Temperature and its effect on Electro-Mechanical Relay Operation

A much neglected and misunderstood area in the application of electro-mechanical relays is the effect of temperature both on the relays and that generated by the relays themselves. Failure to understand or to make allowances for these effects can lead to the relay failing to operate when called to do so, or worse, the premature failure of the contacts.

When reviewing manufacturers data, note should be taken of the ambient temperature at which the data for that relay is specified – this is for a "cold" coil i.e. not previously operated and not heated by a previously applied contact load. Different manufacturers specify their data at temperatures which vary typically from 20°C to 25°C depending on the manufacturer – and this means that direct comparison between competing products must be made with care.

Electro-mechanical relays can be divided into two principal areas, the magnetic system (the coil and its associated components) and the contact system.

The Magnetic System:
The relay coil is both affected by heat and is a generator of heat.

Minimum Pull in Voltage U_M (VDC vs Temperature °C)
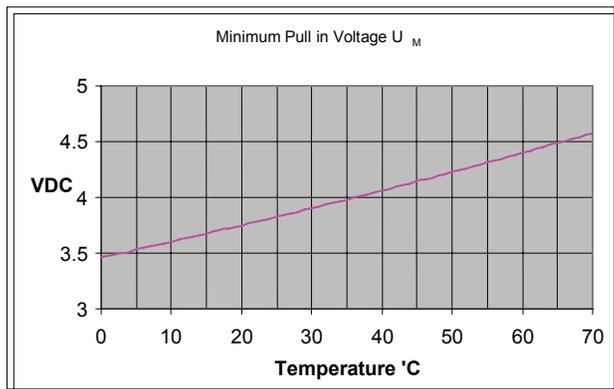
The relay coil is wound from copper wire, the resistance of which increases by 0.4% per degree C. The minimum magnetic field required to operate a relay remains constant (being a design feature), as the temperature rises and the available current to generate the magnetic field falls due to the increase in the coil resistance then, eventually, the relay will fail to operate when required. This is usually seen when the relay is required to operate (pull-in) with an operating voltage less than the specified nominal voltage and fails to do so. Some manufacturers publish graphs showing how the pull-in voltage changes with temperature but many do not – in this case it is possible to do a series of calculations using (I=U/R) and derive ones own figures from the published specification. The graph above shows typical figures for a Durakool DG31 relay with a nominal 5Vdc coil with a minimum pull-in voltage of 3.75Vdc at 20°C. The graph clearly shows that by the time the ambient temperature has risen to 50°C, 4.25Vdc would be required to operate this relay. Note that quoted resistance figures for the coil generally have tolerances of ±10% or more and that the ambient temperature is the temperature in the immediate vicinity of the relay coil and not the temperature outside in the open air! The ambient temperature will be affected by the relay itself and any other heat generating components in the enclosure or close by.

More frequently specified by manufacturers is the maximum operating voltage with respect to temperature and is usually given as a ratio of actual coil voltage divided by the nominal coil voltage plotted against temperature rise. This is normally only a concern if the relay is being over driven, but over driving also has repercussions elsewhere in the contact system, in particular can lead to excessive contact bounce, and should be avoided if possible. However, most relays can be overdriven by a small percentage, e.g. operating a 24Vdc relay at 26Vdc, without problems.

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Coil self heating is due to the power consumption by the coil itself and the heat is dissipated by the coil into the relay enclosure (if there is one) and hence into the surrounding atmosphere. The rate of dissipation is dependent on the surface areas and materials used in the relay construction; and is also proportional to the coil temperature and the surrounding ambient. The final coil temperature is reached some time after power is applied to the coil. The time taken to reach the final coil temperature is commonly known as the thermal time constant of the coil, whilst the temperature rise per unit of applied coil power is the thermal resistance of the relay.

The temperature rise inside the coil can be significant, as much as 25ºC, or more, above ambient depending upon the type of relay. For example, a Durakool DY Series industrial relay with a 0.9W coil can get to 95ºC inside the coil, when operating at its specified maximum temperature of 70ºC. Care needs to be taken that the correct temperature rating coil insulation is specified and used. NEMA & Underwriter's Laboratories have defined a series of temperature Classes relating to the maximum hot spot temperature permitted. The two most commonly used for relays are Class B = 130ºC and Class F = 155ºC. Occasionally, Class H is used for high temperature environments. Class H = 180ºC. In the case of the Durakool DY relay, Class B would be sufficient (in fact, the DY has a Class F coil as standard).

The power consumption for DC relays in Watts (or more usually mW) may be calculated using Ohm's law and the formula $P = U \times I$ or U^2/R or I^2/R and will vary from as low as 130mW up to as much as 2W or more for larger industrial power relays. As can be seen from above, the lower the power consumption, the lower the heat generated. Furthermore, power can be saved by operating the relay at the minimum pull-in voltage or by operating the relay at its nominal voltage and then reducing the coil voltage to its minimum hold-in point to keep the relay operated. The power consumption in both these cases can be simply calculated by $P = U^2/R$ where U = the pull-in voltage and R = the coil resistance.

E.g. using the example above where the coil resistance = 70R, the nominal voltage = 5Vdc and the minimum pull-in voltage = 3.75Vdc. The nominal power consumption at 20ºC = $5^2/70$ = 0.357mW but if the relay is operated at the minimum pull-in at 20ºC = $3.75^2/70$ = 200mW.

Thus it is possible to reduce the self heating affect, but care should be taken not to reduce the pull-in voltage to such a low level that the relay will fail to pull-in when the ambient temperature rises above the nominal 20ºC. It should also be remembered that it is quite common for air temperatures to exceed 30ºC and the ambient temperature inside an enclosure will easily exceed this figure and will be significantly higher in direct sunlight.

