the relay coil, slowly increase the drive voltage and read the contact resistance. Does it change?

Reduce the drive voltage until you can see exactly at what voltage the switch opens. Record that voltage. Now increase the voltage, SLOWLY, until it turns on again. You might have to do this a few times to get the exact numbers. **Is the Turn-on voltage the same as the Turn-off voltage? Why or why not?**

Note: For more accurate ohms measurements, you can use a 4-wire technique. [For a discussion on 4-wire Ohms measurements, see the Agilent 34401A manual.]



Conclusion: This hysteresis effect, where the On-voltage and the Off-voltage differ, is a useful feature of the reed relay. As the switch closes, the reluctance varies, concentrating the magnetic field inside the switch and enabling the switch to stay closed

Brainstorm Question: If you were to slowly ramp up the power supply, what would happen if the turn-on voltage and the turn-off voltage were exactly the same?

Contact Life

Most reed switches are considered to be at the end of their useful lives when the contact resistance goes above about 1 ohm. Larger armature relays that exert considerable force upon closure have a “wiping action” that keeps the contacts free from oxidation. This is especially important if the switched circuit carries virtually no current (called a ‘dry’ condition). A typical reed switch has a life of about 1 to 10 million operations, while that of an armature switch might be only 100,000 operations. In some designs, it’s critical to be able to predict the wearout phenomenon that is caused by metal fatigue or oxidation. One solution for this issue is found in the Agilent 34970A Data Acquisition System. It has a built-in contact counter to tell how many times each reed switch has been cycled, enabling the user to assess contact life and replace suspect relays before failure.

Unwanted Thermal EMF

Exercise:

Measure the contact voltage by switching the Agilent 34401A function to Vdc, Autorange, 6 Digits. This will give you 1 microvolt of resolution. Is the voltage zero? Is that what you expected? Hold ONE end of the relay with your hand, at the junction of the kovar lead and the copper lead.

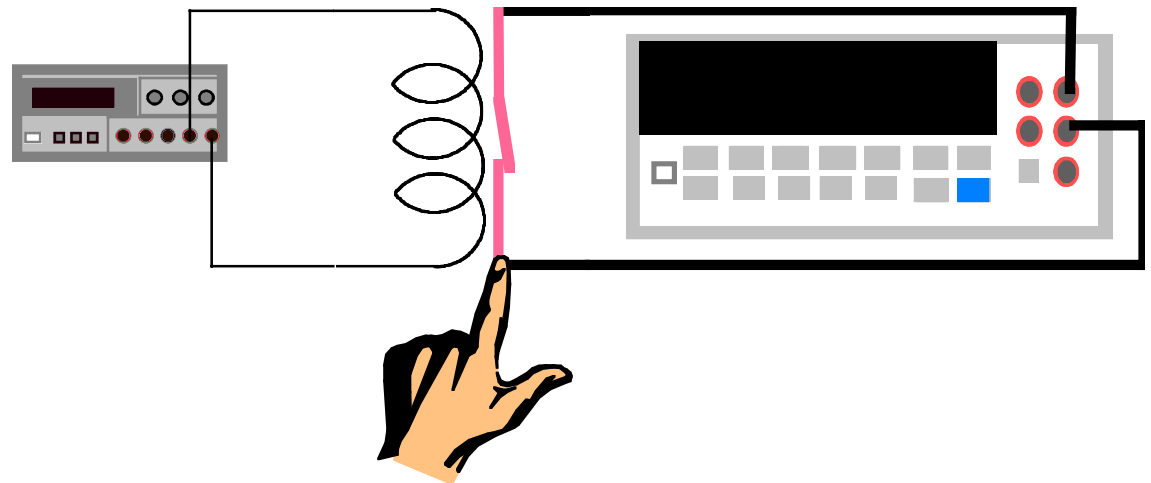


FIG 6: Heating up the junction between the switch lead and the copper wire.

Does the DMM reading change? How much? Now move your hand to the other end of the switch and try it again. Does the reading change? **What’s happening here?** [Note: for an explanation of thermal voltages, read Agilent Application Note 290: Practical Temperature Measurements.]

