HEAVY MOVABLE STRUCTURES, INC. ELEVENTH BIENNIAL SYMPOSIUM

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Relay Based Control Logic Applications and Troubleshooting Methodologies Tony Glaum, P.E. HDR, Inc.

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Introduction

There are many different types of relays and limit switches available. However, not all are suitable for use on a movable structure, and of the types that are suitable, not all work well in every environment or in every application that may be encountered on a movable structure. This paper will address the common types of relays found on various types of structures, and identify areas where care should be taken in the selection and application of control equipment and components.

Types of Control Relays and Limit Switches

Control Relays

Before electronics, computers, and PLC's, many industrial processes relied on machine-tool type relays to control their machinery. In the movable bridge industry, the use of machine-tool relays became common place. At the time, motor starters and contactors were large and bulky, and required large operating coils in order to operate. As a result, the relays that controlled these motor starters and contactors had to be fairly heavy-duty in order to handle the switching currents required to operate these devices. As the electrical control industry developed, a wider variety of control-type relays began to emerge. Operating mechanisms and coils became smaller and the operating currents decreased, thus



CAPTION: Example of an industrial control relay commonly used on movable spans

manufacturers began making smaller types of control relays to suit various applications. Today's relay market offers a wide variety of relays, including machine-tool relays, definite purpose contactors, general purpose type relays (commonly knows as "ice-cube" relays), and miniature ice-cube relays.

Typically, relays have several ratings that need to be taken into consideration when selecting the types of relays that are appropriate for a given system. Some of the more important items to consider are the mechanical life of the relay, electrical life, and contact rating. The mechanical life is rated in the number of times the relay can be expected to operate before the moving parts begin to fatigue and fail. These include the springs, flexible wiring within the relay, and physical guides. Typically this number is substantially higher than the electrical life rating. The electrical life rating is the number of times the relay can be expected to be operated before the contacts begin to show signs of wearing and failing. It should be noted that this rating is usually in terms of switching current at rated load. For most control relay applications, it can be expected that the normal current duty that the contacts are exposed to is far less than the contact rating.

Another important consideration when applying relay logic is the number of available contacts per relay. Some of the smaller general purpose relays contain as few as one or two Form-C contacts. Machine-tool type relays can be expandable, and can contain 12 or more Form-A or Form-B contacts. During the design process, this must be kept in mind so the schematic can be easily implemented as designed.

Reliability

Reliability of a control system is important to maintain reliable operation of the overall project. It is oftentimes difficult to predict when a particular electric component may fail. Unlike machinery systems, where machinery wear is often evident or can be measured, with electrical components they could be working perfectly one day, and the next day not work at all with little or no warning. However, there are some ways to intelligently predict impending failure.

- Noise
 - Oftentimes a relay may be functioning correctly, but may be making a significant amount of audible noise as compared with similar relays. This is usually a sign that the relay is getting ready to fail and should be replaced.
- Heat
 - With most electrical components, excessive heat is the main cause of failure. Excessive heat will damage the insulation of the wires in the coil, as well as damage the surface of the contacts and the insulation of the wire in the vicinity of the relay. Several sources of heat can be found and identified. If the relay is in a location where the ambient temperature is excessive, relays can be expected to fail prematurely. Loose wiring on the current-carrying terminals of the relay can generate enough of heat to affect the insulation. Repeated closing of the contacts onto faulted wiring can cause heat build up in the contact area. The heat generated by lightning strikes or high voltage that migrates down the wiring and goes to ground near the relay can cause damage, as can the heat generated by failed relays or electrical short circuits adjacent or near the relay, or even within the same cabinet.
- Appearance
 - If a relay appears to be considerably darker than the other relays, it is a signal that the relay has been hot and that failure is imminent. This is especially true when dealing with "ice-cube" type relays.
 - A bulging or "leaking" coil, if visible, can be an indication that some wiring inside the coil have failed even though the coil may still be working.
- Environment
 - If many different types of relays and contactors exist within a common cabinet, constant arcing in the contacts from one relay can affect other relays within the same cabinet. For example arcing in the contacts of a power relay releases small amounts of corrosive gasses and vapors that, over time, can settle on vulnerable parts of more sensitive components such as relays providing input contacts into low power, low voltage components. These gasses can even migrate over time from a power cabinet through conduit or other avenues into separate cabinets.
- History
 - On many control systems, there are multiple relays that have similar duty cycles. When it becomes apparent that relays are beginning to wear out, consideration should be made into replacing other relays within the system that have seen similar duty along with the failed relay.
 - Recent events should be taken into account in order to try to predict failure. If a significant electrical event has taken place, for example a particularly bad lightning storm, a suspected power surge from the utility power source, or a faulted cable, it is

possible that component damage might have also occurred in other parts of the overall system.