A less common failure can occur, especially amongst high current / low voltage relays such as used in the automotive industry. These relays require high contact pressures to keep the contact resistance as low as possible and it can happen that there is sufficient energy available in the coil to operate the relay but not to keep the contacts pressed hard closed – this can and will cause premature failure of the contacts due to heating of the contacts and contact blades. This is exacerbated by the heating effect from the contact blades themselves due to the higher contact resistance. (See below). Similarly, reduced contact pressures lead to poor vibration resistance.

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Temperature and its effect on Electro-Mechanical Relay Operation (cont.)

Coil self heating effects can be reduced by using bistable or polarised relays. Bistable relays require a short pulse to make them operate – whilst this will generate a self-heating effect, it is of such a short duration as to be negligible. Polarised relays use a permanent magnet to bias the magnetic circuit and therefore require less energy to operate.

The situation with AC coils is similar but more complex due to the coil impedance and therefore the coil current will be affected by the frequency of the AC supply. Many AC Coil relays are dual rated to work with either 50Hz or 60Hz supplies but the current drawn for a given AC voltage will always be more for 50Hz supplies than for 60Hz.

The power consumption for AC coils may be calculated by using the following formula $P = U \times I \times \cos\varphi$ where $\cos\varphi$ = the coil power factor and U and I are the rms values. For an AC coil the power consumption is expressed as VA and generally at 50Hz for the European Market and 60Hz for North America.

The Contacts

The contacts can and do have a significant effect on the local ambient temperature – as a rough guide a set of contacts at their full rated load might cause the ambient temperature to rise as much as 10ºC . So, for a relay that first switched at 20ºC, within a short space of time the ambient temperature could have risen to 30ºC. We can see the effect this will have by looking at the example above. The DG31 relay has a minimum pull-in voltage of 3.75Vdc at 20ºC and if we operate the DG31 at 3.75V at 20ºC the relay will pull-in correctly and the contacts start to conduct. Within a short space of time the ambient will rise to 30ºC, now if we release the relay coil and seek to re-operate it at 3.75Vdc, it will not pull-in properly as it requires a pull-in voltage of about 3.9Vdc. Of course, some relays might work because of the 10% tolerance but others will not.

Heating in the contacts arises from three areas, 1) the contact resistance, 2) Heat generated by an electric arc when the contacts open or close and 3) from the resistance of the contact blades themselves. The resistance of the contact blades is not normally a problem but needs to be taken into account when considering very high current relays such as the automotive types where currents upwards of 180A or more are commonly switched.

Contact Resistance

The contact resistance is due to two principal causes, 1) Contact Contamination – which can be as a result of the manufacturing process as it is impossible to make a completely contamination free contact, and 2) Constriction resistance caused by the rough surface of contacts not allowing the current between the two closed contacts to flow across and through the entire contact surface. – it is this effect which is so critical in the larger power relays mentioned earlier as it can be reduced by increased contact pressure deforming the rough surface. The effects of contact contamination can be reduced by the wiping action of the contacts, by choice of contact material and by allowing an electrical arc from the switching process to clean the contact surface.

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Generally, with regard to temperature, the effects of contact resistance (which is normally very low) are minimal except when the contacts are switching very high currents. However, arcing, which occurs when the contacts open or close can quickly raise the temperature to a point where the contact material melts and contact damage (e.g. welding) occurs. When the contacts close they will bounce, this contact bounce will cause the arc to be re-established as the contacts re-open and close thus prolonging the heating effect from the arc. The heat generated in the contact blades is radiated into the relay enclosure and also conducted down the contact blades and out into the PCB or attached wiring. If the relay is working with excessive arcing it is not unusual to see discoloration and softening of the contact blades. When this occurs catastrophic failure of the relay is imminent!

PCB Tracks

If high current relays are PCB mounted, the track size on the PCB is very important in order to help dissipate the heat in the contact blades. Care should be taken that heat sensitive components are not mounted too close to power relays. Heating of the contact blades also occurs if the PCB tracks to the relay are not correctly sized for the current they have to carry and as a result get hot themselves, transferring their heat to the contact blades. Similar problems have been known to occur when relays have been mounted in sockets damaged by the insertion of a test probe thus weakening the socket's grip on the relay pin, or damaged by multiple insertions. The heat generated in the socket by the poor contact pressure travels up the relay pins and causes premature failure of the contacts.

Crimp Terminals

External issues can also have an unexpected and direct effect upon the relay coil. For example, it is common practice, especially in the automotive industry but also in industrial applications, to use crimp connectors to make a connection with the relay terminal blades. The quality of the crimp itself is extremely important. A poor crimp will get hot, in some cases hot enough to cause a fire. Consideration should also be given to the quality of the crimp connector itself, especially in high current applications. The crimp connector needs to be a tight fit on the relay terminal blade, scoring two grooves into the surface of the blade. This results in cold weld connection with low resistance. A poor crimp connector will not grip the relay blade tightly enough or will deform after a few insertions leading to a high contact resistance between the connector and the relay blade. and overheating. Even if there is no ignition, the heat in the crimp will travel up the relay blade into the body of the relay where the plastic around the blade terminal could melt. Apart from the obvious danger, the contact pressures might change making the situation worse. In addition, vapor and particles from the melting plastic can cause contact contamination and increased contact resistance. A further effect is that the increased ambient heat around the coil will affect the coils pull-in performance as discussed previously.

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