The kovar wire is ferrous... it has to be ferrous in order for the reed switch to operate under a magnetic field. But the wire to the DMM is copper, and the two metals combine to form a kovar/copper thermocouple. That means unwanted offsets will occur unless the two ends are at EXACTLY the same temperature. Without proper attention paid to this phenomenon, the offset can be hundreds of microvolts... a huge number for some applications.

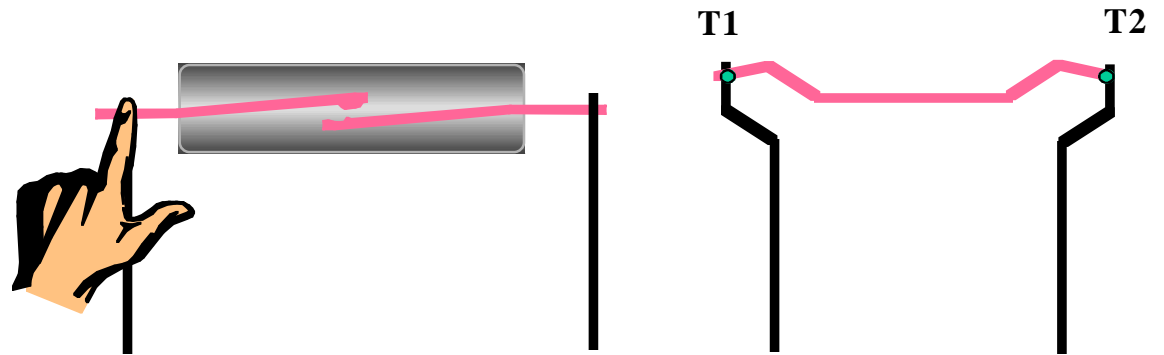


FIG 7: Thermal voltages produced by kovar/copper junction. The circuit is equivalent to two thermocouples in series. $V_{thermal}$ is proportional to $T1-T2$. To eliminate the thermal voltage, force $T1$ to equal $T2$.

Brainstorm Question: How could we get rid of these thermal voltages?

Some ideas:

- Multiple switches arranged differentially:

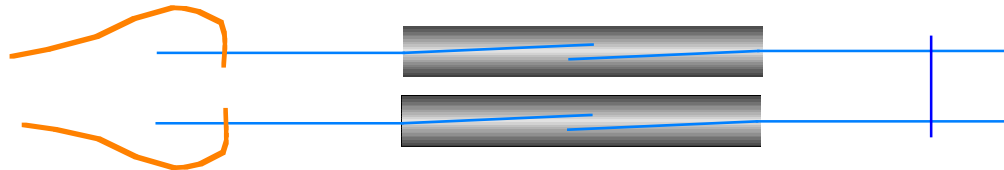


FIG 8: Welded kovar leads minimize thermals; copper/kovar junctions are physically close together so that their temperatures are nearly the same.

- Welded kovar wiring, closely spaced:

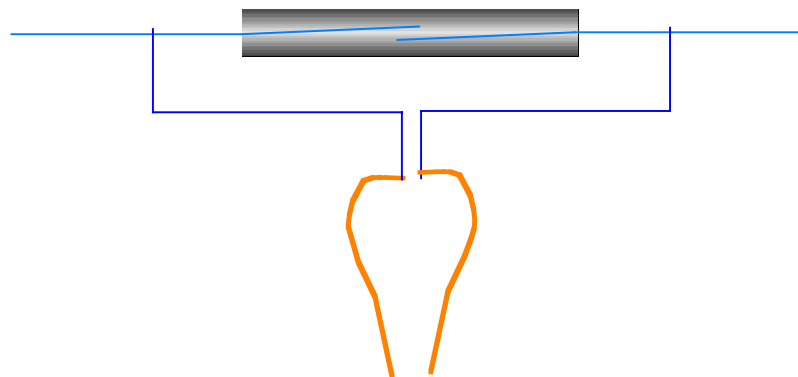


FIG 9: Welded kovar leads on a single reed switch; Cu/kovar junctions physically close.

In both FIG 8 and FIG 9, the idea is to move the junctions close together. This way, the thermal gradient across the junctions should be minimal, and the offset due to the copper/kovar junction switch will be diminished.