Logic Problems

Partial retro-fits to existing systems can cause relay logic problems. With many types of relay contacts, the contact is made of copper or a copper alloy material, and is coated with silver cadmium oxide. This allows the contacts to switch currents without corroding the underlying copper, and prevents welding or sticking of the contacts together. With silver-cadmium-oxide plated contacts, the arcing action of rated and below-rated current provides a cleaning action to the contacts. These types of contacts are very good at turning off and on relay coils. However, in the case of partial retro-fits, if these same contacts are converted to provide very low-level logic inputs into devices such as a PLC, a situation may exist where there no longer is enough current and voltage to keep the surface of these contacts clean. The result can be intermittent or unpredictable input into the sensing device. To compensate for switching very low voltages and currents, special contacts are available. These types of contacts are good if the switching current is never exceeded. However, if the switching current is exceeded, the plating will quickly erode, and they would need to be replaced. This is not a common problem on movable bridges where the control voltages and currents are 120 volts and .1 or .2 amps, but is noteworthy, especially as technology evolves and the use of PLC's becomes more commonplace in industrial control areas.

Limit Switches

Limit switches can be a source of failure and frequent maintenance on a movable bridge. Special care must be taken in mounting limit switches in order to minimize the chance of failure and need for seasonal adjustments. Many movable strucures are subject to different temperature conditions, and behave slightly different during different seasons. In the spring time, when the structure starts to warm up but the substructure remains cold, many spans behave slightly differently than they do in the summer and fall when the span and sub-structure are both relatively warm. These differences in the structure and sub-structure are usually not significant to the overall span itself, but can be significant enough to affect when the limit switch operates. In the case of a rolling leaf bascule, a seated limit switch near the rolling element that is even 1/8" out of adjustment can easily translate to 2 or more inches in vertical elevation at the toe of the span, depending on span length.



CAPTION: Plunger limit switch experiencing forces caused by span expansion and contraction

Bridge motion relative to limit switch mounting is an important design consideration, even in the seated position. Plunger limit switches at the expansion end of a vertical lift bridge can experience bending forces on the plunger mechanism as the span expands and contracts. It is important that limit switches are mounted on the span where they will be positively engaged, be mounted where they are easily accessible for inspection and adjustment, and are also protected from the weather as much as practical. Mounting methods should be considered to allow the switch to be securely attached to the support, yet will easily allow for adjustment when the need arises. Operators and maintenance personnel should be aware of the locations of all limit switches that can affect the operation, and know what to do if one fails.

Limit Switch Operating Speed

For many years, plunger-type limit switches were being implemented that simply brought two or four contacts together as the bridge moved. These contacts were either copper or plated copper. During seating, a movable span tends to move rather slowly, and with the harsh conditions and operating currents, over time the contacts can become worn. This is a different phenomenon than the one that occurs with relay contacts. Because spans tend to move slowly near the seated position, when the pressure is released from the plunger, the contacts in a plunger switch separate fairly slowly. This allows any arcing that may occur to be on the switch for a longer period of time, which erodes the contacts fairly quickly. One common way of "cleaning" the contacts is for the maintenance personnel to take a hard object, such as a screwdriver or sand-paper, and scrape the surface of the contacts. This action cleans the contacts and they start working, but tend to fail soon afterwards. During the scraping, two things happen. One is the surface plating is partially removed, which exposes the copper underneath, allowing corrosion to occur at an accelerated rate. The other thing that happens is that the surfaces are now not smooth, which allows any arcing that occurs to occur locally on isolated places of the contacts rather than spread over the surface of the contacts. This contributes to even more rapid deterioriation of the surfaces and decreased reliability. Some manufacturers are converting from the open, slow-acting type of contacts to faster, enclosed snap-action switches within the plunger enclosure.

Some of the types of limit switch contacts in common use today include the plunger-type open contacts, enclosed snap-action contacts, and proximity switches. Each of the types of limit switches and their associated enclosures and mounting methods need to be applied using good design practices, as each types have their pro's and con's, and seldom are two situations exactly the same. Even the same type of structure in two different climates will behave slightly different. While no two situations are exactly alike, one thing that is common on most types of structures is the demand for increased reliability. As the traveling public becomes more fast-paced, and the volumes of traffic increases, both on highway and rail bridges, the need to reduce or eliminate failures is constantly increasing. Where maintenance practices that have worked for many years may have been adequate in the past, as structures and components age and the demand for reliability increases, periodic review of maintenance practices or pro-active replacement of limit switches can be a relatively inexpensive option to a failure that affects the traveling public or transportation of cargo.

