

Preventing HMI and Switch Damage *from DC Inductive Loads*

This article refers to DC circuits only. It provides an introduction to the common problems of switching inductive loads and how to overcome them. Due to the nature of this subject, it is not intended as an exhaustive or authoritative guide to physical concepts, electrical currents, electronics or wiring and is not intended to replace a working knowledge of these subjects. It should not be considered a replacement to the manufacturer's guidelines. Definitions used herein are common but not absolute and are therefore subject to critical examination. As such, EAO accepts no responsibility for any damage resulting from any interpretation of this article.

Common problems

Advanced Human Machine Interface (HMI) components like EAO's switches are engineered like fine watches to achieve reliable, long service lives and to minimise the need for replacement. Used in optimal conditions, they are expected to last several million operations. However, this can be drastically reduced when insufficient consideration is given to the wiring and circuitry.

Special attention must be paid when switching DC motors, solenoids, fans, relays and other devices that are categorised as inductive loads. Without extra circuit protection, switches and other HMI controllers can be severely damaged by high voltage spikes from these devices. EAO is frequently asked why this happens and how to prevent this.

Inductive loads

An inductor is simply a conductive loop of wire that generates a magnetic field when a current is passed through it. Any device that has coils of wire as an integral part of its design can be classed as inductive. Some common examples are motors, relays, electromagnets and transformers. However, in electronics, even a piece of wire can be classed as inductive because it has the property of inductance, i.e. it can store energy in the form of an electromagnetic field. The general symbol for an inductor is that of a coil or winding, as shown in Fig. 1 (overleaf)

Fig. 2 shows a typical circuit with switch, inductor and power supply. When an inductor is connected to a power supply and the switch is closed, the coil builds up a magnetic field and becomes become



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Fig.1 – Common symbol for inductor.



Fig. 2 Inductive load in circuit, switch closed, no fly-back diode.



Fig. 3 Induced current, switch open, no fly-back diode.

fully energized. While it's building, the coil inhibits the flow of current until the field is fully built. Current flows 'forward' from the positive terminal of the voltage source to its negative terminal, through the inductor.

When the switch is opened, the current is interrupted and the magnetic field changes in strength and collapses. This induces a current to flow through the circuit in the opposite direction, according to Lenz's Law. A negative potential is created where there was once a positive potential, and vice versa (see Fig 3). This is commonly known as a fly-back voltage or counter EMF.

The inductor now acts like a new power source, but with a much greater potential difference (measured in volts) between the positive and negative than the original power source. It can be vastly higher - several hundred to several thousand volts - even when the nominal circuit voltage is 12VDC. This high voltage spike, shown visually in Fig. 4, is governed by the equation:



where V is the voltage across the inductance, L is the inductance of the load, and (di/dt) is the rate of change of current with respect to time. The more quickly the current is changed in the inductance, the higher the voltage.

How does this impact on switches and other elements of the circuit? All this additional energy has to go somewhere. While some of it is dissipated within the coil and magnetic field, much of it flows round the circuit from the inductor and is discharged by arcing across the switch's contacts primarily as heat. This can severely damage switch contacts and greatly shorten the product's service life.

The Time Constant

EAO is frequently asked how the time constant of an inductive load can affect a switch or other HMI elements. Two things are important: the inductance of the device (L) and the resistance (R) in the circuit. In low resistance circuits, the fly-back voltage is less readily dissipated so more arcing occurs across the contacts. Where there is a high ratio of L over R, the arcing will take longer to break down and the resultant damage to contacts may be higher. As the ratio gets higher, higher resistance switch contacts are necessary.

Recommended practice

To avoid excessive arcing, EAO strongly advises using a diode or an alternative like a transorb. Diodes are simple semi-conductors



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Fig. 4 Representation of fly-back voltage when switch is opened.



Fig. 5 Diodes and current flow.



Fig. 6 Inductive load with a diode placed in parallel.

which allow current to flow from anode to cathode but not in reverse (Fig. 5). In a diode, it is the negative terminal at the pointed end of the arrow symbol where current flows out of the device. The cathode is marked by a band.

Fig. 6 shows a circuit with an inductive load and a diode placed in parallel. The induced current is re-routed down an alternative path back through the inductor.

In this way, the inductor draws a current from itself (hence the name 'fly-back') in a continuous loop until the energy is dissipated harmlessly through losses in the wire and across the diode.

The diode needs to be placed correctly in the circuit so that during normal operation is it not activated, but during the fly-back state it becomes active and conducts current away from the rest of the circuit and back through the inductor. It should be placed as close to the inductive load as possible. If a diode is positioned far away from the inductive load the cable will act as an aerial and radiate electrical noise which could cause interference on the equipment.

Using a diode will:

1. Prolong switch life

Arcing will erode a switch's contacts much faster than under normal use, reducing the expected product lifetime and requiring sooner than expected maintenance or replacement. Gold contacts in particular are more easily melted and eroded by arcing. HMI components damaged by inductive spikes are considered to be abused and are not eligible for warranty repair.

2. Help protect other circuit elements

Fly-back voltages can destroy controllers and in milder cases cause program failures and flash memory corruption.

Choosing a diode

The diode should be chosen so that the reverse breakdown voltage is greater than the voltage driving the inductive load. The DC blocking voltage can be found in the datasheet of a diode supplier. The forward current should be equal or greater than the maximum induced current flowing from the inductor. A nominal voltage of around 0.6 - .7V is required for them to operate.

Disadvantages of using a diode

One disadvantage is that the diode allows current to continue flowing, which may cause an inductive device such as a relay to remain actuated for slightly longer; some circuit designs must



A varistor or two inverse-series Zener diode (collectively called a transorb) may be used instead of the simple diode. It will protect against over voltage with both polarities if connected to ground.

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Fig. 7 Inductive load with a transorb placed in parallel.

account for this delay in the dropping-out of the relay. This delay may lead to decreased life of the relay contacts due to arcing.

Alternative methods

In some DC circuits, a varistor or two inverse-series Zener diode (collectively called a transorb) may be used instead of the simple diode. Because these devices dissipate significant power, the relay may drop-out faster than it would with a simple rectifier diode. An advantage to using a transorb over just one diode however, is that it will protect against over voltage with both polarities if connected to ground, forcing the voltage to stay between the confines of the breakdown voltages of the Zener diodes. A Zener diode connected to ground will protect against positive transients to the value of the Zener breakdown, and will protect against negative transients greater than a normal forward diode drop.