In FIG 8, we are relying upon the switch voltages to cancel differentially. This is a great lesson that we all need to use in engineering. Whenever possible, ALWAYS, ALWAYS use a differential measurement.



Brainstorm: Find some other techniques to minimize the thermocouple effect.

Why Weld?

Why don't we just bend the reed wires around and onto the circuit board, so they are close together?

In some applications, we can do just that, but if the switch is not designed to have the leads bent, two things can happen:

1. The magnetic path is diminished, causing the relay to have a longer time delay before it turns on, if it turns on at all.
2. The bending of the leads can cause stress on the end of the glass vial, and a minute crack can develop that will eventually cause failure of the glass or oxidation of the contacts.

Strain Relief

When we are forced to bend the reed switch leads, we need to utilize a stress-relieving technique. You may have heard the term "strain relief" applied to cables. For example, most home appliances have a molded piece of plastic that surrounds the ac power cord at the point where it enters the appliance. That extra cushioning is there to prevent the cord from chafing and from being bent at an extreme angle. It relieves the strain on the cable; hence, the term "strain relief".

The same term is applicable to a multitude of manufacturing processes. One of the simplest is in the bending of a wire such as the kovar lead that extends from the reed switch. In order to bend that wire without unknowingly cracking the glass, it is imperative that we use a clamping device on the wire, and not stress the glass directly. See FIG 10.