Control Logic Considerations

Fail Safe Control Logic

Control logic, especially on a movable span, needs to operate in the "fail-safe" mode to the extent practical. In this context, fail-safe refers to an action taken allowing a device or relay to de-energize or "dropout", as opposed to the action causing a relay or device to energize or "pick-up". A good example of fail safe logic is the emergency stop, or E-Stop, button. When an E-Stop button is pressed, it typically causes a relay to de-energize, or it de-energizes an area of the control system, thereby causing the system to stop.



CAPTION: Limit switches in a corrosive environment.

This is opposed to a non-fail-safe system, which relies on pressing a button to energize a relay coil. In this

instance, if the relay coil is a critical element, there can be no assurance that something has not occurred that would render the relay inoperable. For example, if a wire comes loose or is broken, or the relay fails while de-energized due to a variety of factors (such as lightning surges, corrosion, accidental impact, loose wire termination, varmint damage, etc.), the relay may not function when it is required. Movable bridges are especially vulnerable to this type of failure because for many movable bridges the control system is in the "off" state for the majority of the time, in some cases for up to months at a time without being used. In these situations, periodic inspection and testing becomes even more important.

A fail-safe vs. non-fail-safe system can easily be identified in the case of the E-Stop pushbutton, but can sometimes become harder to identify in other situations where a limit switch may cause a relay to energize, which in turn energizes another component or components. One example is a seating switch causing a seating relay to operate or drop out, which then causes a brake to electrically set or release. In these instances, all operating conditions must be analyzed. Oftentimes the tendency is to design a system that will work under normal conditions, but the "negative test" is often overlooked. A negative test is described as testing a system not only for what it will do, but testing other conditions, such as what it will not do in certain situations, especially out-of-sequence situations. For example, a span lock is not supposed to be able to be driven unless the span is at seat, and the span control will not lower the span because it is at seat. A negative test would be to lift the span, simulate a "lock not pulled" condition while not at seat, and verify the span will not lower.

Common-Mode Failure

One often overlooked reliability issue is that of common-mode failure, or the tendancy to have a system where the failure of one common item will disable both normal and the alternate operating modes. This type of failure should be considered in a variety of situations not strictly dealing with the relays themselves, but in dealing with all aspects of the electrical system. It is important to identify situations where a failed cable would cause not only the affected circuit to fail, but also analyze the consequence of the failure of the other wires within that cable and what effect it would have on the overall operation. For example, on a double-leaf bascule bridge, common mode failure points would be anywhere that the power wiring for the normal motor and emergency motor share any common components, raceways, boxes, or



CAPTION: Bundle of cables rubbing on structure. Failure of one cable could damage all cables, leaving the span inoperable.

cables where the failure of one cable will damage both circuits, leaving the span in-operational.

The application of bypass switches is another potential area for common mode failure. Bypass switches typically have one or two contacts in them, and are usually applied to bypass a failed limit switch which energizes a control relay. However, if the coil of the control relay itself has failed, and the bypass switch operation is meant to energize the relay coil, the bypass switch may not provide the expected result. Depending on the circumstance, if the normal and emergency drive system both require the failed relay to operate in order to move the span, a failure of this type would cause the span to be non-operational, even though there is a perceived level of redundancy. Situations such as these should be carefully analyzed both in new designs and at existing locations to identify what risks to reliability exist. One often overlooked area is the issue of spare parts. In the example above, if re-wiring the system is not a practical option, a relatively inexpensive preventative action could be to ensure there is a functioning spare relay readily available, which would provide at least some means of getting back in operation relatively quickly.

Conclusions

As control systems age, and traffic increases, reliability becomes more of a concern for the owners and operators. Selecting control system components that are suitable for not only the intended control function, but also for the local environment, operating conditions, and maintenance practices will improve the overall reliability of the system. Identifying and correcting potential failures before they occur can have substantial impacts on the reliability of the span. In today's society, waiting for an outage may not be in the best interests of the owners or the stake-holders. By identifying potential failures, and taking proactive measures to eliminate or reduce the likelihood of these failures can significantly improve overall reliability and decrease operating and maintenance costs in the long run.