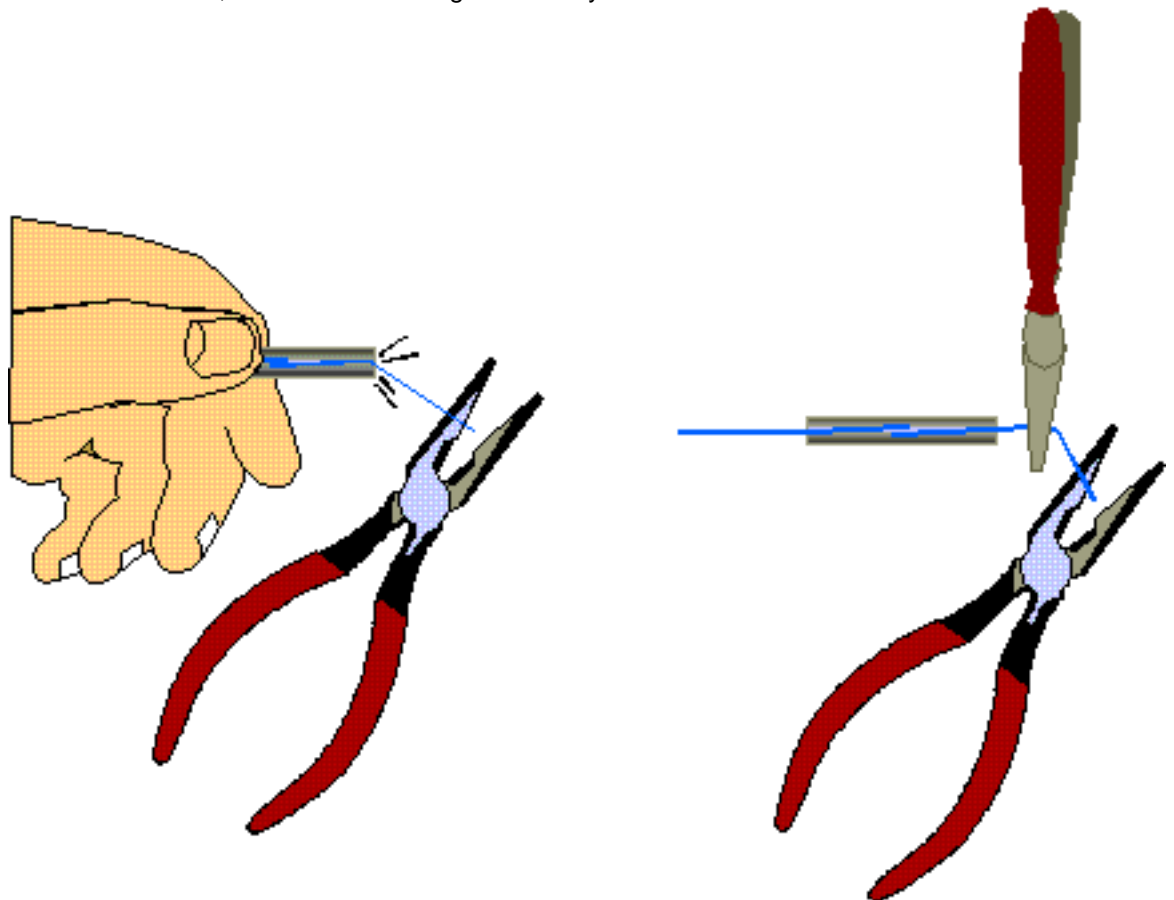




FIG 10: The use of a clamp to bend the switch lead minimizes strain on the relay.

The two-plier method of FIG 10 may not be the best process to ensure stress-free bending of the switch, but it is certainly better than grabbing the relay with the hand and bending the switch lead against the body of the glass case.

Brainstorm: What other applications require strain relief? Think about aircraft, bridges, cables and moving parts, and about several engineering disciplines other than your own.

Brainstorm: What other problem do you create when you hold the reed switch with your bare hand?

THERMAL EXPANSION and RELIABILITY

Many reed switches are encapsulated in a glass tube. Why do you think this is so?

Sometimes the glass tube is connected to the kovar leads via a glass frit... essentially a slurry of glass pieces that are heated to the melting point. This interface is one of the weakest points of the switch. When the entire switch is heated, the glass expands at a different rate from that of the kovar leads, creating a great deal of physical stress on the glass/metal interface. The result can be a catastrophic failure or, simply a leaky glass tube that invites corrosion.

In the early days of semiconductors, one of the most prevalent causes of failure was the mismatch between the thermal expansion coefficient of the substrate (ceramic) and the chip (silicon).

Brainstorming question: Where else is thermal expansion, or DIFFERENCES in thermal expansion, a problem?

Examples:

- Power turbines. A large turbine in a hydroelectric plant can take hours to start, due to the tremendous change in physical size due to thermal expansion.
- The tires on a dragster

CONTACT BOUNCE:

One of the earliest high-volume applications of reed switches was in computer keyboards, where the key was equipped with a permanent magnet that passed by the reed switch. As the reed switch closed, it signaled the decoding circuit that a key had been pressed. When the switch is used as a digital input device, as in this case, we have to realize that any bouncing of the switch contacts causes multiple signals to be sent to the decoder circuit, so a "de-bouncing" circuit must be implemented. This situation is well covered in the experiment from Dr. Walter Banzhaf of the University of Hartford [See Agilent Educator's Website].

Brainstorming Question: Where would YOU use a reed switch?

Examples:

- Inside the human body when a non-contacting switch is required... activate it by use of a powerful magnet.
- In a hazardous atmosphere that calls for completely sealed contacts
- As a tachometer, driven by a series of magnets on a wheel



Tradeoffs:

The discipline of engineering less a study in design than it is a study in decision making. We are constantly asked to trade one benefit for another, rarely getting both at the same time. As an example, just look at a few of the tradeoffs we could be asked to make on the simple reed switch:

- Cost vs. Speed
- Cost vs. Size
- Cost vs. Vendor's delivery time
- Cost vs. Current carrying capacity
- Voltage limit vs. Current carrying capacity
- Speed vs. Power dissipation
- Thermal emf. vs. Ferrous content of the switch elements
- Contact R vs. Coil current
- Contact R vs. Temperature
- Contact R. vs. Contact size
- Delay time vs. Coil current
- Delay time vs. IC driver protection
- Leakage R. vs. Ease of handling in manufacturing
- Breakdown voltage vs. Size
- Coil-to-switch capacitance vs. Cost of guard shield
- Thermal emf vs. Highest voltage
- VSWR vs. Size and current
- Closure time vs. Release time
- Inductive coupling vs. Magnetic driving force required
- Reed switch vs. Armature
- RFI vs. Shield cost
- And the list goes on....

Conclusions:

The reed switch, though an extremely simple device, can be used to demonstrate a number of engineering tradeoffs that span electrical, mechanical and chemical disciplines. In fact, the many questions posed in the above exercises barely scratch the surface of the lowly reed switch.